CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 DOCUMENT PURPOSE

This technical support document (TSD) is a standalone report that presents the technical analyses that the U.S. Department of Energy (DOE or Department) has conducted in preparation for amending energy conservation standards for electric motors.

1.2 SUMMARY OF NATIONAL BENEFITS

DOE's analyses indicate that the proposed standards would save a significant amount of energy. Estimated lifetime savings for electric motors purchased over the 30-year period that begins in the year of compliance with new and amended standards (2015–2044) would amount to 7.0 quads (full-fuel-cycle energy).[1] This is equivalent to 30 percent of total U.S. industrial primary energy consumption in 2011.[2]

The estimated cumulative net present value (NPV) of total consumer costs and savings attributed to the proposed standards for electric motors ranges from 8.7 billion (at a 7-percent discount rate) to $23.3 billion (at a 3-percent discount rate). This NPV expresses the estimated total value of future operating-cost savings minus the estimated increased equipment costs for equipment purchased in 2015–2044.

In addition, the proposed standards would have significant environmental benefits. Estimated energy savings would result in cumulative emission reductions of 396 million metric tons (Mt)[3] of carbon dioxide (CO_2), 674 thousand tons of sulfur dioxide (SO_2), 499 thousand tons of nitrogen oxides (NO_X) and 0.8 tons of mercury (Hg).[4]

The value of the CO_2 reductions is calculated using a range of values per metric ton of CO_2 (otherwise known as the Social Cost of Carbon (SCC)) developed by an interagency process (see Chapter 14 for more details.) DOE estimates the present monetary value of the CO_2 emissions reduction is between $2.5 and $36.6 billion. DOE also estimates the present monetary value of the NO_X emissions reduction is $0.3 billion at a 7-percent discount rate and $0.6 billion at a 3-percent discount rate.[5]

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[1] One quad (quadrillion Btu) is the equivalent of 293.1 billion kilowatt hours (kWh) or 172.3 million barrels of oil.
[2] Based on U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook (AEO) 2013 data.
[3] A metric ton is equivalent to 1.1 short tons. Results for NO_X and Hg are presented in short tons.
[4] DOE calculates emissions reductions relative to the AEO2013 Reference case, which generally represents current legislation and environmental regulations for which implementing regulations were available as of December 31, 2012
[5] DOE is currently investigating valuation of avoided Hg and SO_2 emissions.

Table 1-1 summarizes the national economic costs and benefits expected to result from the proposed standards for electric motors.

Table 1-1 Summary of National Economic Benefits and Costs of Electric Motors Energy Conservation Standards

Category	Present Value Billion 2012$	Discount Rate
Benefits		
Operating Cost Savings	14.8	7%
	34.9	3%
CO_2 Reduction Monetized Value ($11.8/t case)*	2.5	5%
CO_2 Reduction Monetized Value ($39.7/t case)*	11.8	3%
CO_2 Reduction Monetized Value ($61.2/t case)*	18.9	2.5%
CO_2 Reduction Monetized Value ($117.0/t case)*	36.6	3%
NO_X Reduction Monetized Value (at $2,639/ton)**	0.3	7%
	0.6	3%
Total Benefits†	26.9	7%
	47.4	3%
Costs		
Incremental Installed Costs	6.1	7%
	11.7	3%
Net Benefits		
Including CO_2 and NO_X Reduction Monetized Value	20.8	7%
	35.7	3%

* The interagency group selected four sets of SCC values for use in regulatory analyses. Three sets of values are based on the average SCC from the three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth set, which represents the 95th percentile SCC estimate across all three models at a 3-percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values in parentheses represent the SCC in 2015. The SCC time series incorporate an escalation factor.
** The value represents the average of the low and high NO_X values used in DOE's analysis.
† Total Benefits for both the 3% and 7% cases are derived using the series corresponding to SCC value of $39.7/t in 2015.

1.3 OVERVIEW OF STANDARDS FOR ELECTRIC MOTORS

The Energy Policy and Conservation Act (EPCA), 42 U.S.C. § 6311, *et seq,* as amended by the Energy Policy Act of 1992 (EPACT) established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress passed into law the Energy Independence and Security Act of 2007 (EISA 2007) (Pub.

L. No. 110–140) Section 313(b)(1) of EISA 2007 updated the energy conservation standards for those electric motors already covered by EPCA and established energy conservation standards for a larger scope of motors not previously covered. (42 U.S.C. 6313(b)(2))

EPCA also directs that the Secretary of Energy shall publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such product. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. 6313(b)(4))

As described previously, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments went into effect on December 19, 2010, DOE had indicated during the course of public meetings held in advance of today's proposal that motors manufactured after December 19, 2015, would need to comply with any applicable new standards that DOE may set as part of this rulemaking. Today's proposed standards would apply to motors manufactured starting on December 19, 2015.

On September 22, 2010, DOE published an *Energy Conservation Standards Rulemaking Framework Document for Electric Motors*. This document describes the procedural and analytical approaches that DOE anticipated that it would use to evaluate the establishment of energy conservation standards for electric motors.[6] On October 18, 2010, DOE held a public meeting to discuss the proposed analytical framework. The analytical framework presented at the public meeting described different analyses, such as life-cycle cost and payback, the methods proposed for conducting them, and the relationships among the various analyses. Representatives of motor manufacturers, trade associations, and energy efficiency advocacy groups attended the framework document public meeting and submitted both oral and written comments. DOE also published a Request for Information (RFI) seeking public comments from interested parties regarding establishment of energy conservation standards for several types of definite and special purpose motors for which EISA 2007 did not provide energy conservation standards.[7]

DOE incorporated comments received in response to the framework document and the RFI, as well as information obtained from discussions with manufacturers and subject matter experts (SMEs) into its engineering analysis. On July 23, 2012, DOE published the preliminary technical support document (TSD). A public meeting was held on August 21, 2012 to discuss these preliminary analyses. Following the preliminary analysis public meeting, DOE held additional meetings with manufacturers as part of the consultative process for the manufacturer impact analysis (Chapter 12). During this period, DOE received numerous comments regarding

[6] This document is available at the DOE website: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/42
[7] This document is available at the DOE website: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/42

the preliminary analyses. DOE has incorporated the comments received at the public meeting, manufacturer interviews, and submitted in written comments into today's proposed rule.

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE studies new or amended standards, it must consider, to the greatest extent practicable, the following seven factors (42 U.S.C. 6295(o)(2)(B)(i)):

(1) the economic impact of the standard on the manufacturers and consumers of the affected products;

(2) the savings in operating costs throughout the estimated average life of the product compared to any increases in the initial cost, or maintenance expense for the products that are likely to result from the imposition of the standard;

(3) the total projected amount of energy savings likely to result directly from the imposition of the standard;

(4) any lessening of the utility or the performance of the covered products likely to result from the imposition of the standard;

(5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard;

(6) the need for national energy conservation; and

(7) other factors the Secretary considers relevant.

Other statutory requirements are set forth in 42 U.S.C. 6295(o)(1)–(2)(A), (2)(B)(ii)–(iii), and (3)–(4).

DOE considers the participation of interested parties a very important part of the process for setting energy conservation standards. Through formal public notifications (*i.e., Federal Register* notices), DOE encourages the participation of all interested parties during the comment period in each stage of the rulemaking. Beginning with the preliminary analysis for this rulemaking and during subsequent comment periods, interactions among interested parties provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A), 6313(a)(6)(A)) To determine whether economic justification exists, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the seven factors listed above. (42 U.S.C. 6295(o)(2)(B)(i), 6316(a))

After the publication of the framework document, the energy conservation standards rulemaking process involves three additional, formal public notices, which DOE publishes in the Federal Register. The first of the rulemaking notices is a notice of public meeting (NOPM), which is designed to publicly vet the models and tools used in the preliminary rulemaking and to facilitate public participation before the NOPR stage. The second notice is the notice of proposed rulemaking (NOPR), which presents a discussion of comments received in response to the NOPM and the preliminary analyses and analytical tools; analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for each product. The third notice is the final rule, which presents a discussion of the comments received in response to the NOPR; the revised analyses; DOE's weighting of these impacts; the amended energy conservation standards DOE is adopting for each product; and the effective dates of the amended energy conservation standards.

The analytical framework presented in this TSD presents the different analyses, such as the engineering analysis and the consumer economic analyses (*e.g.*, the life-cycle cost (LCC) and payback period (PBP) analyses), the methods used for conducting them, and the relationships among the various analyses. Table 1.3.1 outlines the analyses DOE conducts for each stage of the rulemaking.

. Table 1.4.1 Analyses by Rulemaking Stage

	Preliminary	NOPR	Final Rule
Market and technology assessment	✓	✓	✓
Screening analysis	✓	✓	✓
Engineering analysis	✓	✓	✓
Energy use characterization	✓	✓	✓
Product price determination	✓	✓	✓
Life-cycle cost and payback period analyses	✓	✓	✓
Life-cycle cost subgroup analysis		✓	✓
Shipments analysis	✓	✓	✓
National impact analysis	✓	✓	✓
Preliminary manufacturer impact analysis	✓		
Manufacturer impact analysis		✓	✓
Utility impact analysis		✓	✓
Employment impact analysis		✓	✓
Emissions Analysis		✓	✓
Regulatory impact analysis		✓	✓

DOE developed spreadsheets for the engineering, LCC, PBP, and national impact analyses (NIA) for each equipment class. The LCC workbook calculates the LCC and PBP at various energy efficiency levels. The NIA workbook does the same for national energy savings (NES) and national net present values (NPVs). All of these spreadsheets are available on the DOE website for electric motors:

http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/50

As part of the information gathering and sharing process, DOE interviewed electric motor manufacturers. DOE selected companies that represented production of all types of equipment, ranging from small to large manufacturers. DOE had four objectives for these interviews: (1) solicit manufacturer feedback on the draft inputs to the engineering analysis; (2) solicit feedback on topics related to the preliminary manufacturer impact analysis; (3) provide an opportunity, early in the rulemaking process, for manufacturers to express their concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

DOE incorporated the information gathered during these interviews into its engineering analysis (chapter 5) and its manufacturer impact analysis (chapter 12). Following the publication of the preliminary analyses and the associated public meeting, DOE held additional meetings with manufacturers as part of the consultative process for the manufacturer impact analysis for the NOPR phase of the rulemaking.

1.5 STRUCTURE OF THE DOCUMENT

The TSD describes the analytical approaches and data sources used in this rulemaking. The TSD consists of the following chapters and appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to the electric motor rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the methodology, the analytical tools, and relationships among the various analyses, summarizes issues and comments DOE received from its preliminary interviews with manufacturers, and explains DOE's responses to those comments.
Chapter 3	Market and Technology Assessment: provides DOE's definition of an electric motor, lists the proposed equipment classes, and names the major industry players. This chapter also provides an overview of electric motor technology, including techniques employed to improve motor efficiency.
Chapter 4	Screening Analysis: identifies all the design options that improve electric motor efficiency, and determines which of these DOE evaluated and which DOE screened out of its analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer price and increased efficiency. Presents detailed cost and efficiency information for the units of analysis.

Chapter 6	Markups Analysis: discusses the methods used for establishing markups for converting manufacturer prices to customer equipment prices.
Chapter 7	Energy Use Characterization: discusses the process used for generating energy-use estimates for the considered products as a function of efficiency levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the effects of standards on individual customers and users of the products and compares the LCC and PBP of equipment with and without higher energy conservation standards.
Chapter 9	Shipments Analysis: discusses the methods used for projecting the total number of electric motors that would be affected by standards.
Chapter 10	National Impact Analysis: discusses the methods used for forecasting national energy consumption and national consumer economic impacts in the absence and presence of standards.
Chapter 11	Customer Subgroup Analysis: discusses the effects of standards on any identifiable subgroups of consumers who may be disproportionately affected by any proposed standard level. This chapter compares the LCC and PBP of products with and without higher energy conservation standards for these consumers.
Chapter 12	Manufacturer Impact Analysis: discusses the effects of standards on the finances and profitability of electric motor manufacturers.
Chapter 13	Emissions Analysis: discusses the effects of standards on pollutants including – sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury – as well as carbon emissions.
Chapter 14	Monetization of Emission Reductions Benefits: discusses the effects of standards on the monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X).
Chapter 15	Utility Impact Analysis: discusses the effects of standards on the electric utility industry.
Chapter 16	Employment Impact Analysis: discusses the effects of standards on national employment.
Chapter 17	Regulatory Impact Analysis: discusses the impact of non-regulatory alternatives to efficiency standards.

Appendices:

App.5-A	Engineering Data
App.5-B	Sample Teardown Report
App.5-C	Efficiency Modeling Validation
App.7-A	Energy Use Scenario for Medium Electric Motors
App.8-A	User Instructions for Life-Cycle Cost Spreadsheet
App.8-B	Life-Cycle Cost and Payback Period Results
App.8-C	Life-Cycle Cost Sensitivity Analysis
App.10-A	User Instructions for Shipments and National Impact Analysis Spreadsheet Models
App.10-B	National Impact Analysis Sensitivity Analysis for Alternative Product Price Trend Scenarios
App.10-C	Full-Fuel-Cycle Multipliers
App.10-D	National Impact Analysis Sensitivity for Alternative Scenarios of Price Elasticity of Demand
App.12-A	Manufacturer Impact Analysis Interview Guide
App.12-B	GRIM Overview
App.14-A	Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866: Technical Model Update
App.14-B	Technical Update of Social Cost of Carbon For Regulatory Impact Analysis Under Executive Order 12866
App.17-A	Regulatory Impact Analysis: Supporting Materials

CHAPTER 2. ANALYTICAL FRAMEWORK

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CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

Section 6295(o)(2)(A) of 42 United States Code (U.S.C.) requires the U.S. Department of Energy (DOE) to set forth energy conservation standards that are technologically feasible and economically justified, and would achieve the maximum improvement in energy efficiency. This provision applies to electric motors via 42 U.S.C. 6316(a). This chapter provides a description of the general analytical framework that DOE uses in developing such standards. The analytical framework is a description of the methodology, analytical tools, and relationships among the various analyses that are part of this rulemaking. For example, the methodology that addresses the statutory requirement for economic justification includes analyses of life-cycle cost (LCC), economic impact on manufacturers and users, national benefits, impacts, if any, on utility companies, and impacts, if any, from lessening competition among manufacturers.

Figure 2.1.1 summarizes the stages and analytical components of the rulemaking process. The focus of this figure is the center column, which lists the analyses that DOE conducts. The figure shows how the analyses fit into the rulemaking process, and how they relate to each other. Key inputs are the types of data and information that the analyses require. Some key inputs exist in public databases; DOE collects other inputs from stakeholders or persons with special knowledge. Key outputs are analytical results that feed directly into the standards-setting process. Arrows connecting analyses show types of information that feed from one analysis to another.

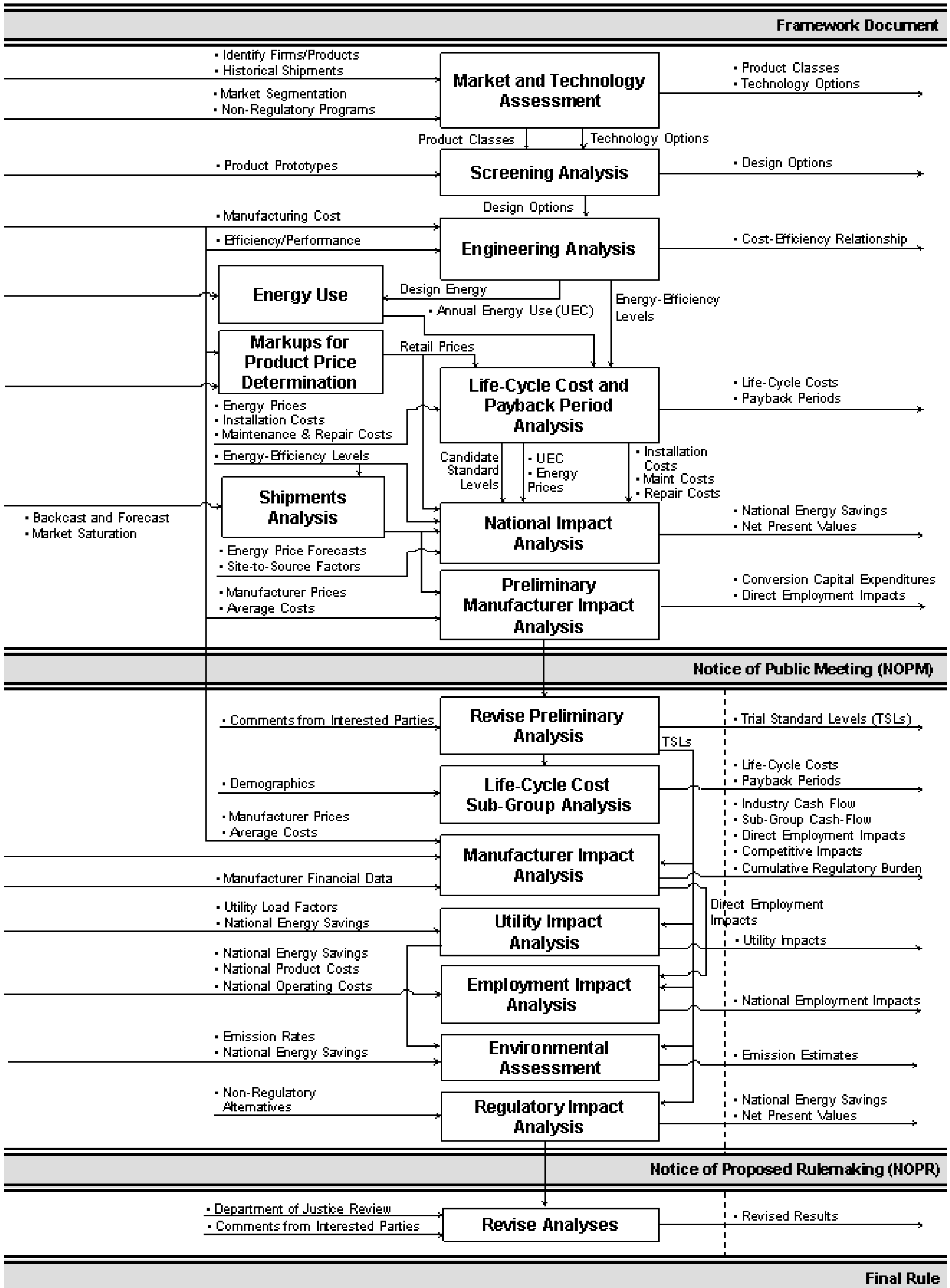

Figure 2.1.1 Flow Diagram of Analyses for the Energy Conservation Standards Rulemaking Analysis Process

The analyses performed prior to the notice of proposed rulemaking (NOPR) stage as part of the preliminary analyses and described in the preliminary technical support document (TSD) are listed below. These analyses were revised for the NOPR based in part on comments received, and are reported in this NOPR TSD. The analyses will be revised once again for the final rule based on any new comments or data received in response to the NOPR.

- A market and technology assessment to characterize the relevant equipment markets and existing technology options, including prototype designs.

- A screening analysis to review each technology option and determine if it is technologically feasible; is practical to manufacture, install, and service; would adversely affect equipment utility or equipment availability; or would have adverse impacts on health and safety.

- An engineering analysis to develop cost-efficiency relationships that show the manufacturer's cost of achieving increased efficiency.

- An energy use analysis to determine the annual energy use in the field of the considered equipment as a function of efficiency level.

- A markups analysis to develop distribution channel markups to convert manufacturer selling prices to customer installed prices.

- An LCC and payback period (PBP) analysis to calculate, at the consumer level, the relationship between savings in operating costs compared to any increase in the installed cost for equipment at higher efficiency levels.

- A shipments analysis to forecast equipment shipments, which then are used to calculate the national impacts of standards and future manufacturer cash flows.

- A national impact analysis (NIA) to assess the impacts at the national level of potential energy conservation standards for each of the considered equipment, as measured by the net present value (NPV) of total consumer economic impacts and the national energy savings (NES).

- A manufacturer impact analysis to assess the potential impacts of energy conservation standards on manufacturers, such as impacts on capital conversion expenditures, marketing costs, shipments, and research and development costs.

The additional analyses DOE performed for the NOPR stage of the rulemaking analysis include those listed below. DOE further revises the analyses for the final rule based on comments received in response to the NOPR.

- A consumer subgroup analysis to evaluate variations in customer characteristics that might cause a standard to affect particular consumer sub-population differently than the overall population.

- A manufacturer impact analysis to estimate the financial impact of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity.
- An emissions analysis to assess the effects of the considered standards on emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), and mercury (Hg).

- A monetization of emission reduction benefits resulting from reduced emissions associated with potential new and amended standards.

- A utility impact analysis to estimate the effects of the considered energy conservation standards on installed electricity generation capacity and electricity generation.

- An employment impact analysis to assess the indirect impacts of the considered energy conservation standards on national employment.

- A regulatory impact analysis to assess alternatives to energy conservation standards that could achieve substantially the same regulatory goal.

2.2 BACKGROUND

On October 5, 1999, DOE published in the *Federal Register*, a final rule to implement the EPACT 1992 electric motor requirements. 64 FR 54114. In response to EISA 2007, on March 23, 2009, DOE updated, among other things, the corresponding electric motor regulations at 10 CFR part 431 with the new definitions and energy conservation standards. 74 FR 12058. On December 22, 2008, DOE proposed to update the test procedures under 10 CFR part 431 both for electric motors and small electric motors. 73 FR 78220. DOE finalized key provisions related to small electric motor testing in a 2009 final rule at 74 FR 32059 (July 7, 2009), and further updated the test procedures for electric motors and small electric motors at 77 FR 26608 (May 4, 2012). The May 2012 final rule primarily focused on updating various definitions and incorporations by reference related to the current test procedure. In that rule, DOE promulgated a regulatory definition of "electric motor" to account for EISA 2007's removal of the previous statutory definition of "electric motor." DOE also clarified definitions related to those motors that EISA 2007 laid out as part of EPCA's statutory framework, including motor types that DOE had not previously regulated. See generally, id. at 26613-26619. DOE published a new proposed test procedure rulemaking on June 26, 2013 that attempts to further refine some existing electric motor definitions and proposes to add certain definitions and test procedure preparatory steps to address a wider variety of electric motor types than are currently regulated. 78 FR 38456.

Regarding the compliance date that would apply to the requirements of today's proposed rule, EPCA directs the Secretary of Energy to publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such equipment. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. § 6313(b)(4))

As described previously, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments went into effect on December 19, 2010, DOE had indicated during the course of public meetings held in advance of today's proposal that motors manufactured after December 19, 2015, would need to comply with any applicable new standards that DOE may set as part of this rulemaking. Today's proposed standards would apply to motors manufactured starting on December 19, 2015. However, DOE is interested in receiving comments on the ability of manufacturers to meet this deadline.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

When initiating a standards rulemaking, DOE develops information on the present and past industry structure and market characteristics for the equipment concerned. This activity assesses the industry and equipment both quantitatively and qualitatively based on publicly available information and encompasses the following: (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory equipment efficiency improvement initiatives, and (3) trends in equipment characteristics and retail markets. This information serves as resource material throughout the rulemaking.

DOE reviewed existing literature and interviewed manufacturers to get an overall picture of the industry serving the United States market. Industry publications and trade journals, government agencies, trade organizations, and equipment literature provided the bulk of the information, including: (1) manufacturers and their approximate market shares, (2) equipment characteristics, and (3) industry trends. The appropriate sections of the NOPR describe the analysis and resulting information leading up to the proposed trial standard levels, while supporting documentation is provided in the TSD.

DOE categorizes covered equipment into separate equipment classes and formulates a separate energy conservation standard for each equipment class. The criteria for separation into different classes are type of energy used, capacity, and other performance-related features such as those that provide utility to the consumer or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295(q) and 6316(a)).

As part of the market and technology assessment, DOE developed a list of technologies for consideration for improving the efficiency of electric motors. DOE typically uses information about existing and past technology options and prototype designs to determine which technologies manufacturers use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies for consideration. Initially, these technologies encompass all those DOE believes are technologically feasible.

DOE developed its list of technologically feasible design options for electric motors from trade publications, technical papers, research conducted in support of previous rulemakings concerning these equipment, and through consultation with manufacturers of components and systems. Since many options for improving equipment efficiency are available in existing equipment, equipment literature and direct examination provided additional information. Chapter 3 of the TSD includes the detailed list of all technology options identified.

2.4 SCREENING ANALYSIS

After DOE identified the technologies that could potentially improve the energy efficiency of electric motors, DOE conducted the screening analysis. The purpose of the screening analysis is to evaluate these technologies to determine which options to consider further and which options to screen out.

The screening analysis examines whether various technologies: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on equipment utility or availability; and (4) have adverse impacts on health and safety. In consultation with interested parties, DOE reviews the list to determine if the technologies described in chapter 3 of the TSD are practicable to manufacture, install, and service; would adversely affect equipment utility or availability; or would have adverse impacts on health and safety. In the engineering analysis, DOE further considers the efficiency enhancement options (i.e., technologies) that it did not screen out in the screening analysis. Chapter 4 of the TSD contains further detail on the criteria that DOE uses.

2.5 ENGINEERING ANALYSIS

The engineering analysis establishes the relationship between the manufacturing production cost and the efficiency of electric motors. This relationship serves as the basis for cost/benefit calculations in terms of individual consumers, manufacturers, and the Nation. Chapter 5 discusses equipment classes DOE analyzed, the representative baseline units, the efficiency levels analyzed, the methodology DOE used to develop the manufacturing production costs, and the cost-efficiency curves.

In the engineering analysis, DOE evaluates a range of equipment efficiency levels and their associated manufacturing costs. The purpose of the analysis is to estimate the incremental manufacturer selling prices (MSPs) for equipment that would result from increasing efficiency levels above the level of the baseline model in each equipment class. The engineering analysis considers technologies not eliminated in the screening analysis. The LCC analysis and NIA use the cost-efficiency relationships developed in the engineering analysis.

DOE typically structures its engineering analysis around one of three methodologies: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options used to achieve such increases; and/or (3) the reverse-engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials derived from teardowns of the equipment being analyzed.

DOE's analysis for the electric motor rulemaking is based on a combination of the efficiency-level approach and the reverse engineering approach. Primarily, DOE elected to derive its production costs by tearing down electric motors and recording detailed information regarding individual components and designs. DOE used the costs derived from the engineering teardowns and the corresponding nameplate nominal efficiency of the torn down motors to report the relative costs of achieving improvements in energy efficiency. DOE derived material prices from current, publicly available data as well as input from subject matter experts and manufacturers. For most representative units analyzed, DOE was not able to test and teardown a max-tech unit because such units are generally cost-prohibitive and are not readily available. Therefore, DOE supplemented the results of its test and teardown analysis with software modeling.

Chapter 5 of the TSD describes the methodology that DOE used to perform the efficiency level analysis and derive the cost-efficiency relationship.

2.6 MARKUPS TO DETERMINE EQUIPMENT PRICE

DOE uses markups to convert the manufacturer selling prices estimated in the engineering analysis to consumer prices, which then were used in the LCC, PBP, national impact, and manufacturer impact analyses. DOE calculates a separate markup for the baseline component of equipment's cost (baseline markup) and for the incremental increase in cost due to standards (incremental markup).

To develop markups, DOE identifies how the equipment is distributed from the manufacturer to the customer. After establishing appropriate distribution channels, DOE used data from the financial filings of manufacturers and distributors and other sources to determine how prices are marked up as the equipment passes from the manufacturer to the end consumer. See chapter 6 of the TSD for details on the development of markups.

2.7 ENERGY USE ANALYSIS

The energy use analysis, which assesses the energy savings potential from higher efficiency levels, provides the basis for the energy savings values used in the LCC and subsequent analyses. The goal of the energy use analysis is to generate a range of energy use values which reflects actual equipment use in the field. The analysis uses information on the use of actual equipment in the field to estimate the energy that would be used by new equipment at various efficiency levels. Chapter 7 of the TSD provides more detail about DOE's approach for characterizing energy use of electric motors.

2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

New or amended energy conservation standards affect equipment's operating expenses—usually decreasing them—and consumer prices for the equipment—usually increasing them. DOE analyzed the net effect of standards on consumers by evaluating the net change in LCC. To evaluate the net change in LCC, DOE used the cost-efficiency relationship derived in the engineering analysis along with the energy costs derived from the energy use analysis. Inputs to the LCC calculation include the installed cost of equipment to the consumer (consumer purchase price plus installation cost), operating expenses (energy expenses and maintenance costs), the lifetime of the unit, and a discount rate. These inputs are described in detail in chapter 8 of the TSD.

Because the installed cost of equipment typically increases while operating cost typically decreases in response to new standards, there is a time in the life of equipment having higher-than-baseline efficiency when the operating-cost benefit (in dollars) since the time of purchase is equal to the incremental first cost of purchasing the higher-efficiency equipment. The length of time required for equipment to reach this cost-equivalence point is known as the payback period (PBP).

Recognizing that several inputs used to determine consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analyses by modeling both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. DOE developed an LCC and PBP spreadsheet model that incorporates both Monte Carlo simulation and probability distributions by using Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in program.

The LCC and PBP analyses are described in more detail in chapter 8 of the TSD.

2.9 SHIPMENTS ANALYSIS

Projections of equipment shipments are needed to calculate the potential effects of standards on national energy use, NPV, and future manufacturer cash flows. DOE generated both shipments projections for each equipment class. The shipments projections calculate the total number of electric motors shipped each year over a 30-year period, beginning in December 19, 2015. To create these projections, DOE combined current year shipments, discussed in the shipments analysis (chapter 9), with a shipment analysis model driven by economic growth and machinery production growth for equipment, including electric motors and generated unit shipment values through the analysis period. Chapter 9 of the TSD provides additional details on the shipments analysis.

2.10 NATIONAL IMPACT ANALYSIS

The national impact analysis estimates energy savings and assesses the NPV of consumer LCC savings at the national scale. The results can be used to identify the potential energy conservation standard that, for a given equipment class, yields the greatest energy savings while remaining cost effective from a consumer perspective. DOE estimated both NES and NPV for all candidate standard levels for each electric motors equipment class. To make the analysis more accessible and transparent to all interested parties, it is documented in a Microsoft Excel spreadsheet model that can be downloaded from the DOE Energy Efficiency & Renewable Energy (EERE) website (http://www.eere.energy.gov/buildings/appliance_standards/).

The NIA considers total installed cost (which includes manufacturer selling prices, distribution chain markups, sales taxes, and installation costs), operating expenses (energy, repair, and maintenance costs), equipment lifetime, and discount rate. However, where the LCC considers the savings and costs associated with standards for a set of representative units, the NIA considers the savings and costs associated with all units affected by standards during the entire analysis period. Chapter 10 provides additional details regarding the NIA.

A key component of DOE's NIA analysis is the energy efficiencies forecasted over time for the base case (without new standards) and each of the standards cases. The efficiency forecast shows the distribution of shipments of electric motors by efficiency level, which determines the percentage of shipments affected by a standard. To develop its efficiency forecast, DOE first assessed present-day (2012) efficiency and then considered how the efficiency of new units might change by the first year of the analysis period and throughout the analysis period in the absence of new or amended Federal standards.

To estimate the impact that new or amended standards may have in the year compliance is required, DOE used both a "roll-up" scenario and a "shift" scenario. Under the "roll-up" scenario, DOE assumes: (1) product efficiencies in the base case that do not meet the standard level under consideration would "roll-up" to meet the new standard level; and (2) product efficiencies above the standard level under consideration would not be affected. Under the "shift" scenario, DOE retains the pattern of the base-case efficiency distribution but re-orients the distribution at and above the new minimum energy conservation standard.

2.10.1 National Energy Savings Analysis

The major inputs for determining the NES for equipment analyzed are annual unit energy consumption, shipments, lifetimes, and site-to-source conversion factors. DOE calculated national energy consumption for each year by multiplying unit energy consumption by the number of units in the installed base in that year. NES for a given year, then, is the difference in national energy consumption between the base case (without new efficiency standards) and each standards case. DOE estimated energy consumption and savings first in terms of site energy and then converted the savings into source energy. Cumulative energy savings are the sum of the NES estimates for each year.

DOE has historically presented NES in terms of primary energy savings. DOE has recently published a Statement of Policy regarding its intent to incorporate full-fuel-cycle (FFC) metrics into its analyses, and outlining a proposed approach. DOE stated that it intends to calculate FFC energy and emission impacts by applying conversion factors generated by the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to the NEMS-based results currently used by DOE. 76 FR 51281 (Aug. 18, 2011) as amended at 77 FR 49701 (August 17, 2012). Additionally, DOE will review alternative approaches to estimating these factors and may decide to use a model other than GREET to estimate the FFC energy and emission impacts in any particular future appliance efficiency standards rulemaking. For this preliminary analysis, DOE calculated FFC energy savings using a NEMS-based methodology described in appendix 10-B. Chapter 10 of this TSD presents both the primary NES and the FFC energy savings for the considered trial standard levels (TSLs).

2.10.2 Net Present Value Analysis

The inputs for determining net present value (NPV) of consumer benefits are: (1) total annual installed cost; (2) total annual savings in operating costs; (3) a discount factor; (4) present value of costs; and (5) present value of savings. DOE calculated net savings each year as the difference between the base case and each standards case in total savings in operating costs and total increases in installed costs. DOE calculated savings over the life of equipment, accounting for differences in yearly electricity rates. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 percent and 7 percent to discount future costs and savings to present values.

DOE calculated increases in total installed costs as the difference in total installed cost between the base case and standards case (*i.e.*, once the standards take effect). Because the more efficient equipment bought in the standards case usually cost more than equipment bought in the base case, cost increases appear as negative values in the NPV.

DOE expressed savings in operating costs as decreases associated with the lower energy consumption of equipment bought in the standards case compared to the base case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

2.11 CONSUMER SUBGROUP ANALYSIS

The consumer subgroup analysis evaluates economic impacts on selected groups of consumers who might be adversely affected by a change in the national energy conservation standards for the considered equipment. DOE performed LCC subgroup analyses for consumers from low-electricity price regions, small businesses, and consumers from specific sectors (industry, agriculture, commercial). DOE evaluated the potential LCC impacts and PBPs for these consumers using the LCC spreadsheet model. Chapter 11 of the TSD provides more detail.

2.12 MANUFACTURER IMPACT ANALYSIS

DOE performed a manufacturer impact analysis (MIA) to estimate the financial impact of energy conservation standards on manufacturers of electric motors, and to calculate the impact of such standards on employment and manufacturing capacity. The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA relies on the government regulatory impact model (GRIM), an industry-cash-flow model customized for this rulemaking. The GRIM inputs are information regarding the industry cost structure, shipments, and revenues. This includes information from many of the analyses described above, such as manufacturing costs and prices from the engineering analysis and shipments forecasts. The key GRIM output is the industry net present value (INPV). Different sets of assumptions (scenarios) will produce different results. The qualitative part of the MIA addresses factors such as equipment characteristics, characteristics of particular firms, and market and equipment trends, and includes assessment of the impacts of standards on subgroups of manufacturers. The complete MIA is described in chapter 12 of the TSD.

DOE conducted each MIA in this rulemaking in three phases. In Phase I, DOE created an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepared an industry cash-flow model and an interview questionnaire to guide subsequent discussions. In Phase III, DOE interviewed manufacturers and assessed the impacts of standards both quantitatively and qualitatively. DOE assessed industry and subgroup cash flow and NPV using the GRIM. DOE then assessed impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

2.13 EMISSIONS ANALYSIS

In the emissions analysis, DOE will estimate the reduction in power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg) from potential energy conservation standards for the considered products. In addition, DOE will estimate emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These are referred to as "upstream" emissions. Together, these emissions account for the full-fuel-cycle (FFC). In accordance with DOE's FFC Statement of Policy (76 FR 51282 (Aug. 18, 2011), as amended at 77 FR 49701 (Aug. 17, 2012)), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

DOE conducts the emissions analysis using emissions factors derived from data in the latest version of EIA's *Annual Energy Outlook (AEO)*, supplemented by data from other sources. EIA prepares the Annual Energy Outlook using NEMS. Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. The text below refers to *AEO 2013*, which generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of December 31, 2012.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), but it remained in effect. See *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008); *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008). On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See EME Homer City Generation, LP v. EPA, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. *AEO 2013* assumes that CAIR remains a binding regulation through 2040.

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the adoption of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2015, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21, 2011. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for HCl as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2013* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, NEMS shows a reduction in SO_2 emissions when electricity demand decreases (e.g., as a result of energy efficiency standards). Emissions will be far below the cap that would be established by CSAPR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2015 and beyond.

CAIR established a cap on NO_X emissions in eastern States and the District of Columbia. Energy conservation standards are expected to have little or no physical effect on these emissions in those States covered by CAIR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by the caps, so DOE estimates NO_X emissions reductions from potential standards in the States where emissions are not capped.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE’s energy conservation standards would likely reduce Hg emissions. DOE will estimate mercury emissions reduction using emissions factors based on *AEO 2013*, which incorporates the MATS.

Power plants may emit particulates from the smoke stack, which are known as direct particulate matter (PM) emissions. NEMS does not account for direct PM emissions from power plants. DOE is investigating the possibility of using other methods to estimate reduction in PM emissions due to standards. The great majority of ambient PM associated with power plants is in the form of secondary sulfates and nitrates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly SO_2 and NO_x. The monetary benefits that DOE estimates for reductions in SO_2 and NO_x emissions resulting from standards are in fact primarily related to the health benefits of reduced ambient PM.

2.14 MONETIZING REDUCED CO_2 AND OTHER EMISSIONS

DOE plans to consider the estimated monetary benefits likely to result from the reduced emissions of CO_2 and NO_X that are expected to result from each of the standard levels considered.

To estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE plans to use the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

The Interagency Working Group on Social Cost of Carbon released an update of its previous report in 2013.[a] The most recent estimates of the SCC in 2015, expressed in 2012$, are $12.9, $40.8, $62.2, and $117 per metric ton of CO_2 avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO_2 emissions.

DOE multiplies the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounts the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

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[a] *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, May 2013. http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also estimates the potential monetary benefit of reduced NO_X emissions resulting from the standard levels it considers. For NO_x emissions, estimates suggest a very wide range of monetary values, ranging from 468 to $4,809 per ton in 2012$).[b] In accordance with OMB guidance, [c] DOE calculates a range of monetary benefits using each of the economic values for NO_X and real discount rates of 3 percent and 7 percent.

DOE is evaluating appropriate valuation of avoided SO_2 and Hg emissions. Whether monetization of reduced Hg emissions will occur in this rulemaking is yet to be determined.

2.15 UTILITY IMPACT ANALYSIS

To estimate the impacts of potential energy conservation standards for electric motors on the electric utility industry, DOE uses a variant of the EIA's National Energy Modeling System called NEMS-BT.[d] NEMS is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that EIA has developed over several years, primarily for the purpose of preparing the *AEO*. NEMS produces a widely recognized forecast for the United States through 2035 and is available to the public.

The utility impact analysis is a comparison between the NEMS-BT model results for the base case and standard cases. The utility impact analysis reports the changes in installed capacity and generation that result from each standard level by plant type. DOE models the anticipated energy savings impacts from potential amended energy conservation standards using NEMS-BT to generate forecasts that deviate from the *AEO* Reference Case.

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[b] For additional information, refer to U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, Washington, DC.

[c] OMB, Circular A-4: Regulatory Analysis (Sept. 17, 2003).

[d] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581 (March 2000), available at: http://tonto.eia.doe.gov/ftproot/forecasting/05812000.pdf. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT. ("BT" refers to DOE's Building Technologies Program, under whose aegis this work is performed.)

2.16 EMPLOYMENT IMPACT ANALYSIS

The imposition of standards can affect employment both directly and indirectly. Direct employment impacts are changes, produced by new standards, in the number of employees at plants that produce the covered equipment. DOE evaluated direct employment impacts in the manufacturer impact analysis. Indirect employment impacts that occur because of the imposition of standards may result from consumers shifting expenditures between goods (the substitution effect) and from changes in income and overall expenditure levels (the income effect). DOE utilizes Pacific Northwest National Laboratory's ImSET model to investigate the combined direct and indirect employment impacts. The ImSET model, which was developed for DOE's Office of Planning, Budget, and Analysis, estimates the employment and income effects energy-saving technologies produced in buildings, industry, and transportation. In comparison with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments. Further detail is provided in chapter 16 of the TSD.

2.17 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared a regulatory impact analysis (RIA) pursuant to Executive Order 12866, Regulatory Planning and Review, 58 FR 51735, October 4, 1993, which is subject to review by the Office of Information and Regulatory Affairs at the Office of Management and Budget. The RIA addresses the potential for non-regulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the equipment covered under this rulemaking.

DOE recognizes that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the impacts existing initiatives might have in the future. Further detail is provided in chapter 17 of the TSD.

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter provides a profile of the electric motor industry in the United States. The U.S. Department of Energy (DOE) developed the market and technology assessment presented in this chapter primarily from publicly available information. This assessment is helpful in identifying the major manufacturers and their equipment characteristics, which form the basis for the engineering and life-cycle cost (LCC) analyses.

This chapter consists of two sections: the market assessment and the technology assessment. The market assessment provides an overall picture of the market for the equipment concerned, including a scope of the equipment covered, equipment classes, industry structure, manufacturer market shares; regulatory and non-regulatory efficiency improvement programs; and market trends and quantities of equipment sold. The technology assessment identifies a preliminary list of technology options for reducing motor losses to consider in the screening analysis.

The information DOE gathers for the market and technology assessment serves as resource material for use throughout the rulemaking. DOE considers both quantitative and qualitative information from publicly available sources and interested parties.

3.2 MARKET ASSESSMENT

This section addresses the scope of the rulemaking, identifies potential equipment classes, estimates national shipments of electric motors, and the market shares of electric motor manufacturers. This section also discusses the application and performance of existing equipment and regulatory and non-regulatory programs that apply to electric motors.

3.2.1 Electric Motor Definitions

The Energy Policy and Conservation Act (EPCA), as amended by the Energy Policy Act of 1992 (EPACT 1992), had previously established a definition for "electric motor" as "any motor which is a general purpose T-frame, single-speed, foot-mounting, polyphase squirrel-cage induction motor of the National Electrical Manufacturers Association [NEMA] Design A and B, continuous rated, operating on 230/460 volts and constant 60 Hertz line power as defined in NEMA Standards Publication MG1–1987." (42 U.S.C. 6311(13)(A) (1992)) Through subsequent amendments to EPCA and, in particular, the Energy Independence and Security Act that was signed into law on December 19, 2007 (EISA 2007), Congress struck the EPACT 1992 definition and replaced it with language that covered a broader scope of general purpose electric motors. (See 42 U.S.C. 6311(13)(A)-(B) (2010))

Consequently, the new terminology adopted as a result of EISA 2007 generated confusion over the definitions of the terms "electric motor" and "general purpose electric motor." As a result, DOE sought to clarify its interpretations of these definitions in a rulemaking about test procedures for electric motors. On May 4, 2012, DOE published in the *Federal Register* a test procedure final rule for electric motors which clarified the two definitions. 77 FR 26608. A regulatory definition of "electric motor" was promulgated in light of EISA 2007's removal of the statutory definition of "electric motor." The definition of "general purpose motor" (now "general purpose electric motor") was taken directly from the industry standard NEMA MG 1-1993, "Motors and Generators," and was intended to specify a broad category of motors that were potentially subject to regulation.

The test procedure was intended to clear up confusion over the definitions of "electric motor" and "general purpose electric motor." The test procedure final rule defined the two terms as follows:

"Electric motor means a machine that converts electrical power into rotational mechanical power."

and

"General purpose electric motor means any electric motor that is designed in standard ratings with either:

(1) Standard operating characteristics and mechanical construction for use under usual service conditions, such as those specified in NEMA MG 1–2009, paragraph 14.2, "Usual Service Conditions," (incorporated by reference, see § 431.15) and without restriction to a particular application or type of application; or

(2) Standard operating characteristics or standard mechanical construction for use under unusual service conditions, such as those specified in NEMA MG 1–2009, paragraph 14.3, "Unusual Service Conditions," (incorporated by reference, see §431.15) or for a particular type of application, and which can be used in most general purpose applications."

EISA 2007 also introduced and established energy conservation standards for several new categories of electric motors. As such, the test procedure final rule sought to clarify DOE's interpretation of these terms. Ultimately, DOE created new definitions for the terms "general purpose electric motor (subtype I)," "general purpose electric motor (subtype II)," "NEMA Design B motor," and "fire pump electric motor," which are shown below.

As a result of the recent electric motors test procedure final rule, section 431.12 of Title 10 of the Code of Federal Regulations, Part 431 (10 CFR 431) now defines a general purpose electric motor (subtype I) as a general purpose electric motor that:

(1) Is a single-speed, induction motor;
(2) Is rated for continuous duty (MG 1) operation or for duty type S1 (IEC);
(3) Contains a squirrel-cage (MG 1) or cage (IEC) rotor;
(4) Has foot-mounting that may include foot-mounting with flanges or detachable feet;
(5) Is built in accordance with NEMA T-frame dimensions or their IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;

(6) Has performance in accordance with NEMA Design A (MG 1) or B (MG 1) characteristics or equivalent designs such as IEC Design N (IEC);
(7) Operates on polyphase alternating current 60-hertz sinusoidal power, and:
(i) Is rated at 230 or 460 volts (or both) including motors rated at multiple voltages that include 230 or 460 volts(or both), or
(ii) Can be operated on 230 or 460 volts (or both); and
(8) Includes, but is not limited to, explosion-proof construction.

Further, the recent electric motors test procedure final rule amended 10 CFR 431.12, which now defines a general purpose electric motor (subtype II) as any general purpose electric motor that incorporates design elements of a general purpose electric motor (subtype I) but, unlike a general purpose electric motor (subtype I), is configured in one or more of the following ways:

(1) Is built in accordance with NEMA U-frame dimensions as described in NEMA MG 1–1967 or in accordance with the IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(2) Has performance in accordance with NEMA Design C characteristics as described in MG 1 or an equivalent IEC design(s) such as IEC Design H;
(3) Is a close-coupled pump motor;
(4) Is a footless motor;
(5) Is a vertical solid shaft normal thrust motor (as tested in a horizontal configuration) built and designed in a manner consistent with MG 1;
(6) Is an eight-pole motor (900 rpm); or
(7) Is a polyphase motor with a voltage rating of not more than 600 volts, is not rated at 230 or 460 volts (or both), and cannot be operated on 230 or 460 volts (or both).

Also, as a result of the electric motors test procedure final rule, 10 CFR 431.12 defines a NEMA Design B motor as a squirrel-cage motor that is:

(1) Designed to withstand full-voltage starting;
(2) Develops locked-rotor, breakdown, and pull-up torques adequate for general application as specified in sections 12.38, 12.39 and 12.40 of NEMA MG 1– 2009 (incorporated by reference, see § 431.15);
(3) Draws locked-rotor current not to exceed the values shown in section 12.35.1 for 60 hertz and 12.35.2 for 50 hertz of NEMA MG 1–2009; and
(4) Has a slip at rated load of less than 5 percent for motors with fewer than 10 poles.

Finally, the electric motors test procedure final rule, amended 10 CFR 431.12 by defining a fire pump electric motor in the following manner:

Fire pump electric motor means an electric motor, including any IEC-equivalent, that meets the requirements of section 9.5 of NFPA 20.

3.2.1.1 Expanded Scope Definitions

In order to facilitate the potential application of energy conservation standards to motors built in certain configurations, DOE is proposing definitions for these expanded scope motor types. The definitions under consideration would address motors currently subject to standards, specific motors DOE is considering requiring to meet standards, and some motors that DOE is, at this time, declining to regulate through energy conservation standards. Some of these clarifying definitions, such as the definitions for NEMA Design A and C motors, come from NEMA MG 1-2009. However, DOE understands that some motors, such as partial motors and integral brake motors, do not have standard, industry-accepted definitions. For such motor types, DOE worked with subject matter experts (SMEs), manufacturers, and the Motor Coalition to create working definitions.[a] DOE lists these motors in section 3.2.3 of this TSD chapter, but notes that these definitions are discussed in detail in the Test Procedures for Electric Motors notice of proposed rulemaking (NOPR). (78 FR 38456, June 26, 2013)

3.2.2 Equipment Class Groups and Equipment Classes

Within each category of electric motors it addressed, EISA 2007 set separate energy conservation standards by horsepower rating, enclosure type, and pole configuration. These standards correspond to Table 12-12 of NEMA MG 1–2011 (equivalent to NEMA Premium[b]) for general purpose electric motors (subtype I) and Table 12-11 of NEMA MG 1–2011 (equivalent to EPACT 1992 values) for 1 to 200 horsepower general purpose electric motors (subtype II), fire pump electric motors, and NEMA Design B electric motors greater than 200 horsepower.[c] (42 U.S.C. 6313(b)(2))

In general, when DOE amends energy conservation standards, it divides covered equipment into classes. By statute, these classes are based on: (a) the type of energy used; (b) the capacity of the equipment; or (c) any other performance-related feature that justifies different efficiency levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) As a result of changes in EISA 2007, particularly with the addition of general purpose electric motors (subtype II) as a subset of motors covered by the term “electric motor,” there are a large number of motor design features that DOE considered in this rulemaking. In the following sections, DOE discusses the design features that it is considering as part of its analysis.

Due to the number of electric motor characteristics (e.g., horsepower rating, pole configuration, and enclosure), DOE is using two constructs, at this stage, to help develop appropriate energy conservation standards for electric motors: “equipment class groups” and

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[a] The members of the Motor Coalition include: National Electrical Manufacturers Association, American Council for an Energy-Efficient Economy, Appliance Standards Awareness Project, Alliance to Save Energy, Earthjustice, Natural Resources Defense Council, Northwest Energy Efficiency Alliance, Northeast Energy Efficiency Partnerships, and Northwest Power and Conservation Council.

[b] NEMA Premium efficiency levels refer to the efficiency values in NEMA MG 1-2011 Tables 12-12 and 20-B.

[c] EISA 2007 also set energy conservation standards for general purpose NEMA Design B motors from 201–500 horsepower at the NEMA MG 1Table 12-11 levels.

"equipment classes." An equipment class group is a collection of electric motors that share a common design type. Equipment class groups include motors over a range of horsepower ratings, enclosure types, and pole configurations. Essentially, each equipment class group is a collection of a large number of equipment classes with the same design type. An equipment class represents a unique combination of motor characteristics for which DOE will determine an energy efficiency conservation standard. For example, given a combination of motor design type, horsepower rating, pole configuration, and enclosure type, the motor design type dictates the equipment class group, while the combination of the remaining characteristics dictates the specific equipment class.

For the NOPR analysis DOE has created four equipment class groups based on three main motor characteristics: the designated NEMA design letter, whether the motor meets the definition of a fire pump electric motor and whether the motor meets the definition of an integral brake electric motor or non-integral brake electric motor. DOE's resulting equipment class groups are for NEMA Design A and B motors (including IEC-equivalent designs), NEMA Design C motors (including IEC-equivalent designs), fire pump electric motors (including IEC-equivalent designs) and electric motors with brakes. Within each of these four broad groups, DOE uses combinations of other pertinent motor characteristics to enumerate its individual equipment classes. To illustrate the differences between the two terms, consider the following example. A NEMA Design B, 50 horsepower (hp), 2-pole enclosed electric motor and a NEMA Design B, 100 hp, 6-pole open electric motor would both be in the same equipment class group (equipment class group 1), but each motor would represent a unique equipment class, which will ultimately have its own efficiency standard. There are 580 potential equipment classes which consist of all permutations of electric motor design types (i.e., NEMA Design A and B, NEMA Design C, fire pump electric motor, or electric motor with brake), standard horsepower ratings (i.e., standard ratings from 1 to 500 horsepower), pole configurations (i.e., 2-, 4-, 6-, or 8-pole), and enclosure types (i.e., open or enclosed). Table 3.1 illustrates the relationships between equipment class groups and the characteristics used to define equipment classes. In the following sections, DOE discusses each of these design features.

Table 3.1 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design	Horsepower	Poles	Enclosure
1	NEMA Design A & B*	1–500	2, 4, 6, 8	Open
				Closed
2	NEMA Design C*	1–200	4, 6, 8	Open
				Closed
3	Fire Pump*	1–500	2, 4, 6, 8	Open
				Closed
4	Brake Motors*	1–30	4, 6, 8	Open
				Enclosed

*Including IEC equivalents.

DOE notes that should it establish amended energy conservation standards for electric motors with this arrangement of equipment class groups and equipment classes, it would no longer disaggregate its standards by general purpose electric motor subtype I and II. Additionally, in light of DOE's plan to expand the scope of energy conservation standards in this rulemaking, the equipment class groups listed in Table 3.1 would include motor types that previously may not have been subject to energy conservation standards, including motors that may not fall under the categories of subtype I or II motors.

3.2.2.1 Electric Motor Design

Various industry organizations, such as NEMA and IEC, publish performance criteria that provide specifications that electric motors must meet in order to be assigned different design types. As these design types represent a certain set of performance parameters, they provide electric motor users with an easy reference to use when designing their equipment and when purchasing a motor to drive their equipment. The electric motors covered under this rulemaking must meet one of three NEMA design types. For medium polyphase alternating current (AC) induction motors, the three NEMA design types considered general purpose and covered by EPCA, as amended by EISA 2007, are Design A, Design B, and Design C. The definitions for these three motor types are as follows:

In NEMA MG 1–2011 paragraph 1.19.1.1, "A Design A motor is a squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor torque as shown in 12.38, pull-up torque as shown in 12.40, breakdown torque as shown in 12.39, with locked-rotor current higher than the values shown in 12.35.1 for 60 hertz and 12.35.2 for 50 hertz and having a slip at rated load of less than 5 percent."

Under 10 CFR 431.12,[d] "NEMA Design B motor means a squirrel-cage motor that is (1) designed to withstand full-voltage starting, (2) develops locked-rotor, breakdown, and pull-up torques adequate for general application as specified in sections 12.38, 12.39 and 12.40 of NEMA Standards Publication MG 1–2009 (incorporated by reference, *see* § 431.15), (3)draws locked-rotor current not to exceed the values shown in section 12.35.1 for 60 hertz and 12.35.2 for 50 hertz of NEMA Standards Publication MG 1–2009, and (4) has a slip at rated load of less than 5 percent for motors with fewer than 10 poles."

In NEMA MG 1–2011 paragraph 1.19.1.3,"A Design C motor is a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor torque for special high-torque application up to the values shown in 12.38, pull-up torque as shown in 12.40, breakdown torque up to the values shown in 12.39, with locked-rotor current not to exceed the values shown in 12.34.1 [12.35.1] for 60 hertz and 12.35.2 for 50 hertz, and having a slip at rated load of less than 5 percent."

[d] As this definition was adopted and codified into the CFR, DOE added some minor language to specify which version of NEMA MG 1 should be used and DOE corrected some minor typographical errors that referred the reader to the wrong tables for locked rotor current specifications.

NEMA Design A and NEMA Design B electric motors have different locked-rotor current requirements. NEMA Design A electric motors have no locked-rotor current limits whereas NEMA Design B electric motors are required to stay below certain maximums specified in NEMA MG 1-2011 paragraph 12.35.1. This tolerance for higher locked-rotor current will allow NEMA Design A motors to reach the same efficiency levels as NEMA Design B with fewer design changes and constraints. However, NEMA Design A and NEMA Design B motors have the same requirements for locked-rotor, pull-up, and breakdown torque and are consequently used in many of the same applications. Additionally, as is shown in section 3.2.5 below, NEMA Design B motors constitute a significantly larger population of the electric motors that are shipped relative to NEMA Design A motors.

NEMA Design C electric motors, on the other hand, have different torque requirements than NEMA Design A or B motors. NEMA Design C electric motors typically have higher torque requirements. DOE believes that this performance change represents a change in utility which can also affect efficiency. Additionally, the difference in torque requirements will restrict which applications can use which NEMA Design types. As a result, NEMA Design C motors will not always be replaceable with NEMA Design A or B motors, or vice versa.

DOE notes that Congress held NEMA Design A and NEMA Design B motors to the same energy conservation standards prescribed by EPACT 1992 (42 U.S.C. 6311(13)(A)) and EISA 2007 (42 U.S.C. 6311 (13)(A)) (see requirements for general purpose electric motors (subtype I)). For the preliminary analysis, DOE has followed the precedent set by EPACT 1992 and EISA 2007 and has considered NEMA Design A and B motors in a group together, while placing NEMA Design C motors in their own equipment class group. Finally, DOE notes that all equivalent IEC design types are also covered by this energy conservation standards rulemaking and should be considered with their corresponding NEMA Design type.

3.2.2.2 Fire Pump Electric Motors

EISA 2007 prescribed energy conservation standards for fire pump electric motors. (42 U.S.C. § 6313(b)(2)(B)) Fire pump electric motors are motors with special design characteristics that make them more suitable for emergency operation. As stated previously, DOE adopted a definition of "fire pump electric motor," which incorporated portions of the National Fire Protection Association (NFPA) Standard 20, "Standard for the Installation of Stationary Pumps for Fire Protection" (2010). Such electric motors, per the requirements of NFPA 20, are required to be marked as complying with NEMA Design B performance standards and be capable of operating even if it overheats or may be damaged due to continued operation. These additional requirements for a fire pump electric motor constitute a change in utility, apart from other general purpose electric motors, which DOE believes could also affect its performance and efficiency. Therefore, DOE has preliminarily established a separate equipment class group for fire pump electric motors.

3.2.2.3 Electric Motors with Brakes

In its NOPR analyses, DOE considered whether the term "electric motor" should include an integral brake electric motor or a non-integral brake electric motor (collectively, "brake motors"). In the test procedure NOPR, DOE proposed definitions both for integral and non-integral brake electric motors. 78 FR 38456 (June 26, 2013). Both of these electric motor types are contained in one equipment class group as separate from the equipment class groups established for NEMA Design A and B motors, NEMA Design C motors, and fire pump electric motors.

3.2.2.4 Horsepower Rating

Horsepower is a measurement directly related to the capacity of an electric motor to perform useful work and, therefore, it is one of DOE’s primary criteria in designating equipment classes. Horsepower rating defines the output power of an electric motor, where 1 horsepower equals 745.7 watts. It is generally true that efficiency scales with horsepower. In other words, a 50-horsepower motor is usually more efficient than a 10-horsepower motor. Also, because of its larger frame size and additional active material (e.g., copper wiring and electrical steel), the 50-horsepower motor will be able to achieve a higher, maximum level of efficiency. Horsepower is a critical performance attribute of an electric motor, and because there is a direct correlation between horsepower and efficiency, DOE is using horsepower rating as an equipment class setting criterion.

3.2.2.5 Pole Configuration

An electric motor’s pole configuration corresponds to the number of magnetic poles present in the motor. Consequently, the number of magnetic poles (or “poles”) dictates the revolutions per minute (RPM) of the rotor and shaft. For each pole configuration there is a corresponding synchronous speed, in RPMs, which is the theoretical maximum speed at which a motor might operate without a load. All of the electric motors covered by this rulemaking are asynchronous motors, meaning they cannot reach this speed. There is an inverse relationship between the number of poles and a motor’s speed. As the number of poles increases from two to four to six to eight, the synchronous speed drops from 3,600 to 1,800 to 1,200 to 900 RPMs. Because the number of poles has a direct impact on the rotational speed of a motor shaft, it also affects a motor’s utility and performance, including efficiency. Therefore, DOE is also using pole configuration as a means of differentiating equipment classes for the NOPR analysis.

3.2.2.6 Enclosure Type

In general, there are two variations of enclosure types, either open or enclosed. DOE currently defines both of these terms under 10 CFR 431.12. An electric motor meets the current definition of an “enclosed motor” if it is “an electric motor so constructed as to prevent the free exchange of air between the inside and outside of the case but not sufficiently enclosed to be termed airtight.” An open motor is defined under 10 CFR 431.12 as “an electric motor having ventilating openings which permit passage of external cooling air over and around the windings of the machine.”

As in EPACT 1992, EISA 2007 prescribes separate energy conservation standards for open and enclosed electric motors. (42 U.S.C. 6313 (b)(1)) Electric motors manufactured with open construction allow a free interchange of air between the electric motor’s interior and exterior. Electric motors with enclosed construction have no direct air interchange between the motor’s interior and exterior (but are not necessarily air-tight) and may be equipped with an internal fan for cooling (see NEMA MG 1−2011, paragraph 1.26). Whether an electric motor is open or enclosed affects its utility; open motors are generally not used in harsh operating environments, whereas totally enclosed electric motors often are. The enclosure type also affects an electric motor's ability to dissipate heat, which directly affects efficiency. For these reasons, DOE used an electric motor's enclosure type (open or enclosed) as an equipment class setting criterion in the preliminary analysis.

Table 3.2, Table 3.3, Table 3.4, and Table 3.5 illustrate the relationship between equipment class and various motor design characteristics. Yellow highlighted cells mark which equipment class are representative units in the engineering analysis.

Table 3.2 NEMA Design A and B Equipment Classes

Horsepower	Enclosure	Two Poles	Four Poles	Six Poles	Eight Poles
1.0	Open	EC#1	EC#2	EC#3	EC#4
	Enclosed	EC#5	EC#6	EC#7	EC#8
1.5	Open	EC#9	EC#10	EC#11	EC#12
	Enclosed	EC#13	EC#14	EC#15	EC#16
2.0	Open	EC#17	EC#18	EC#19	EC#20
	Enclosed	EC#21	EC#22	EC#23	EC#24
3.0	Open	EC#25	EC#26	EC#27	EC#28
	Enclosed	EC#29	EC#30	EC#31	EC#32
5.0	Open	EC#33	EC#34	EC#35	EC#36
	Enclosed	EC#37	EC#38	EC#39	EC#40
7.5	Open	EC#41	EC#42	EC#43	EC#44
	Enclosed	EC#45	EC#46	EC#47	EC#48
10.0	Open	EC#49	EC#50	EC#51	EC#52
	Enclosed	EC#53	EC#54	EC#55	EC#56
15.0	Open	EC#57	EC#58	EC#59	EC#60
	Enclosed	EC#61	EC#62	EC#63	EC#64
20.0	Open	EC#65	EC#66	EC#67	EC#68
	Enclosed	EC#69	EC#70	EC#71	EC#72
25.0	Open	EC#73	EC#74	EC#75	EC#76
	Enclosed	EC#77	EC#78	EC#79	EC#80
30.0	Open	EC#81	EC#82	EC#83	EC#84
	Enclosed	EC#85	EC#86	EC#87	EC#88
40.0	Open	EC#89	EC#90	EC#91	EC#92
	Enclosed	EC#93	EC#94	EC#95	EC#96
50.0	Open	EC#97	EC#98	EC#99	EC#100
	Enclosed	EC#101	EC#102	EC#103	EC#104
60.0	Open	EC#105	EC#106	EC#107	EC#108
	Enclosed	EC#109	EC#110	EC#111	EC#112
75.0	Open	EC#113	EC#114	EC#115	EC#116
	Enclosed	EC#117	EC#118	EC#119	EC#120
100.0	Open	EC#121	EC#122	EC#123	EC#124
	Enclosed	EC#125	EC#126	EC#127	EC#128
125.0	Open	EC#129	EC#130	EC#131	EC#132
	Enclosed	EC#133	EC#134	EC#135	EC#136
150.0	Open	EC#137	EC#138	EC#139	EC#140
	Enclosed	EC#141	EC#142	EC#143	EC#144
200.0	Open	EC#145	EC#146	EC#147	EC#148

	Enclosed	EC#149	EC#150	EC#151	EC#152
	Open	EC#153	EC#154	EC#155	EC#156
250.0	Enclosed	EC#157	EC#158	EC#159	EC#160
	Open	EC#161	EC#162	EC#163	EC#164
300.0	Enclosed	EC#165	EC#166	EC#167	EC#168
	Open	EC#169	EC#170	EC#171	EC#172
350.0	Enclosed	EC#173	EC#174	EC#175	EC#176
	Open	EC#177	EC#178	EC#179	EC#180
400.0	Enclosed	EC#181	EC#182	EC#183	EC#184
	Open	EC#185	EC#186	EC#187	EC#188
450.0	Enclosed	EC#189	EC#190	EC#191	EC#192
	Open	EC#193	EC#194	EC#195	EC#196
500.0	Enclosed	EC#197	EC#198	EC#199	EC#200

Table 3.3 NEMA Design C Equipment Classes

Horsepower	Enclosure	Four Poles	Six Poles	Eight Poles
	Open	EC#201	EC#202	EC#203
1.0	Enclosed	EC#204	EC#205	EC#206
	Open	EC#207	EC#208	EC#209
1.5	Enclosed	EC#210	EC#211	EC#212
	Open	EC#213	EC#214	EC#215
2.0	Enclosed	EC#216	EC#217	EC#218
	Open	EC#219	EC#220	EC#221
3.0	Enclosed	EC#222	EC#223	EC#224
	Open	EC#225	EC#226	EC#227
5.0	Enclosed	EC#228	EC#229	EC#230
	Open	EC#231	EC#232	EC#233
7.5	Enclosed	EC#234	EC#235	EC#236
	Open	EC#237	EC#238	EC#239
10.0	Enclosed	EC#240	EC#241	EC#242
	Open	EC#243	EC#244	EC#245
15.0	Enclosed	EC#246	EC#247	EC#248
	Open	EC#249	EC#250	EC#251
20.0	Enclosed	EC#252	EC#253	EC#254
	Open	EC#255	EC#256	EC#257
25.0	Enclosed	EC#258	EC#259	EC#260
	Open	EC#261	EC#262	EC#263
30.0	Enclosed	EC#264	EC#265	EC#266
	Open	EC#267	EC#268	EC#269
40.0	Enclosed	EC#270	EC#271	EC#272
	Open	EC#273	EC#274	EC#275
50.0	Enclosed	EC#276	EC#277	EC#278
	Open	EC#279	EC#280	EC#281
60.0	Enclosed	EC#282	EC#283	EC#284
	Open	EC#285	EC#286	EC#287
75.0	Enclosed	EC#288	EC#289	EC#290
	Open	EC#291	EC#292	EC#293
100.0	Enclosed	EC#294	EC#295	EC#296
	Open	EC#297	EC#298	EC#299
125.0	Enclosed	EC#300	EC#301	EC#302
150.0	Open	EC#303	EC#304	EC#305

	Enclosed	EC#306	EC#307	EC#308
	Open	EC#309	EC#310	EC#311
200.0	Enclosed	EC#312	EC#313	EC#314

Table 3.4 Fire Pump Electric Motor Equipment Classes

Horsepower	**Enclosure**	**Two Poles**	**Four Poles**	**Six Poles**	**Eight Poles**
	Open	EC#315	EC#316	EC#317	EC#318
1.0	Enclosed	EC#319	EC#320	EC#321	EC#322
	Open	EC#323	EC#324	EC#325	EC#326
1.5	Enclosed	EC#327	EC#328	EC#329	EC#330
	Open	EC#331	EC#332	EC#333	EC#334
2.0	Enclosed	EC#335	EC#336	EC#337	EC#338
	Open	EC#339	EC#340	EC#341	EC#342
3.0	Enclosed	EC#343	EC#344	EC#345	EC#346
	Open	EC#347	EC#348	EC#349	EC#350
5.0	Enclosed	EC#351	EC#352	EC#353	EC#354
	Open	EC#355	EC#356	EC#357	EC#358
7.5	Enclosed	EC#359	EC#360	EC#361	EC#362
	Open	EC#363	EC#364	EC#365	EC#366
10.0	Enclosed	EC#367	EC#368	EC#369	EC#370
	Open	EC#371	EC#372	EC#373	EC#374
15.0	Enclosed	EC#375	EC#376	EC#377	EC#378
	Open	EC#379	EC#380	EC#381	EC#382
20.0	Enclosed	EC#383	EC#384	EC#385	EC#386
	Open	EC#387	EC#388	EC#389	EC#390
25.0	Enclosed	EC#391	EC#392	EC#393	EC#394
	Open	EC#395	EC#396	EC#397	EC#398
30.0	Enclosed	EC#399	EC#400	EC#401	EC#402
	Open	EC#403	EC#404	EC#405	EC#406
40.0	Enclosed	EC#407	EC#408	EC#409	EC#410
	Open	EC#411	EC#412	EC#413	EC#414
50.0	Enclosed	EC#415	EC#416	EC#417	EC#418
	Open	EC#419	EC#420	EC#421	EC#422
60.0	Enclosed	EC#423	EC#424	EC#425	EC#426
	Open	EC#427	EC#428	EC#429	EC#430
75.0	Enclosed	EC#431	EC#432	EC#433	EC#434
	Open	EC#435	EC#436	EC#437	EC#438
100.0	Enclosed	EC#439	EC#440	EC#443	EC#442
	Open	EC#443	EC#444	EC#445	EC#446
125.0	Enclosed	EC#447	EC#448	EC#459	EC#450
	Open	EC#451	EC#452	EC#453	EC#454
150.0	Enclosed	EC#455	EC#456	EC#457	EC#458
	Open	EC#459	EC#460	EC#461	EC#462
200.0	Enclosed	EC#463	EC#464	EC#465	EC#466
	Open	EC#467	EC#468	EC#469	EC#470
250.0	Enclosed	EC#471	EC#472	EC#473	EC#474
	Open	EC#475	EC#476	EC#477	EC#478
300.0	Enclosed	EC#479	EC#480	EC#481	EC#482
	Open	EC#483	EC#484	EC#485	EC#486
350.0	Enclosed	EC#487	EC#488	EC#489	EC#490
400.0	Open	EC#491	EC#492	EC#493	EC#494

	Enclosed	EC#495	EC#496	EC#497	EC#498
450.0	Open	EC#499	EC#500	EC#501	EC#502
	Enclosed	EC#503	EC#504	EC#505	EC#506
500.0	Open	EC#507	EC#508	EC#509	EC#510
	Enclosed	EC#511	EC#512	EC#513	EC#514

Table 3.5 Brake Motor Equipment Classes

Horsepower	Enclosure	Four Poles	Six Poles	Eight Poles
1.0	Open	EC#515	EC#516	EC#517
	Enclosed	EC#518	EC#519	EC#520
1.5	Open	EC#521	EC#522	EC#523
	Enclosed	EC#524	EC#525	EC#526
2.0	Open	EC#527	EC#528	EC#529
	Enclosed	EC#530	EC#531	EC#532
3.0	Open	EC#533	EC#534	EC#535
	Enclosed	EC#536	EC#537	EC#538
5.0	Open	EC#539	EC#540	EC#541
	Enclosed	EC#542	EC#543	EC#544
7.5	Open	EC#545	EC#546	EC#547
	Enclosed	EC#548	EC#549	EC#550
10.0	Open	EC#551	EC#552	EC#553
	Enclosed	EC#554	EC#555	EC#556
15.0	Open	EC#557	EC#558	EC#559
	Enclosed	EC#560	EC#561	EC#562
20.0	Open	EC#563	EC#564	EC#565
	Enclosed	EC#566	EC#567	EC#568
25.0	Open	EC#569	EC#570	EC#571
	Enclosed	EC#572	EC#573	EC#574
30.0	Open	EC#575	EC#576	EC#577
	Enclosed	EC#578	EC#579	EC#580

3.2.3 Expanded Scope of Coverage

During the October 18, 2010, framework public meeting, DOE received comments regarding the energy savings potential from expanding the scope of coverage beyond subtype I, subtype II, and fire pump electric motors. DOE addressed these comments in chapter 2 of the preliminary TSD. DOE's discussion of expanding the scope of coverage refers to the decision to analyze energy conservation standards for electric motor types that currently do not have energy conservation standards. DOE has the statutory authority to establish such standards without first promulgating a coverage determination rulemaking based on the modifications resulting from EISA 2007, which struck the statutory definition for "electric motors." DOE recognizes the energy savings potential of scope expansion for motors not previously covered under energy conservation standards, as well as motors that may not fall into the subtype I, subtype II, and fire pump electric motor categories. In today's rule, DOE is proposing to expand the scope of conservation standards to all motors with characteristics listed in Table 3.6 and then specifically name motors for which no standards will be established.

Table 3.6 Characteristics of Motors Regulated Under Expanded Scope of Coverage

Motor Characteristic
Is a single-speed, induction motor,
Is rated for continuous duty (MG 1) operation or for duty type S1 (IEC),
Contains a squirrel-cage (MG 1) or cage (IEC) rotor,
Operates on polyphase alternating current 60-hertz sinusoidal power,
Has a 2-, 4-, 6-, or 8-pole configuration,
Is rated 600 volts or less,
Has a three-digit NEMA frame size (or IEC metric equivalent) or an enclosed 56 NEMA frame size (or IEC metric equivalent) is less than 500 horsepower, and
Has no more than 500 horsepower, but greater than or equal to 1 horsepower (or kilowatt equivalent), and
Meets all of the performance requirements of a NEMA Design A, B, or C electric motor or an IEC design N or H electric motor.

Table 3.7 lists electric motors that are not currently subject to conservation standards, but would be subject to energy conservations standards if DOE decides to expand coverage to electric motors with all of the characteristics listed in Table 3.6 (with the exception of specifically named motors that would otherwise not be covered). Such motors fall into the equipment class groups listed in Table 3.1 based on their respective design type.

Table 3.7 Electric Motor Types DOE Plans on Regulating Under Newly Expanded Scope of Conservation Standards

Electric Motor Type	
NEMA Design A from 201 to 500 horsepower	Electric motors with non-standard endshields or flanges
Electric motors with moisture resistant windings	Electric motors with non-standard bases
Electric motors with sealed windings	Electric motors with special shafts
Partial electric motors	Vertical hollow-shaft electric motors
Totally enclosed non-ventilated (TENV) electric motors	Electric motors with sleeve bearings
Immersible electric motors	Electric motors with thrust bearings
Integral brake electric motors	Non-integral brake electric motors

In the March 30, 2011, Request for Information (RFI) related to electric motors, DOE requested comment on expanding the scope of energy conservation standards to motors that were not currently subject to standards, including some motor types listed in Table 3.7 and Table 3.8. (76 FR 17577) The motor types listed in Table 3.8 are motor types which, at this time, DOE does not plan on subjecting to energy conservation standards. While some of these motors conform to many or all of the characteristics listed in Table 3.6, DOE understands that covering such motors might not be warranted due to special operating conditions or testing difficulties as discussed below.

Table 3.8 Electric Motors Excluded from Expanded Scope of Coverage

Electric Motor Type	
Air-Over Electric Motors	Direct Current Motors
Component Sets	Single Phase Motors
Intermittent Duty Motors	Liquid-Cooled Motors
Definite-Purpose Inverter-Fed Electric Motors	Submersible Motors
Multispeed Motors	Non-general purpose open 56 frame motors 1 horsepower and greater*

*DOE has not included these motors in its NOPR analysis, but has tentatively proposed their coverage for the final rule, barring any submitted data that suggests they should be excluded.

Air-Over Electric Motors

Air-over electric motors require an external means of cooling to allow continuous duty operation. These motors may be subject to over-heating and therefore cannot run continuously without a specified amount of air flowing over the motor housing. The required air flow amount is usually determined by the manufacturer as part of the motor design and performance characteristics.

DOE is not planning on covering air-over motors because of the test setup complexities required for these motors. DOE's primary test procedure, the Institute of Electrical and Electronics Engineers, Inc. (IEEE) Standard 112–2004 Test Method B (IEEE 112B), requires certain measurements to be taken at a steady-state temperatures[e]. Reaching a steady-state temperature requires a motor to be rated and operate under continuous-duty conditions; otherwise the motor could overheat and be damaged before reaching a steady-state temperature. IEEE 112B does not provide directions on how to setup an air-over motor for testing, which would otherwise require an external cooling apparatus. DOE is not aware of test procedures that provide guidance on how to test such motors.

Liquid-Cooled Motors

Liquid-cooled electric motors rely on a special cooling apparatus that pumps liquid into and around the motor housing. The liquid is circulated around the motor to dissipate heat and prevent the motor from overheating during continuous-duty operation. The user of a liquid-cooled motor could employ different liquids or liquid temperatures which could affect the measured efficiency of a motor. IEEE 112B does not provide standardized direction for testing liquid-cooled motors, and therefore DOE is not proposing to include them in the scope of coverage.

Submersible Motors

Submersible motors are similar to liquid-cooled motors in that they use liquid to dissipate the heat produced during continuous duty operation. However, unlike liquid-cooled motors,

[e] Section 3.3.2 of IEEE 112B requires the conductor losses to be measured when the machine is at a specified temperature.

submersible motors are only meant to operate while completely submerged in water, as opposed to having a hose and pump apparatus circulating liquid around the motor enclosure.

DOE is not aware of any test procedures for motors that can only operate continuously in special environments, such as underwater. Therefore, DOE is proposing to exclude submersible motors from the expanded scope of coverage.

Component Sets

Component sets are comprised of any combination of motor parts, such as a stator, rotor, shaft, stator housing, shaft bearings, endshields, or other electrical parts. DOE delineated between component sets and partial motors in chapter 2 of the preliminary TSD when it called out partial motors as motors only missing one or both endshields. Component sets are typically sold to be turned into complete electric motors or installed in equipment by the end-user.

DOE believes component sets do not constitute a complete motor that could be tested under IEEE 112B. Additionally, DOE is not aware of any test procedures that would accommodate the testing of component sets of motors. While DOE is planning on including partial motors in the expansion of energy conservation standards by testing them with a custom-built endshield that could be attached as a ‘dummy’ endplate for testing, DOE believes component sets would require too many or various hardware additions to make a complete motor. Therefore, DOE is not proposing to include component sets in the expanded scope of coverage.

Intermittent-Duty Electric Motors

Intermittent-duty motors are motors that, by definition, are not able to operate continuously under full load. DOE does not plan to include such motors in the expanded scope for energy conservation standards because it does not believe intermittent-duty motors present significant opportunities for energy savings. Additionally, IEEE 112B requires measurements to be taken at steady-state temperatures. Reaching a steady-state temperature requires a motor to be rated and operate under continuous-duty conditions; otherwise the motor could overheat and be damaged before reaching a steady-state temperature. Intermittent-duty motors are not capable of continuous-duty operation and, therefore, never reach a steady-state temperature which IEEE 112B requires for certain calculations. Otherwise, DOE is not aware of any test procedures which provide for testing an intermittent or non-continuous-duty motor, and it is not proposing to cover them in today’s rulemaking.

Definite-Purpose Inverter-Fed Electric Motors

Inverter-only motors cannot be run continuously when directly connected to a 60-hertz, AC polyphase sinusoidal power source. Therefore a separate, special electronic controller, called an inverter, is used to alter the power signal to the motor.

Inverter controllers are not necessarily 100 percent efficient when manipulating the power signal being fed into the motor. Consequently, the IEEE 112B-measured efficiency of an inverter-only motor would not reflect the true efficiency of that motor, but would also include any losses inherent in the inverter controller. DOE believes testing an inverter-only motor with the inverter controller connected would not accurately record the efficiency of the motor per se. DOE is not proposing to include inverter-only motors under the expanded scope motors covered by energy conservation standards, because it is not aware of any test procedures that recognize and differentiate losses caused by the inverter controller.

Multispeed Motors

For this rulemaking, the speed of an electric motor subject to energy conservation standards is determined by its magnetic pole configuration (2-, 4-, 6-, or 8-pole), and the frequency (60-hertz) of the motor's incoming power signal. The pole configuration is directly determined by the stator winding configuration as discussed in section 3.2.2.5.

In general, multispeed motors are motors with multiple, separate stator winding configurations that enable the motor to perform at different speeds contingent upon which winding configuration is connected to the power source. For example, a multispeed motor could be wound with a 2-pole winding configuration and a 4-pole winding configuration. When the power source is connect to the 2-pole winding configuration, the motor shaft will rotate at or near (depending on slip) 3,600 revolutions per minute (RPM), and when the 4-pole winding configuration is connected to the power source the same motor shaft will rotate at or near 1,800 RPM.

DOE is not proposing to include multispeed motors in the expanded scope of motors covered under conservation standards, because it is not aware of any test procedures that provide methods for testing a motor with more than one nameplate-rated speed.

Direct Current Motors

Direct current (DC) motors are motors that run on DC power input. For this rulemaking, DOE is covering only electric motors that operate on polyphase, sinusoidal AC power and can be tested under IEEE 112B. DC motors cannot be tested under IEEE 112B, but require testing under other methods.

Single Phase Motors

Single phase motors operate on a single phase, AC power source. For this rulemaking, DOE is covering only electric motors that operate on polyphase, sinusoidal AC power and can be tested for efficiency under IEEE 112B. DOE does not propose to include single phase motors in this rulemaking because they cannot be tested according to IEEE 112B.

Non-general Purpose Open 56 Frame Motors 1 Horsepower and Greater

Regarding 56-frame motors at 1-hp or greater, DOE is proposing standards for polyphase, enclosed 56-frame motors that are rated at 1-hp or greater. DOE is also tentatively proposing TSL 2 for polyphase, open 56-frame special and definite purpose motors that are rated at 1-hp or greater as advocated by the Motor Coalition. With respect to these motors (i.e. 56-frame, open, special and definite purpose), DOE seeks additional data related to these motors, including, but not limited to the following categories: motor efficiency distributions; shipment breakdowns between horsepower ratings, open and enclosed motors, and between general and special and definite purpose electric motors; and information regarding the typical applications that use these motors. If this proposal is adopted in the final rule, DOE will account for a substantial majority of 56-frame motors that are not already regulated by efficiency standards and ensure coverage for all general purpose motors along with a substantial number of special and definite purpose motors.

Based on currently available data, DOE estimates that approximately 270,000 polyphase, open 56-frame special and definite purpose motors (1-hp or greater) were shipped in 2011 and at least 70% of these motors have efficiency levels below NEMA Premium.[f] In addition, based on these data, DOE believes that establishing TSL 2 for this subset of 56-frame motors would result in national energy savings of 0.58 quads (full-fuel-cycle) and net present value savings of $1.11 billion (2012$), with a 7 percent discount rate.[g] DOE has not merged its data and analyses related to this subset of 56-frame motors with the other analyses in today's NOPR. As described above, DOE seeks additional information that can be incorporated into its final analysis.

3.2.4 Advanced Electric Motors

The motors and motor systems listed in Table 3.9 are technologies that DOE tentatively views as "advanced electric motors." DOE believes that these technologies are advanced electric motors because there are significant differences between these motors or controllers and general purpose motors that run directly on polyphase AC power. DOE believes that if it were to include these types of motors as part of its standards analysis, extensive test procedure changes would be required because they have drastically different electromechanical properties relative to squirrel-cage induction motors and they do not run directly off of polyphase, AC sinusoidal power sources, which is required for testing with IEEE 112B.

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[f] Shipments for these 56-open frame motors were estimated from data provided by the Motor Coalition. DOE assumed 56-frame open motors are distributed across 2-, 4-, and 6- pole configurations and 1 to 5 horsepower ratings. With this assumption, DOE used the shipments distributions from ECG 1 motors across these motor configurations and ratings to establish shipments data for open 56-frame motors by motor configuration and horsepower rating. Efficiency distributions were based on a limited survey of electric motor models from six major manufacturer catalogs.

[g] DOE used the same NIA model and inputs described in section **Error! Reference source not found.** to estimate these values of NES and NPV, but adjusted the shipments and efficiency distributions to match the data specific to these 56-frame open motors.

Table 3.9 Advanced Electric Motors

Motor Description
Electric Motors + Inverter Drives
Permanent magnet motors
Electrically commutated motor
Switched reluctance motors

Electric Motors + Inverter Drives

The current scope of coverage includes motors with a single, constant rotational speed. A motor's rotational speed is determined by the frequency of the power source, as well as the pole configuration of the motor. The equation determining a motor's speed is:

$$Speed\ of\ motor = \frac{120 \times (Frequency\ of\ power\ source)}{Number\ of\ Motor\ Poles}$$

Inverter drives, also called variable-frequency drives (VFDs), variable-speed drives, adjustable frequency drives, AC drives, microdrives, or vector drives, work by changing the voltage and frequency of the power source fed into an electric motor. The equation above shows that controlling the frequency of the power source of a motor allows the user to control the speed of that motor. One of the biggest advantages of a VFD is the ability to reduce the speed of a motor when the full, nameplate-rated speed is not needed. This practice can save energy over a motor's lifetime. VFDs can also control start-up characteristics of motors, such as locked-rotor current or locked-rotor torque, which allows motors to achieve higher efficiencies when running at rated speed.[1]

DOE is aware of the energy saving potential of motors that run on VFDs.[2] However, DOE does not know of any relevant test procedures for testing motors run on a VFD. IEEE 112B requires a motor to be tested at its nameplate-rated speed, but motors only capable of running on an inverter will not have a nameplate rated speed. Furthermore, the energy saving potential of electric motors operating on inverter drives is primarily due to operation below rated speed. A test procedure that only measures the efficiency of adjustable speed systems at full speed will not provide an accurate assessment of efficiency across the range of speeds these systems will operate at.

Permanent Magnet Motors

In both polyphase AC induction motors and permanent magnet motors, the stator is energized by three-phase alternating current, which induces a magnetic field that rotates around the stator. This rotating magnetic flux induces a voltage in the squirrel-cage rotor, which in turn creates a current in the squirrel-cage rotor. These currents then create an opposing magnetic field in the rotor that causes it to rotate at a slower speed than the stator field.[h] In permanent magnet motors, the rotor uses an embedded permanent magnet to create a constant magnetic field that causes the rotor to rotate as the stator magnetic field rotates. Since the rotor is rotating at the same speed as the rotating stator field, the motor can be referred to as a synchronous motor. Permanent magnet motors have several advantages over AC induction motors including a higher efficiency potential, higher power/torque density, lower operating temperature, smaller size and quieter operation.[3] In AC induction motors, some of the stator current is used to induce rotor current in order to produce magnetic flux in the rotor. These additional currents generate heat in the motor, leading to increased losses. Permanent magnet motors, on the other hand, do not require a current in the rotor to produce magnetic flux since the flux is already provided by the permanent magnets. With no current in the rotor there are no rotor losses, which contributes to the high efficiency of permanent magnet motors.

Permanent magnet motors can be classified into two major groups: those with permanent magnets mounted on the surface of the rotor and those with permanent magnets placed in the interior of the rotor core. Surface permanent magnet (SPM) motors employ arc-shaped magnets glued or secured to the outer surface of the rotor core. This arrangement is not as structurally robust as the arrangement used in interior permanent magnet (IPM) motors, which instead have their permanent magnets placed inside of slots made in the interior of the laminated rotor core, thereby increasing retention of the magnet during high-speed operation compared to SPM designs. Different magnet grades are used in permanent magnet motors, with ceramic-ferrites and rare-earth metals being the most common choices. Although rare-earth magnets are more expensive than ceramic-ferrites, they have a higher magnetic energy density which permits increased energy output from a motor. However, the market for rare-earth metals is highly concentrated, with the vast majority of supply coming from China.[4] Wide-spread adoption of permanent magnet motors could be hindered by the inability of suppliers to respond to increased global demand as well supply disruptions caused by Chinese export policy.

Synchronous motors are typically not capable of starting from a fixed frequency AC power source. If the rotor is stationary when the stator field starts rotating at full speed, the rotor will not develop enough starting torque to overcome its own inertia. One popular method for overcoming this constraint is to use a VFD to start the motor. By increasing the frequency of the AC signal from zero to the desired running speed, the rotor is able to operate at synchronous speed with the accelerating stator field. This method of starting has the added benefit of the energy savings associated with adjustable speed control. Alternatively, some designs of interior permanent magnet motors incorporate a squirrel cage in the rotor, allowing the rotor to start across-the-line like an AC induction motor. These types of self-starting motors are called line start permanent magnet (LSPM) motors. During the motor transient start up, the squirrel cage in the rotor contributes to the production of enough torque to start the rotation of the rotor, albeit at an asynchronous speed. When the speed of the rotor approaches synchronous speed, the constant magnetic field of the permanent magnet locks to the rotating stator field, thereby pulling the rotor into synchronous operation. LSPM motors would be suitable in applications where the higher

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[h] When a motor operates with the rotor rotating at a speed slower than the rotating stator field, it is considered to be "asynchronous."

efficiency of permanent magnet motors is desired, but for which the added cost of a VFD remains prohibitive.

DOE is aware of the energy saving potential of permanent magnet motors. DOE does not know of any relevant test procedures for testing these motors. IEEE 112B is specific to polyphase induction motors and does not specify how to segregate losses for permanent magnet motors.

Electronically Commutated Motors

Electronically commutated motors (ECMs), also called brushless DC motors, are permanent-magnet synchronous motors combined with an on-board electronic controller that can measure and regulate the motor's performance. The commutator in older, brushless motors previously consisted of a rotary mechanical component that manipulated the power being fed to the stator. In ECMs, an electronic microprocessor controls the rotary mechanical component − and, consequently, the power supply. The use of the microprocessor permits greater customized control over motor performance. Some ECMs run on a DC power supply, while others run on a single phase or polyphase AC power supply which is rectified (i.e., converted) to DC power in the motor's controllers. The microprocessor in the motor control converts this DC power into a trapezoidal three-phase AC signal (unlike the sinusoidal AC signal used to power the permanent magnet motors discussed in the previous paragraph), inducing a rotating magnetic field in the stator windings. The rotor uses an embedded permanent magnet to create a constant magnetic field that causes the rotor to rotate as the stator magnetic field rotates. The position of the rotor is monitored by a microprocessor, which adjusts the magnetic fields in the stator to achieve the desired operating speed and torque. The motor can also communicate its status to the equipment it is powering, offering instant feedback of the unit's performance.

Like other types of permanent magnet synchronous motors, ECMs have several advantages over AC induction motors due to their higher efficiency, higher power/torque density, lower operating temperature, smaller size and quieter operation. ECMs also offer adjustable speed control with their programmable electronics, which can save energy in a manner similar to VFDs, which are discussed earlier in this section. However, the inclusion of programmable electronic controls also increases the cost of manufacturing an ECM.

However, DOE does not know of any relevant test procedures for testing electronically commutated motors. IEEE 112B requires that a motor be tested at its nameplate rated speed. However, motors capable of only being run on an electronic commutator will not have a nameplate rated speed because they are variable speed motors and can be run at a range of speeds as specified by the user. Additionally, the electronic commutator has its own electrical losses which are not accounted for in IEEE 112B. These electrical losses are the result of manipulating the power source into the motor. DOE requests comment on the potential energy savings from electronic commutated motors, as well as any relevant test procedures. DOE also seeks information regarding whether already existing test procedures could be modified to test the efficiency of these motors, including specific recommendations as to how to modify those procedures.

Switched Reluctance Motors

Switched reluctance (SR) motors are synchronous motors that operate on the principle of magnetic reluctance. Magnetic reluctance is a measure of the permeability of a given material with respect to magnetic flux. Compared to high reluctance materials, low reluctance materials offer lower resistance to the passage of magnetic lines of force. In a magnetic circuit, the presence of a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. When low reluctance materials (such as iron) are in the presence of a magnetic field, flux will tend to concentrate in the low reluctance material, forming strong temporary poles that cause an attractive force toward regions of higher flux. Just as in a DC motor, the stator in a SR motor consists of wound field coils. Unlike induction and permanent-magnet motors, the rotor does not contain any windings or magnets. The rotor in a SR motor consists of a low reluctance material, such as laminated silicon steel, with multiple projections that act as magnetic poles through magnetic reluctance. An electronic controller is used to energize each phase in sequence. As each phase is energized, the poles of the rotor are drawn to the position of least magnetic reluctance, which occurs when the poles of the stator and rotor are aligned. A full rotation of the rotor can be achieved by sequentially energizing each phase.

SR motors have several advantages over AC induction motors, such as higher efficiency and simpler construction. Unlike permanent-magnet motors, they do not rely on rare-earth magnets in their construction. However, they also have several disadvantages including high torque ripple (the difference between the maximum and minimum torque during one revolution) and noise (associated with torque ripple). Additionally, SR motors cannot be run on commercially available drives that can both operate induction and permanent-magnet motors, a fact that could discourage users who have already invested in VFDs from adopting SR motors. DOE does not know of any relevant test procedures for testing switched reluctance motors.

3.2.5 Electric Motor Shipments

To prepare an estimate of the national impact of energy conservation standards for electric motors, DOE needed to estimate annual motor shipments. For this stage of the rulemaking, DOE developed shipment projections based on historical data and an analysis of key market drivers for each product.

DOE used this data for three main purposes. First, the shipment data and market trend information contributed to the shipments analysis and base-case forecast for electric motors (chapter 9 of the TSD). Second, DOE used the shipment and catalog data to select the representative equipment classes and units for analysis (chapter 5 of the TSD). Third, DOE used the data to develop the installed stock of equipment for the national impact analysis (chapter 10 of the TSD). Although more detailed shipments data are given in chapter 9, the shipments shown in this chapter illustrate which electric motor characteristics were the most common in 2011.

3.2.5.1 NEMA Design Type

As discussed previously, the scope of DOE's energy conservation standards for electric motors covers four design types: NEMA Design A, NEMA Design B, NEMA Design C, and fire pump electric motors.[i] In 2011, Design B motors were by far the most common electric motor type, comprising of 96.13 percent of all shipments. NEMA Design A was the second most common design type, consisting of 1.05 percent of shipments. Electric motors with brakes consisted of 2.6 percent of shipments. Finally, NEMA Design C and fire pump electric motors constituted just 0.2 percent and 0.02 percent of shipments, respectively.

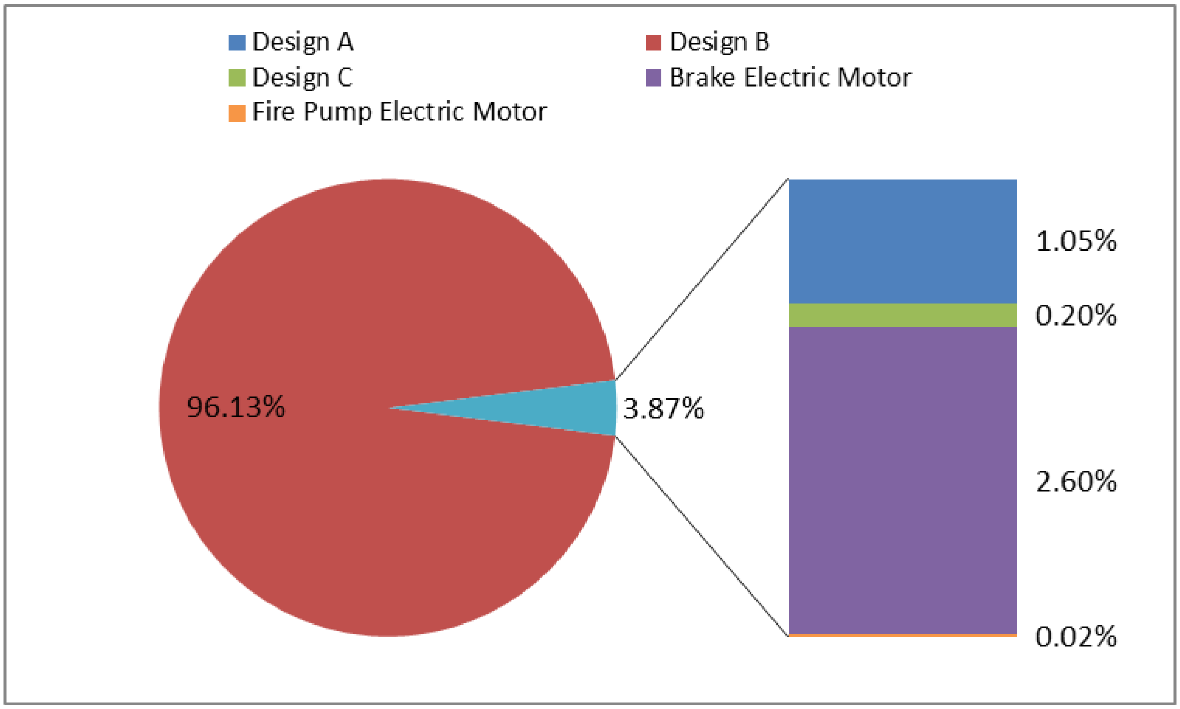

Figure 3.1 Electric Motor Shipments by Design Type for 2012

As will be discussed in more detail in chapter 5 of the TSD, DOE focused its engineering analysis on NEMA Design B motors based on the popularity of the design type. Although NEMA Design C motors, fire pump motors electric motors, and electric motors with brakes consist of a small portion of the motor market, DOE has separately analyzed these motors because of the different utility and performance characteristics that these motors have relative to Design A and B motors.

[i] DOE notes that IEC-equivalent design types are also covered.

3.2.5.2 Horsepower Ratings

For 2012 NEMA supplied shipments data broken down by horsepower rating. Figure 3.2 illustrates the total shipments of electric motors broken down by horsepower rating for equipment class group 1, and Figure 3.3 illustrates the total shipments for equipment class group 2. As is evident by the graph, the vast majority of shipments occurred in the lower range of horsepower rating, with 5-horsepower being the most common rating.

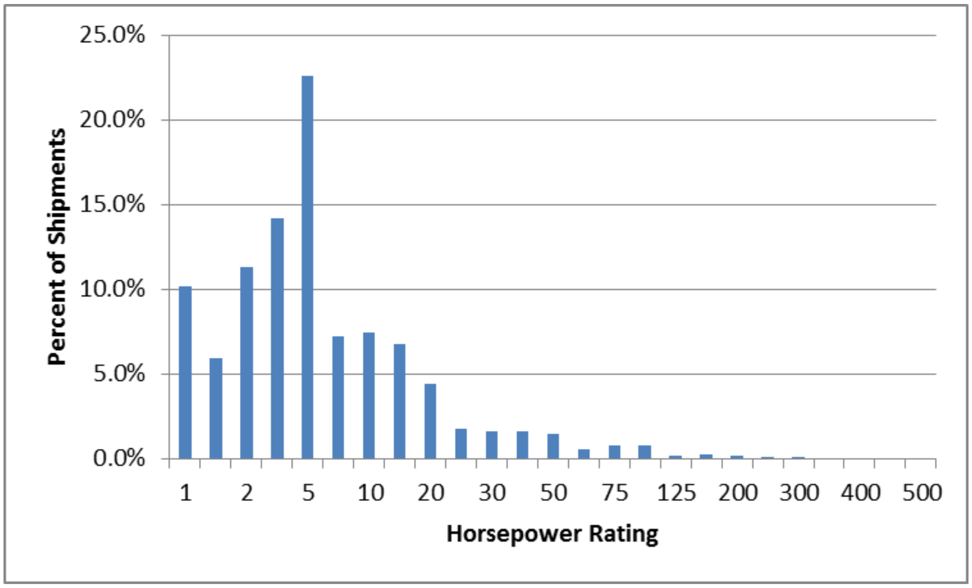

Figure 3.2 ECG1 (NEMA Design A & B) Electric Motors Shipments by Horsepower Rating for 2012

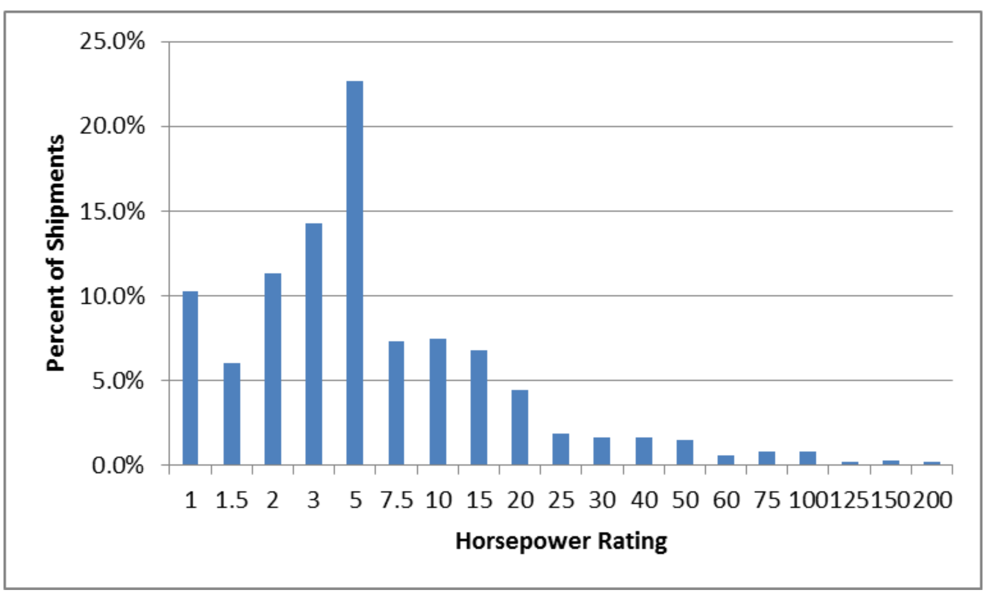

Figure 3.3 ECG 2 (NEMA Design C) Electric Motors Shipments by Horsepower Rating for 2012

3.2.5.3 Pole Configuration

NEMA also supplied 2012 shipments data broken down by pole configuration. As illustrated in Figure 3.4, 4-pole electric motors were by far the most commonly shipped. The next highest group of shipments was 2-pole motors, constituting 18.1 percent of all shipments. Then, 6-pole and 8-pole motors accounted for 10.6 percent and 2.6 percent of electric motor shipments, respectively.

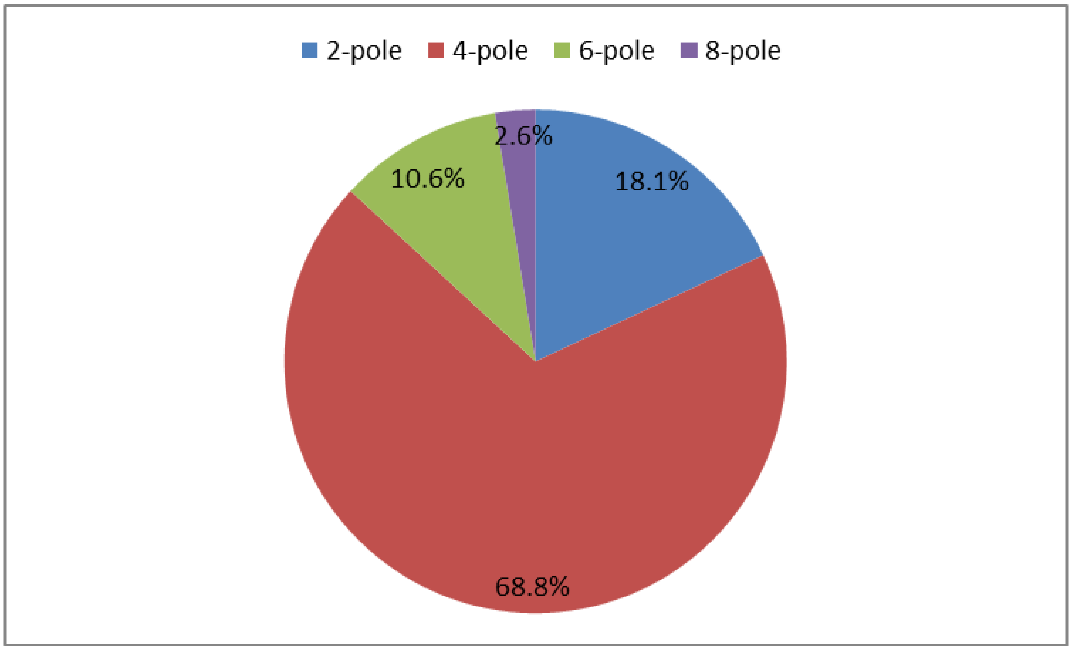

Figure 3.4 Electric Motor Shipments by Pole Configuration for 2012

3.2.5.4 Enclosure Types

Finally, NEMA provided shipment estimates broken down by enclosure types, that is, open or enclosed. In 2012, enclosed motors were shipped roughly three times as frequently as open motors. In 2011, enclosed consisted of about 76 percent of electric motor shipments and open electric motors consisted of about 24 percent of motor shipments.

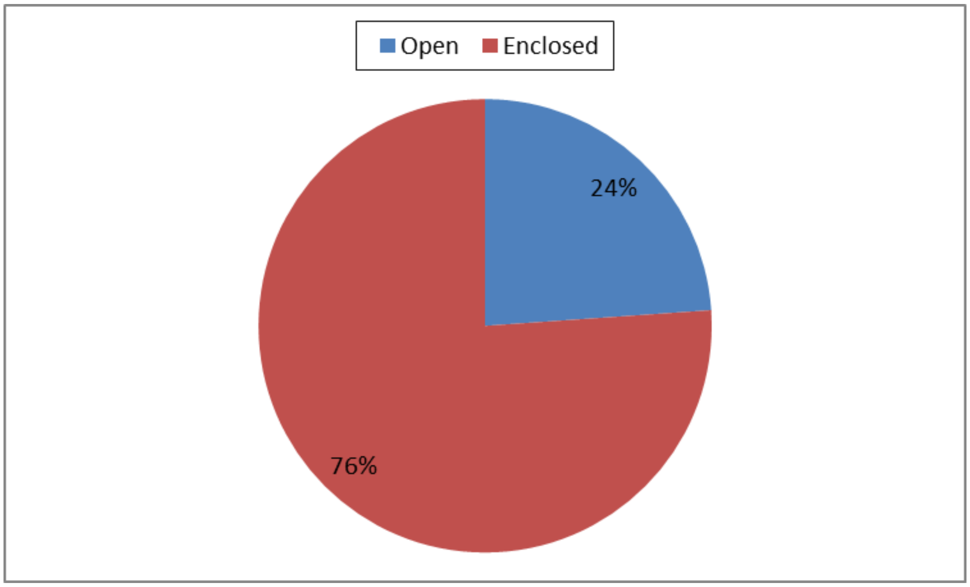

Figure 3.5 Electric Motor Shipments by Enclosure Type for 2012

3.2.6 Manufacturers and Market Share

The major manufacturers that dominate the electric motor market for this rulemaking, in alphabetical order, are:

- Baldor Electric Company;
- General Electric Company;
- Nidec Motor Corporation;
- Regal-Beloit Corporation.;
- Siemens Industry, Inc.;
- Toshiba; and
- WEG

The manufacturers identified above are all major manufacturers with diverse portfolios of equipment offerings, including electric motors covered under EPCA. Over the past decade, there has been a consolidation of motor manufacturing in the United States and this list is a result of those mergers and acquisitions.

DOE does not have empirical data on the market shares of particular manufacturers of electric motors. Nevertheless, estimates of available cumulative data indicate that shipments of electric motors from these companies constitute over a significant portion of the total U.S. market. Further, DOE believes that the cumulative shipment estimates provided by NEMA constitute a good estimate of overall national shipments.

3.2.6.1 Small Businesses

Although the electric motor market is predominantly supplied by large manufacturers, DOE is examining those small businesses that manufacture electric motors during this stage of the rulemaking. The Small Business Administration (SBA) lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). For electric motors, the size standard is matched to NAICS code 335312, Motor and Generator Manufacturing.[5] In general, the SBA defines a small business manufacturing enterprise for "motor and generator manufacturing" as one that has 1,000 or fewer employees. The number of employees in a small business is rolled up with the total employees of the parent company; it does not represent the division manufacturing electric motors. DOE studies the potential impacts to small businesses in greater detail during the manufacturer impact analysis (MIA). Please see chapter 12 for more detail on this analysis.

3.2.7 Application and Performance of Existing Equipment

The general purpose electric motors as well as the definite and special purpose electric motors that can be used in general purpose applications covered in today's analysis are used in a wide range of applications that include the following:

- blowers
- business equipment
- commercial food processing
- compressors
- conveyors
- crushers
- fans
- farm equipment
- general industrial applications
- grinders
- heating, ventilation, and air-conditioning equipment
- machine tools
- milking machines
- pumps
- winches
- woodworking machines

3.2.8 Trade Associations

DOE is aware of one trade association for manufacturers of medium electric motors, the National Electrical Manufacturers Association (NEMA).

3.2.8.1 National Electrical Manufacturers Association

NEMA was established as a trade association in 1926, and has since been divided into five core departments that provide different functions for its members. Those departments are:

- Technical Services
- Government Relations

- Industry Operations
- Business Information Services
- Medical

Through these groups, NEMA establishes voluntary standards for the performance, size, and functionality of electrical equipment to facilitate communication among motor manufacturers, original equipment manufacturers, engineers, purchasing agents, and users. An example of NEMA's role in standardization is the NEMA Standards Publication MG 1, "Motors and Generators," (MG 1) document, which is a reference document for motor and generator manufacturers and users. MG 1 provides guidance to motor manufacturers on performance and construction specifications for a broad range of electric motors. By standardizing around certain parameters, NEMA makes it easier for users to identify and purchase electric motors. MG 1 is a complete industry reference document for standardizing the motors offered in the market. The groups above also set up work that NEMA, as a whole, does to contribute to U.S. public policy and the economic data analysis it performs.

In addition to MG 1, NEMA established and promoted a high efficiency standard through a "NEMA Premium®" label for qualifying motors. NEMA motor manufacturers attach a label to motors that are built to high efficiency standards. These standards exceed those set by EPACT 1992, which requires general-purpose motors from 1 to 200 horsepower to meet certain minimum efficiency levels. See section 3.2.2 and 3.2.10 for more discussion on these minimum efficiency levels.

3.2.9 Regulatory Programs

EPCA, 42 U.S.C. 6311, *et seq.,* as amended by EPACT 1992, established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress passed into law EISA 2007. (Pub. L. No. 110–140) Section 313(b)(1) of EISA 2007 updated the energy conservation standards for those electric motors already covered by EPCA and established energy conservation standards for a larger scope of motors not previously covered. (42 U.S.C. 6313(b)(2))

EPCA also directs that the Secretary [of Energy] shall publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such product. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. 6313(b)(4))

As described previously, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments went into effect on December 19, 2010, DOE had indicated during the course of public meetings held in advance of today's proposal that motors manufactured after December 19, 2015, would need to comply with any applicable new standards that DOE may set as part of this rulemaking. Today's proposed standards would apply to motors manufactured starting on December 19, 2015. As noted in detail in this notice, however, DOE is interested in receiving comments on the ability of manufacturers to meet this deadline.

3.2.10 Non-Regulatory Programs

DOE reviewed voluntary programs that promote energy efficient electric motors in the United States, including the DOE Motor Challenge and Best Practices programs, NEMA Premium energy efficient motors program, and Consortium for Energy Efficiency (CEE) Premium Efficiency motors program.

3.2.10.1 Department of Energy Motor Challenge Program

In general, motor-driven equipment accounts for almost 70 percent of all electricity consumption by U.S. industries. In 1993, DOE launched its industry/government partnership, Motor Challenge Program with the goals of increasing the energy-efficiency of electric motor-driven systems in domestic industry and enhancing environmental quality. The program uses a market-driven approach to promote the design, purchase, installation, and management of energy-efficient electric motors and motor-driven systems and equipment, such as pumps, fans, and compressors. It was designed to help industry capture 5 billion kilowatt-hours per year of electricity savings and 1.2 million metric tons of carbon-equivalent by the year 2000, with projections of much larger and longer-term national energy savings opportunities of over 100 billion kilowatt-hours per year by the year 2010.

The Motor Challenge program encompasses three-phase 60 Hertz motors rated 1 horsepower and above. Its elements and offerings include: DOE Energy Efficiency and Renewable Energy (EERE) Information Center, which provides up-to-date information about the practicality and profitability of electric motor system strategies; design decision tools, such as MotorMaster+ software; Showcase Demonstration projects; training; workshops; and conferences. In general, the response to the program from industry has been overwhelmingly favorable. The Motor Challenge program is no longer active; however, the DOE Energy Efficiency and Renewable Energy (EERE) Information Center and the MotorMaster+ database of industrial motors remain viable.

The EERE Information Center answers questions on energy efficient products and services and refers callers to the most appropriate DOE/EERE resources. Industrial callers are eligible for an advanced level of service that includes engineering assistance, research, and software support for plant staff and industrial service providers working on industrial energy savings projects.

MotorMaster+ is an energy-efficient motor selection and management tool, which includes a database of over 20,000 AC motors. It features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.[j]

3.2.10.2 National Electrical Manufacturers Association Premium Efficiency Motor Program

On January 11, 1989, NEMA established voluntary energy efficiency levels for 1 through 200 horsepower, polyphase squirrel-cage induction motors. For an electric motor to be classified as "energy efficient," it was required to meet certain levels of efficiency in NEMA Standards Publication MG 1–1987 (Revised March 1991). In 1992, the NEMA efficiency levels were incorporated into section 342(b) of EPACT 1992 and subsequently codified in 10 CFR 431.25. In 2001, the NEMA Premium Efficiency Motor Program was established to provide special recognition to electric motors that exceed the required efficiency levels established by EPACT 1992. NEMA Premium-labeled motors help purchasers identify more efficient motors and optimize motor system efficiency commensurate with a particular application. [k]

Going a step beyond EPACT, NEMA Premium applies to single-speed, polyphase; 1 to 500 horsepower; 2-, 4-, and 6-pole; squirrel-cage; induction motors; NEMA Designs A or B; 600 volts or less; and rated for continuous duty operation. Such electric motors are typically used in industrial applications operating more than 2000 hours per year.

3.2.10.3 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a nonprofit corporation that develops initiatives for its North American members to promote the manufacture and purchase of energy efficient equipment, including electric motors and services. Its members include utilities, statewide and regional market transformation administrators, environmental groups, research organizations and state energy offices in the U.S. and Canada. Also included in the CEE collaborative process are manufacturers, retailers, and government agencies.

In 1996, CEE began its Premium-Efficiency Motors Initiative to promote the production, distribution, and adoption of premium efficiency motors over motors meeting the minimum efficiency levels established under EPACT 1992. In 1999, CEE took a systems approach to energy savings and launched its Motor Systems Initiative that viewed the motor as a component of a larger system, where efficient motors, adjustable-speed drives, and system-specific design strategies would provide the greatest opportunity for savings. Then, in 2001, CEE launched its Motor Decisions Matter to promote greater awareness of the benefits of motor systems efficiency. In June 2001, CEE and NEMA aligned to promote NEMA Premium motor efficiency levels that are roughly .5 to 3 percentage points above EPACT 1992 requirements.

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[j] For more information about MotorMaster+, visit http://www1.eere.energy.gov/manufacturing/tech_assistance/software_motormaster.html. The July 10, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.
[k] NEMA's Premium® Motors program can be reviewed at http://www.nema.org/Policy/Energy/Efficiency/Pages/NEMA-Premium-Motors.aspx. The July 10, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.

In May 2007, CEE published the Energy-Efficiency Incentive Programs – Premium-Efficiency Motors & Adjustable Speed Drives in the U.S and Canada, which provides information about the incentive-based programs in North America. These programs concentrate on 1 to 200 horsepower motors, but some include 201 to 500 horsepower motors. It appears that the programs cover commercial and industrial motors rated from 1 to 500 horsepower. There are a number of different programs broken down by region. For more information on these programs, download the report from CEE.[1]

3.3 TECHNOLOGY ASSESSMENT

The electric motors covered in the framework document are all single speed polyphase AC induction motors. Induction motors have two core components: a stator and a rotor. The components work together to convert electrical energy into rotational mechanical power. This is done by creating a rotating magnetic field in the stator which induces currents in the squirrel-cage of the rotor. The squirrel-cage used in the rotor of induction motors consists of longitudinal conductive bars (rotor bars) connected at both ends by rings (end rings) forming a cage-like shape. The currents in the rotor squirrel-cage create magnetic fields in the rotor which then react with the stator's rotating magnetic field to create torque. This torque provides the rotational force delivered to the load via the shaft.

The purpose of the technology assessment is to develop a preliminary list of technology options that may improve the efficiency of electric motors. For the electric motors covered in this rulemaking, energy efficiency losses are grouped into five main categories: stator I^2R losses, rotor I^2R losses, core losses, friction and windage losses, and stray load losses.

Designers have to balance the five basic losses to optimize the various motor performance criteria. There are numerous trade-offs that have to be considered. Efficiency is only one parameter that has to be met. Reducing one loss may increase another. What may be desirable on a 4-pole motor may not be on a 2-pole motor. A complete discussion of these trade-offs is beyond the scope of this report. Different manufacturers utilize different approaches for minimizing motor losses.

3.3.1 Technology Options for I^2R Losses

I^2R losses are produced from either the current flow through the copper windings in the stator (stator I^2R losses) or the squirrel cage of the rotor (rotor I^2R losses). Stator I^2R losses are reduced by decreasing resistance to current flow in the electrical components of a motor. These losses are manifested as heat, which can shorten the service life of a motor.

One method of reducing resistance losses in the stator is decreasing the length of the coil extensions at the end turns. Reducing the length of copper wire in the stator slots not only

[1] CEE's *Summary of Member Programs for Motors and Motor Systems* can be found at http://library.cee1.org/sites/default/files/library/9323/MMSProgSummary2012CEEWebsite_8.xlsx. The July 11, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.

reduces the resistive losses, but also reduces the material cost of the electric motor because less copper is being used.

Another way to reduce stator I^2R losses is to increase the cross-sectional area of the stator winding conductors (e.g., copper wire diameter). This can be accomplished by either increasing the slot fill and/or increasing the size of the stator slots. However, this method replaces some of the stator magnetic cross sectional area and increases the flux density in the stator. Increasing the flux density may increase core losses. Furthermore, there are practical limits to how much slot fill can be increased. Very high slot fills may require hand winding, a manufacturing technique that is far more labor intensive than machine winding. The motor designer must carefully weigh the trade-offs to optimize the motor design.

There are also various ways to reduce rotor I^2R losses. The squirrel-cage is the part of the rotor in which current flows. Squirrel-cages are usually made of aluminum in electric motors. However, one method of increasing the efficiency of the motor is to substitute copper for aluminum when die-casting the rotor squirrel-cage. Copper has a lower electrical resistivity (1.68×10^{-8} ohm-m) than aluminum (2.65×10^{-8} ohm-m). Copper's 63 percent lower electrical resistance compared to aluminum can result in reduced rotor I^2R losses. There are, however, design trade-offs when using die-cast copper in a rotor. Copper's lower resistivity may result in a higher locked-rotor current. This can be mitigated by modifying the geometry of the rotor slots to keep locked-rotor current within NEMA Design B limits.

Increasing the cross-sectional area of the rotor conductor bars can also improve motor efficiency. Resistance is inversely proportional to the cross-sectional area of the material through which current is flowing. By increasing the cross-sectional area, rotor bar resistance will decrease which may reduce rotor I^2R losses. Similarly, increasing the cross-sectional area of the rotor end rings can also reduce rotor I^2R losses. Current flows through the end rings of the rotor and increasing the size of the end ring may decrease resistance and reduce the associated rotor I^2R losses. These two techniques can result in reduced rotor I^2R losses if the increase in rotor current does not exceed the square of the decrease in the rotor resistance.

3.3.2 Technology Options for Core Losses

Core losses are losses created in the electrical steel components of a motor. These losses, like I^2R losses, manifest themselves as heat. Core losses are generated in the steel by two electromagnetic phenomena: hysteresis losses and eddy currents. Hysteresis losses are caused by magnetic domains in the steel resisting reorientation to the alternating magnetic field. Eddy currents are currents that are induced in the steel laminations by the magnetic flux

One technique for reducing core losses is using a higher grade of electrical steel in the core. Higher grades of steel exhibit lower core losses as well as higher magnetic permeability. In general, higher grades of electrical steel exhibit lower core losses. Lower core losses can be achieved by adding silicon and other elements to the steel, thereby increasing its electrical resistivity. Lower core losses can also be achieved by subjecting the steel to special heat treatments during processing.

In studying the different types of steel available, DOE considered two types of materials: conventional silicon steels, and "exotic" steels, which contain a relatively high percentage of boron or cobalt. Conventional steels are commonly used in electric motors manufactured today. The exotic steels are not generally manufactured for use specifically in the electric motors covered in this rulemaking. These steels offer lower core losses than the best conventional electrical steels, but are more expensive per pound. In addition, these steels can present manufacturing challenges because they come in nonstandard thicknesses that are difficult to manufacture.

Conventional steels are commonly used in electric motors manufactured today. There are three types of steel that DOE considers "conventional:" cold-rolled magnetic laminations (CRML), fully processed non-oriented electrical steel, and semi-processed non-oriented electrical steel. Each steel type is sold in a range of grades. In general, as the grade number goes down, so does the amount of core loss associated with the steel (i.e., watts of loss per pound of steel). The induction saturation level also drops, causing the need for increased stack length. Of these three types, CRML steels are the most commonly used, but also the least efficient. The fully processed steels are annealed before punching and therefore do not require annealing after being punched and assembled, and are available in a range of steel grades from M56 through M15. Semi-processed electrical steels are designed for annealing after punching and assembly.

Another possible option for reducing core loss is to use thinner laminations. Thinner laminations generally have lower eddy current losses and this contributes toward improving motor efficiency.

Adding electrical steel laminations to the rotor and stator to lengthen the motor can also reduce the core losses in an electric motor. Increasing the stack length reduces the magnetic flux density, which reduces core losses. However, increasing the stack length affects other performance attributes of the motor, such as starting torque.

3.3.2.1 Amorphous Metal Laminations

Using amorphous metals in the rotor laminations is another technology option to improve the efficiency of electric motors. Amorphous metal is extremely thin, has high electrical resistivity, and has little or no magnetic domain definition. Because of amorphous steel's high resistance it exhibits a reduction in hysteresis and eddy current losses, which reduce overall losses in electric motors. However, amorphous steel is a very brittle material which makes it difficult to punch into motor laminations.[6]

3.3.2.2 Plastic Bonded Iron Powder

Recently, DOE became aware of a new technology that Lund University researchers in Sweden developed in the production of magnetic components for electric motors from plastic bonded iron powder (PBIP). The technique has the potential to cut production costs by 50 percent while doubling motor output.

The method uses two main ingredients: metal powder and plastics. Combining the ingredients creates a material with low conductivity and high permeability. The metal particles are surrounded by an insulating plastic, which prevents electric current from developing in the material. This is critical because it essentially eliminates losses in the core due to eddy currents. Properties of PBIP can differ depending on the processing. If the metal particles are too closely compacted and begin to touch, the material will gain electrical conductivity, counteracting one of its most important features.

Another advantage of PBIP is a reduction in the number of production steps. The number of steps in manufacturing a rotor and stator is reduced from roughly 60 to just a few. A second way to increase savings is to build an inductor with PBIP. During processing, the plastic and metal are molded together using a centrifugal force. During this process, the inductor core consisting of PBIP and pre-wound windings are baked into the core. This inductor is then used as a filter for grid power application. The filter then reduces the use of cooling equipment in the motor design.[7]

3.3.3 Technology Options for Friction and Windage Losses

Friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.

One way to reduce these losses is to optimize the selection of bearings and a lubricant. Using improved bearings and lubricants can minimize mechanical resistance to the rotation of the rotor, which also extends motor life.

Optimizing a motor's cooling system is another technology option to improve the efficiency of electric motors. An optimized cooling system design provides ample motor cooling while reducing air resistance.

3.3.4 Technology Options for Stray-Load Losses

Stray-load loss is defined as the difference between the total motor loss and the sum of the other four losses referred to above. Stray-load losses arise from a variety of sources.

One way to reduce stray-load losses is to reduce the skew in the rotor squirrel cage. The rotor conductor bars of the rotor cage are often skewed. This means the conductor bars are slightly offset from one end of the rotor to the other. By skewing the rotor bars, motor designers can reduce harmonics that add cusps to the speed-torque characteristics of the motor. The cusps in the speed-torque curves mean that the acceleration of the motor will not be completely smooth. The degree of skew matters because reducing the skew will help reduce the rotor resistance and reactance, which can result in improved efficiency. However, reducing the skew may have adverse impacts on the speed-torque characteristics.

Another way to reduce stray-load losses is to improve insulation between the rotor squirrel-cage and the rotor laminations.[8] Motors with insulated rotor cages often exhibit lower stray-load losses when compared to motors with un-insulated rotor cages. Manufacturers use different methods to insulate rotor cages, such as applying an insulating coating on the rotor slot prior to die-casting or heating and quenching the rotor (i.e. rapid cooling, generally by immersion in a fluid instead of allowing the rotor temperature to equalize to ambient) to separate rotor bars from rotor laminations after die-casting.

3.3.5 Summary of the Technology Options under Consideration

Table 3.10 summarizes the technology options discussed in this TSD technology assessment and those that DOE will consider in the screening analysis (see chapter 4). The options that pass all four screening criteria are considered "design options" and are used in the engineering analysis (see TSD chapter 5) as a means of improving the efficiency of electric motors.

Table 3.10 Summary of Technology Options for Improving Efficiency

Type of Loss to Reduce	Technology Option
Stator I^2R Losses	Increase cross-sectional area of copper in stator slots
	Decrease the length of coil extensions
Rotor I^2R Losses	Use a die-cast copper rotor cage
	Increase cross-sectional area of rotor conductor bars
	Increase cross-sectional area of end rings
Core Losses	Use electrical steel laminations with lower losses (watts/lb)
	Use thinner steel laminations
	Increase stack length (i.e., add electrical steel laminations)
Friction and Windage Losses	Optimize bearing and lubrication selection
	Improve cooling system design
Stray-Load Losses	Reduce skew on rotor cage
	Improve rotor bar insulation

Most of the design changes suggested in Table 3.10 produce interacting effects on the motor's breakdown torque, locked-rotor torque, locked-rotor current, and so forth. Therefore, motor designers making a specific design change must evaluate the effects against all of a motor's performance characteristics and not just focus on efficiency.

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

The purpose of the screening analysis is to identify design options that improve electric motor efficiency and determine which options the Department of Energy (DOE) will either evaluate or screen out. DOE consults with industry, technical experts, and other interested parties in developing a list of design options for consideration. Then DOE applies the following set of screening criteria to determine which design options are unsuitable for further consideration in the rulemaking (See Title 10 of the Code of Federal Regulations, Part 430, Subpart C, Appendix A at 4(a)(4) and 5(b)):

(1) *Technological feasibility.* Technologies incorporated in commercial products or in working prototypes will be considered technologically feasible.

(2) *Practicability to manufacture, install, and service*. If mass production of a technology in commercial products and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then DOE will consider that technology practicable to manufacture, install, and service.

(3) *Adverse impacts on product utility or product availability*. If DOE determines that a technology will have significant adverse impacts on the utility of the product to significant subgroups or consumers or result in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the United States at the time, that technology will not be considered further.

(4) *Adverse impacts on health or safety*. If DOE determines that a technology will have significant adverse impacts on health or safety, that technology will not be considered further.

This chapter discusses the design options that DOE considered for improving the energy efficiency of electric motors and describes how DOE applied the screening criteria.

4.2 DISCUSSION OF DESIGN OPTIONS

Several well-established engineering practices and techniques exist for improving the efficiency of an electric motor. Improving the construction materials (*i.e.*, the core steel, the rotor conductor material) and modifying the motor's geometric configuration (*i.e.*, the core and winding assemblies, the rotor, and stator) can make an electric motor more energy efficient.

As discussed in the market and technology assessment (chapter 3), there are four general areas of efficiency loss in electric motors: I^2R, core, friction and windage, and stray-load. In the preliminary analysis DOE presented an initial list of technology options used to reduce energy consumption and thus improve the efficiency of general purpose induction motors. Unfortunately, methods of reducing electrical losses in the equipment are not completely independent of one another. This means that some technology options that decrease one type of loss may cause an increase in a different type of loss in the motor. Thus, it takes a great degree of engineering skill to maximize the efficiency gains in a motor design overall, balancing out the loss mechanisms. In some instances, motor design engineers must make design tradeoffs to maintain utility when finding the appropriate combination of materials and costs. However, there are multiple design pathways to achieve a given efficiency level.

I^2R losses are produced from the current flow through the copper windings in the stator (stator I^2R losses) and the squirrel cage of the rotor (rotor I^2R losses). These losses are manifested as heat, which can shorten the service life of a motor. Core losses are the losses created in the electrical steel components of a motor. These losses, like I^2R losses, manifest themselves as heat. Core losses are generated in the steel by two electromagnetic phenomena: hysteresis losses and eddy currents. Hysteresis losses are caused by magnetic domains in the steel resisting reorientation to the alternating magnetic field. Eddy currents are currents that are induced in the steel laminations by the magnetic flux. Although I^2R and core losses account for the majority of the losses in an induction motor, friction and windage losses and stray-load losses also contribute to the total loss. In an induction motor, friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts. Any losses that are otherwise unaccounted for and not attributed to I^2R losses, core losses, or friction and windage losses are considered stray-load losses.

Table 4.1 presents a general summary of the methods that a manufacturer may use to reduce losses in electric motors. The approaches presented in this table refer either to specific technologies (*e.g.*, aluminum versus copper die-cast rotor cages, different grades of electrical steel) or physical changes to the motor geometries (*e.g.*, cross-sectional area of rotor conductor bars, additional stack length).

Table 4.1 Summary List of Options from Technology Assessment

Type of Loss to Reduce	Technology Option
Stator I^2R Losses	Increase cross-sectional area of copper in stator slots
	Decrease the length of coil extensions
Rotor I^2R Losses	Use a die-cast copper rotor cage
	Increase cross-sectional area of rotor conductor bars
	Increase cross-sectional area of end rings
Core Losses	Use electrical steel laminations with lower losses (watts/lb)
	Use thinner steel laminations
	Increase stack length (i.e., add electrical steel laminations)
Friction and Windage Losses	Optimize bearing and lubrication selection
	Improve cooling system design
Stray-Load Losses	Reduce skew on rotor cage
	Improve rotor bar insulation

4.3 DESIGN OPTIONS NOT SCREENED OUT OF THE ANALYSIS

This section discusses the technology options that DOE considers viable means of improving the efficiency of electric motors.

4.3.1 Increase the Cross-sectional Area of Copper in the Stator Slots

Increasing the cross-sectional area of copper in the stator slots, by either increasing the slot fill percentage and/or increasing the size of the stator slots, can increase motor efficiency. Motor design engineers can achieve higher slot fills by manipulating the wire gauges to allow for a greater total cross-sectional area of wire to be incorporated into the stator slots. This could mean either an increase or decrease in wire gauge, depending on the dimensions of the stator slots and insulation thicknesses. Motor design engineers may also consider increasing the size of the stator slots to accommodate additional copper windings. However, this method replaces some of the stator magnetic cross-sectional area and increases the flux density in the stator. Increasing the flux density may increase core losses. Furthermore, there are practical limits to how much slot fill can be increased. The stator slot openings must be able to fit the wires so that automated machinery or manual labor can pull (or push) the wire into the stator slots. Very high slot fills may require hand winding, a manufacturing technique that is far more labor intensive than machine winding. The motor designer must carefully weigh the trade-offs to optimize the motor design.

Considering the four screening criteria for this technology option, DOE did not screen out with increasing the cross-sectional area of copper in the stator as a means of improving efficiency. Motor design engineers adjust this technology option when manufacturing an electric motor to achieve desired performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increasing the cross-sectional area of copper in the stator to obtain increased efficiency.

4.3.2 Decrease the Length of Coil Extensions

One method of reducing resistance losses in the stator is decreasing the length of the coil extensions at the end turns. Reducing the length of copper wire in the stator slots not only reduces the resistive losses, but also reduces the material cost of the electric motor because less copper is being used.

Considering the four screening criteria for this technology option, DOE did not screen out decreasing the length of the coil extensions as a means of improving efficiency. Motor design engineers adjust this particular variable when manufacturing to obtain performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with decreasing the length of coil extensions to obtain increased efficiency.

4.3.3 Copper Die-Cast Rotor Cage

Aluminum is the most common material used today to create die-cast rotor bars in electric motors. Some manufacturers that focus on producing high-efficiency designs have started to offer electric motors with die-cast rotor bars made of copper. Copper offers better performance than aluminum because copper has a higher electrical conductivity (*i.e.*, a lower electrical resistance) per unit area. However, copper has a higher melting point than aluminum, so the casting process becomes more difficult and is likely to increase both production time and cost for manufacturing a motor.

When assessing the technological feasibility of die-cast rotors, DOE notes that electric motors incorporating this technology option are already commercially available. DOE is aware of two large manufacturers — Siemens and SEW-Eurodrive — that offer die-cast copper rotor motors up to 30-horsepower. Additionally, a French rotor die-casting company called FAVI supplies die-cast copper rotors up to 100-horsepower (75 kW) to manufacturers of electric motors.[a] At larger horsepower ratings, DOE recognizes that assessing the technological

[a] For more information about FAVI die cast copper rotors, visit http://www.favi.com/download.php?fich=rotor/Plaquette+-+ang.pdf. The July 11, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.

feasibility of die-cast rotors is made more complex by the fact that manufacturers do not offer them commercially. That could be for a variety of reasons, among them:

1. Large copper die-cast rotors are physically impossible to construct;
2. They are possible to construct, but impossible to construct to required specifications;
3. They are possible to construct to required specifications, but would require high manufacturing capital investment to do so and be so costly that few (if any) consumers would choose them.

Some exploratory research suggests that different organizations have developed and used die-cast copper rotors in high-horsepower traction (i.e., vehicle propulsion) motors. For example, Oshkosh uses 140-horsepower die-cast copper rotor motors in its ProPulse series hybrid drive system, which is used in the US Army's heavy cargo-hauling HEMTT (Heavy Expanded Mobility Tactical Truck).[b]

DOE recognizes that these motors are designed for a different purpose than most motors in the current scope of this rulemaking. Their existence suggests that copper has been successfully used at high power levels in an application where efficiency is critical and casts doubt on the idea that copper die-cast rotors can be screened out with certainty.

DOE is hesitant to screen out copper die-cast rotors on the basis of technological feasibility. Relative to the above list of possible reasons for their absence from the high-horsepower market, DOE’s analysis does not conclude copper die-cast rotors are either: (1) physically impossible to construct or (2) possible to construct, but impossible to construct to required specifications.

DOE also does not believe it has grounds to screen out copper die-cast rotors on the basis of practicability to manufacture, install, and service. The available facts indicate that manufacturers are already producing electric motors with die-cast copper rotors.

Finally, based on DOE’s own shipments analysis (see TSD Chapter 9) and estimates of worldwide annual copper production,[c] DOE estimates that 0.01–0.02% of worldwide copper supply would be required to use copper rotors for every single motor within DOE’s scope of coverage. At present, DOE does not believe there is sufficient evidence to screen out copper die-cast rotors from the analysis on the basis of adverse impacts to equipment utility or availability.

DOE is aware of the higher melting point of copper (1085 degrees Celsius versus 660 degrees Celsius for aluminum) and the potential impacts this may have on the health or safety of

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[b] For more information about HEMTT, visit http://www.coppermotor.com/wp-content/uploads/2012/04/casestudy_army-truck.pdf. The July 11, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.

[c] For more information about copper production, visit http://minerals.usgs.gov/minerals/pubs/commodity/copper/mcs-2012-coppe.pdf. The July 11, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.

plant workers. However, DOE does not believe at this time that this potential impact is sufficiently adverse to screen out copper as a die cast material for rotor conductors. The process for die casting copper rotors involves risks similar to those of die casting aluminum. DOE believes that manufacturers who die-cast metal at 660 Celsius or 1085 Celsius (the respective temperatures required for aluminum and copper) would need to observe strict protocols to operate safely. DOE understands that many plants already work with molten aluminum die casting processes and believes that similar processes could be adopted for copper. DOE has not received any supporting data about the increased risks associated with copper die casting, and could not locate any studies suggesting that the die-casting of copper inherently represented incrementally more risks to worker safety and health. DOE notes that several OSHA standards relate to the safety of "Nonferrous Die-Castings, Except Aluminum," of which die-cast copper is a part. [d]

Considering the four screening criteria for this technology option, DOE did not screen out copper as a die-cast rotor cage conductor material.

4.3.4 Increase Cross-sectional Area of Rotor Conductor Bars

Increasing the cross-sectional area of the rotor conductor bars can also improve motor efficiency. Resistance is inversely proportional to the cross-sectional area of the material through which current is flowing. By increasing the cross-sectional area, rotor bar resistance will decrease which may reduce rotor I^2R losses.This technique can result in reduced rotor I^2R losses if the increase in rotor current does not exceed the square of the decrease in the rotor resistance. However, changing the shape of the rotor bars may affect the size of the end rings and can also change the torque characteristics of the motor.

Considering the four screening criteria for this technology option, DOE did not screen out increasing the cross-sectional area of rotor conductor bars as a means of improving efficiency. Motor design engineers adjust this particular variable when manufacturing to obtain performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increasing the cross-sectional area of rotor conductor bars to obtain increased efficiency.

4.3.5 Increase Cross-sectional Area of Rotor End Rings

Increasing the cross-sectional area of the rotor end rings can also reduce rotor I^2R losses. Current flows through the end rings of the rotor and increasing the size of the end ring may decrease resistance and reduce the associated rotor I^2R losses. This technique can result in reduced rotor I^2R losses if the increase in rotor current does not exceed the square of the decrease in the rotor resistance.

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[d] For a list of OSHA standards , visit http://www.osha.gov/pls/imis/citedstandard.sic?p_esize=&p_state=FEFederal&p_sic=3364. The July 11, 2013, material from this website is available in Docket #EERE–2010–BT–STD–0027 at regulations.gov.

Considering the four screening criteria for this technology option, DOE did not screen out increasing end ring size as a means of improving efficiency. As with some of the previous technology options, motor design engineers adjust this variable when manufacturing an electric motor to achieve performance and efficiency targets. Automated production and casting equipment, which allow some degree of variability, determine the end ring size. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increasing the size of the rotor end rings to obtain increased efficiency.

4.3.6 Use Electrical Steel Laminations with Lower Losses

Using a higher grade of electrical steel in the core can reduce core losses. Higher grades of steel exhibit lower core losses as well as higher magnetic permeability. Lower core losses can be achieved by adding silicon and other elements to the steel, thereby increasing its electrical resistivity. Lower core losses can also be achieved by subjecting the steel to special heat treatments during processing.

In studying the different types of steel available, DOE considered two types of materials: conventional silicon steels and "exotic" steels, which contain a relatively high percentage of boron or cobalt. Conventional steels are commonly used in electric motors manufactured today. The exotic steels are not generally manufactured for use specifically in the electric motors covered in this rulemaking. These steels offer lower core losses than the best conventional electrical steels, but are more expensive per pound. In addition, these steels can present manufacturing challenges because they come in nonstandard thicknesses that are difficult to manufacture.

There are three types of steel that DOE considers "conventional": cold-rolled magnetic laminations (CRML), fully processed non-oriented electrical steel, and semi-processed non-oriented electrical steel. Each steel type is sold in a range of grades. In general, as the grade number goes down, so does the amount of core loss associated with the steel (i.e. watts of loss per pound of steel). The induction saturation level also drops, causing the need for increased stack length. Of these three types, CRML steels are the most commonly used, but also the least efficient. The fully processed steels are annealed before punching and therefore do not require annealing after being punched and assembled, and are available in a range of steel grades from M56 through M15. Semi-processed electrical steels are designed for annealing after punching and assembly.

Considering the four screening criteria for this technology option, DOE did not screen out lower loss electrical steel in the core as a means of improving efficiency. Design engineers use this approach to achieve desired performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with using lower loss electrical steel.

4.3.7 Thinner Steel Laminations

DOE can use thinner laminations of core steel to reduce eddy currents. DOE can either change grades of electrical steel as described above, or use a thinner gauge of the same grade of electrical steel. The magnitude of the eddy currents induced by the magnetic field becomes smaller in thinner laminations, which can result in a more energy efficient motor.

Considering the four screening criteria for this technology option, DOE did not screen out thinner steel laminations as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with using thinner steel laminations.

4.3.8 Increase Stack Length

Adding electrical steel laminations to the rotor and stator to lengthen the motor can also reduce the core losses in an electric motor. Increasing the stack length reduces the magnetic flux density, which reduces core losses. However, increasing the stack length affects other performance attributes of the motor, such as starting torque. Issues can also arise when installing a longer motor in applications with dimensional constraints.

Considering the four screening criteria for this technology option, DOE did not screen out additional stack length as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option technologically feasible. Regarding the second screening criterion—practicable to manufacture, install, and service—DOE understands that there are practical limits to lengthening a motor due to dimensional constraints of users. However, DOE recognizes that many motor applications are not constrained by motor length. Thus, DOE believes that this technology option meets the second screening criterion. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increased stack length.

4.3.9 Optimize Bearing and Lubricant Selection

One way to improve efficiency is to optimize the selection of bearings and lubricant. Using improved bearings and lubricants can minimize mechanical resistance to the rotation of the rotor, which also extends motor life.

Considering the four screening criteria for this technology option, DOE did not screen out optimizing bearing and lubricant selection as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with better ball bearings and lubricant.

4.3.10 Improve Cooling System Design

Optimizing a motor's cooling system is another technology option to improve the efficiency of electric motors. An optimized cooling system design provides ample motor cooling while reducing air resistance.

Considering the four screening criteria for this technology option, DOE did not screen out an improved cooling system as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with improved cooling systems for electric motors.

4.3.11 Reduce Skew on Conductor Cage

One way to reduce stray-load losses is to reduce the skew in the rotor squirrel cage. The rotor conductor bars of the rotor cage are often skewed. This means the conductor bars are slightly offset from one end of the rotor to the other. By skewing the rotor bars, motor designers can reduce harmonics that add cusps to the speed-torque characteristics of the motor. The cusps in the speed-torque curves mean that the acceleration of the motor will not be completely smooth. The degree of skew matters because reducing the skew will help reduce the rotor resistance and reactance, which can result in improved efficiency. However, reducing the skew may have adverse impacts on the speed-torque characteristics.

Considering the four screening criteria for this technology option, DOE did not screen out adjusting rotor skew as a means of improving efficiency. Rotor skew is one of the variables that motor design engineers can manipulate to obtain certain performance and efficiency targets. The rotor skew is a part of the overall motor design, which is input into automated production equipment that punches and stacks the steel to create a rotor with the desired skew. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with properly manipulating the rotor skew to obtain improved performance.

4.3.12 Improved Rotor Bar Insulation

Another way to reduce stray-load losses is to improve insulation between the rotor squirrel-cage and the rotor laminations. Motors with insulated rotor cages often exhibit lower stray-load losses when compared to motors with un-insulated rotor cages. Manufacturers use different methods to insulate rotor cages, such as applying an insulating coating on the rotor slot prior to die-casting or heating and quenching the rotor (i.e., rapid cooling, generally by immersion in a fluid instead of allowing the rotor temperature to equalize to the ambient temperature) to separate rotor bars from rotor laminations after die-casting.

Considering the four screening criteria for this technology option, DOE did not screen out improved rotor bar insulation as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with improved rotor bar insulation.

4.3.13 Summary of Technology Options Not Screened Out

Table 4.2 summarizes the design options that DOE did not screen out of the analysis.

Table 4.2 Summary List of Technology Options Not Screened Out

Type of Loss to Reduce	Technology Option
Stator I^2R Losses	Increase cross-sectional area of copper in stator slots
	Decrease the length of coil extensions
Rotor I^2R Losses	Use a die-cast copper rotor cage
	Increase cross-sectional area of rotor conductor bars
	Increase cross-sectional area of end rings
Core Losses	Use electrical steel laminations with lower losses (watts/lb)
	Use thinner steel laminations
	Increase stack length (i.e., add electrical steel laminations)
Friction and Windage Losses	Optimize bearing and lubrication selection
	Improve cooling system design
Stray-Load Losses	Reduce skew on rotor cage
	Improve rotor bar insulation

4.4 DESIGN OPTIONS SCREENED OUT OF THE ANALYSIS

DOE screened out the following design options from further consideration because they do not meet the screening criteria.

4.4.1 Amorphous Metal Laminations

Using amorphous metals in the rotor laminations is another technology option to improve the efficiency of electric motors. Amorphous metal is extremely thin, has high electrical resistivity, and has little or no magnetic domain definition. Because of amorphous steel's high resistance it exhibits a reduction in hysteresis and eddy current losses, which reduce overall losses in electric motors. However, amorphous steel is a very brittle material which makes it difficult to punch into motor laminations.[1]

Considering the four screening criteria for this technology option, DOE screened out amorphous metal laminations as a means of improving efficiency. Although amorphous metals have the potential to improve efficiency, DOE does not consider this technology option technologically feasible, because it has not been incorporated into a working prototype of an electric motor. Furthermore, DOE is uncertain whether amorphous metals are practicable to manufacture, install, and service, because a prototype amorphous metal electric motor has not been made and little information is available on the ability to manufacture this technology to make a judgment. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with amorphous metal laminations.

4.4.2 Plastic Bonded Iron Powder

Plastic bonded iron powder (PBIP) could cut production costs while increasing the output of electric motors. Although other researchers may be working on this technology option, DOE is aware of a research team at Lund University in Sweden that published a paper about PBIP. This technology option is based on an iron powder alloy that is suspended in plastic, and is used in certain motor applications such as fans, pumps, and household appliances.[2] The compound is then shaped into motor components using a centrifugal mold, reducing the number of manufacturing steps. Researchers claim that this technology option could cut losses by as much as 50 percent. The Lund University team already produces inductors, transformers, and induction heating coils using PBIP, but has not yet produced an electric motor. In addition, it appears that PBIP technology is aimed at torus, claw-pole, and transversal flux motors, none of which fall under DOE's scope of analysis as defined by the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act.

Considering the four screening criteria for this technology option, DOE screened out PBIP as a means of improving efficiency. Although PBIP has the potential to improve efficiency while reducing manufacturing costs, DOE does not consider this technology option technologically feasible, because it has not been incorporated into a working prototype of an electric motor. Also, DOE is uncertain whether the material has the structural integrity to form into the necessary shape of an electric motor steel frame. Furthermore, DOE is uncertain whether PBIP is practicable to manufacture, install, and service, because a prototype PBIP electric motor has not been made and little information is available on the ability to manufacture this technology to make a judgment. However, DOE is not aware of any adverse impacts on product utility, product availability, health, or safety that may arise from the use of PBIP in electric motors.

4.4.3 Summary of Technology Options Screened Out of the Analysis

Table 4.3 shows the criteria DOE used to screen amorphous metal laminations and plastic bonded iron powder (PBIP) out of the analysis.

Table 4.3 Design Options Screened Out of the Analysis

Design Option	Screening Criteria
Amorphous Metals	Technological feasibility
PBIP	Technological feasibility

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[1] S.R. Ning, J. Gao, and Y.G. Wang. *Review on Applications of Low Loss Amorphous Metals in Motors*. 2010. ShanDong University. Weihai, China.

[2]Horrdin, H., and E. Olsson. *Technology Shifts in Power Electronics and Electric Motors for Hybrid Electric Vehicles: A Study of Silicon Carbide and Iron Powder Materials.* 2007. Chalmers University of Technology. Göteborg, Sweden.

CHAPTER 5. ENGINEERING ANALYSIS

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LIST OF ACRONYMS AND ABBREVIATIONS

A	ampere
AC	alternating current
AWG	American wire gauge
BOM	bill of materials
EL	efficiency level
DOE	United States Department of Energy
EISA	Energy Independence and Security Act of 2007
IEC	International Electrotechnical Commission
in	inch
lbs	pounds
M*	M15, M19, M36, M47, M56 - grade of core steel
MSP	manufacturer selling price
Nm	Newton meter
NCI	Navigant Consulting, Inc.
NEMA	National Electrical Manufacturers Association
NIA	national impact analysis
RPM	revolutions per minute
SEC	Securities and Exchange Commission
SME	subject matter expert
TSD	technical support document
U.S.	United States
V	volt

5.1 INTRODUCTION

The engineering analysis estimates the increase in manufacturer selling price (MSP) associated with technological design changes that improve the efficiency of an electric motor. This chapter presents the U.S. Department of Energy's (DOE's) assumptions, methodology and findings for the electric motor engineering analysis. The output from the engineering analysis is a "cost-efficiency" relationship for each electric motor analyzed which describes how its cost changes as efficiency increases. The output of the engineering analysis is used as an input to the life-cycle cost analysis (Technical Support Document (TSD) chapter 8) and the national impact analysis (TSD chapter 10).

The engineering analysis takes input from the market and technology assessment (see TSD chapter 3) and the screening analysis (see TSD chapter 4). These inputs include equipment classes, baseline electric motor performance, methods for improving efficiency, and design options that have passed the screening criteria. The engineering analysis uses these inputs, coupled with material price estimates, design parameters, and other manufacturer inputs to develop the relationship between the MSP and nominal full-load efficiency of the representative electric motors studied.

At its most basic level, the output of the engineering analysis is a curve that estimates the MSP for a range of efficiency values. This output is subsequently marked-up to determine the end-user prices based on the various distribution channels (see TSD chapter 6). After determining customer prices by applying distribution chain markups, sales tax, and contractor markups, the data is combined with the energy-use and end-use load characterization (see TSD chapter 7) and used as a critical input to the customer's life-cycle cost and payback period analysis (see TSD chapter 8).

In this chapter, DOE discusses the equipment classes analyzed and the representative electric motors selected from all motors considered for energy conservation standards. As discussed in chapters 2 and 3 of this TSD, the electric motors in the scope of coverage of this rulemaking include single-speed, squirrel-cage induction, alternating current (AC), polyphase motors from 1 to 500 horsepower and National Electrical Manufacturers Association (NEMA) Design A, B, and C electric motors, including fire pump electric motors and brake electric motors. The engineering analysis selected three NEMA Design B electric motors to analyze the NEMA Design A and B equipment class group and two NEMA Design C electric motors to analyze the NEMA Design C equipment class group. The fire pump electric motor and brake electric motor equipment class groups will be based on the three NEMA Design B electric motors. DOE also presents the methodology, inputs, and results associated with the development of MSP versus efficiency curves for each of the representative electric motors. Finally, DOE discusses the approach used to scale the efficiency levels analyzed to all other equipment classes for the national impact analysis.

5.2 EQUIPMENT CLASSES AND REPRESENTATIVE UNITS ANALYZED

Due to the large number of equipment classes, DOE did not directly analyze all covered electric motors. Instead, DOE selected certain equipment classes to directly analyze after reviewing electric motors shipments, examining manufacturers' catalog data, and soliciting feedback from interested parties. The equipment classes that DOE directly analyzes and focuses its engineering analysis on are referred to as representative units. Table 5-1 shows the equipment class groups discussed in TSD chapter 3 and the corresponding electric motor designs they encompass. As mentioned above, DOE selected three representative units to analyze in equipment class group 1 and two representative units in equipment class group 2. For equipment class group 3, DOE plans on developing any potential amended energy conservation standards based off of its analysis of equipment class group 1 because fire pump electric motors are required to meet National Electrical Manufacturers Association (NEMA) Design B performance standards. Similarly, any potential standards for equipment class group 4 will be based on the analysis of equipment class group 1 because the brake motors being considered for standards are also NEMA Design B motors.

Table 5-1 Electric Motor Equipment Class Groups

Equipment Class Group (ECG)	Electric Motor Design Type	Horsepower Rating	Pole Configuration	Enclosure
1	NEMA Design A & B*	1–500	2, 4, 6, 8	Open
				Closed
2	NEMA Design C*	1–200	4, 6, 8	Open
				Closed
3	Fire Pump*	1–500	2, 4, 6, 8	Open
				Closed
4	Brake Motors*	1–30	4, 6, 8	Open
				Closed

*Includes International Electrotechnical Commission (IEC) equivalent design types.

DOE considered each of the characteristics listed in Table 5-1 when selecting its representative units. The sections that follow describe the decisions that DOE made with respect to each of these electric motor characteristics.

5.2.1 Electric Motor Design Type

For equipment class group 1 that includes NEMA Design A and B electric motors, DOE only selected NEMA Design B motors as representative units to analyze in the engineering analysis. DOE chose NEMA Design B electric motors because NEMA Design A electric motors can generally meet NEMA Design B efficiency levels due to their less stringent locked-rotor current limits. In other words, NEMA Design B motors slightly limit the incremental increase in energy conservation standards that could be technologically feasible. However, by directly analyzing NEMA Design B motors, it ensures that any potential amendments to the current energy conservation standards could be met by all motors covered in equipment class group 1. Additionally, NEMA Design B units have much higher shipment volumes than NEMA Design A motors. Figure 5.1 shows the relative shipments of each electric motor design type, which demonstrates that NEMA Design B motors constitute the vast majority of all shipments with a market share of 96 percent. Finally, by choosing NEMA Design B motors, DOE could also apply the results of its equipment class group 1 analysis to its equipment class group 3 analysis because fire pump motor designs are held to very similar design constraints as NEMA Design B motors. Equipment class group 4, consisting of brake motors, is also based on equipment class group 1 because DOE is only aware of brake motors being built to NEMA Design B specifications.

For equipment class group 2, DOE selected two representative units to analyze directly. Because Design C is the only NEMA design type covered by this equipment class group, DOE only selected NEMA Design C motors for analysis as its representative units.

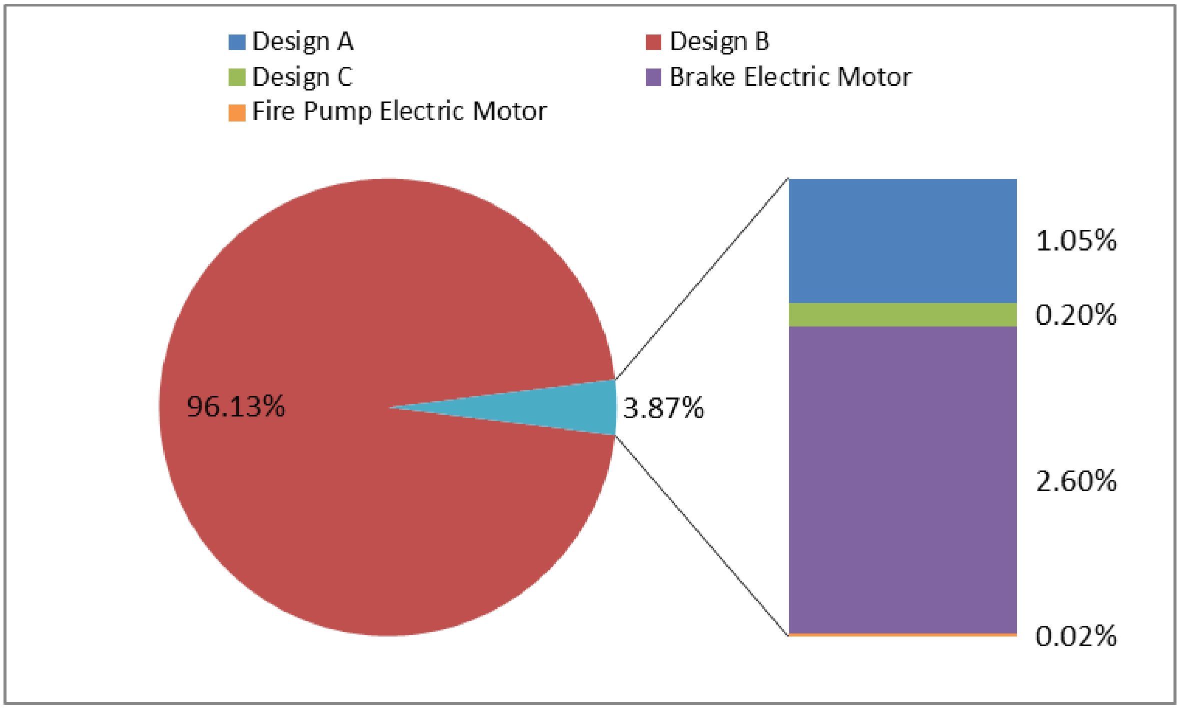

Figure 5.1 Electric Motor Shipments by Design Type for 2012

5.2.2 Horsepower Rating

Horsepower rating is an important equipment class setting criterion, which DOE received multiple comments about when developing its representative units. When DOE selected its representative units, DOE chose those horsepower ratings that constitute a high volume of shipments in the market and provide a sufficiently wide range upon which DOE could reasonably base a scaling methodology. For NEMA Design B motors, for example, DOE chose 5-, 30-, and 75-horsepower-rated electric motors to analyze as representative units. DOE selected the 5-horsepower rating because it is the rating with the highest shipment volume of the electric motors considered. Figure 5.2 shows shipments of electric motors in equipment class group 1 broken down by horsepower rating and demonstrates that the 5-horsepower rating constituted nearly 23 percent of shipments in 2012. DOE selected the 30-horsepower rating as an intermediary between the small and large frame number series electric motors. For the largest frame number series, DOE elected to analyze a 75-horsepower rated electric motor. DOE believes that this rating is an appropriate choice to represent the highest horsepower ratings because there tends to be minimal change in efficiency between the highest horsepower ratings. For consecutive horsepower ratings above 75, the nominal efficiencies that motors must meet in order to be deemed NEMA Premium tend to repeat.[a]

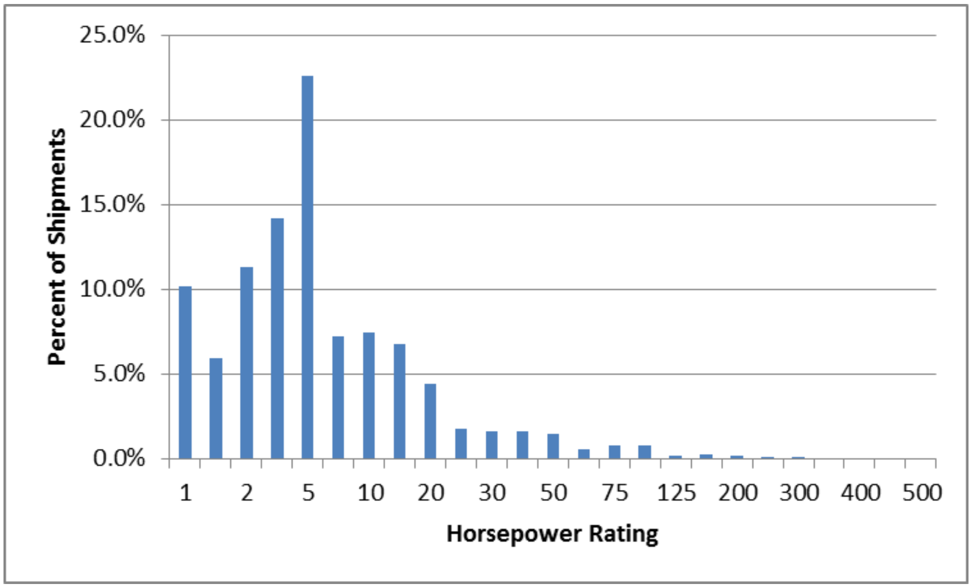

Figure 5.2 ECG 1 (NEMA Design A & B) Electric Motors Shipments by Horsepower Rating for 2012

For NEMA Design C electric motors, DOE only selected two horsepower ratings because of the relatively low shipment volumes and smaller range of horsepower ratings. As with NEMA Design B motors, DOE elected to analyze the 5-horsepower rating because of its relatively high market share. For an upper bound, DOE selected the 50-horsepower rating due to the smaller range of horsepower ratings for NEMA Design C motors. Figure 5.3 shows shipments of electric motors in equipment class group 2 broken down by horsepower rating.

[a] In June 2001, NEMA began a program to provide special recognition to certain electric motors whose energy efficiency was better than that required under the Energy Policy Act of 1992 (EPACT 1992). NEMA created a designation called NEMA Premium. This designation applies to single-speed, polyphase, 1 to 500 horsepower, 2-, 4-, and 6-pole (3600, 1800 and 1200 rpm) squirrel-cage induction motors, NEMA Designs A or B, 600V or less, (5kV or less for medium voltage motors), and continuous rated. The energy efficiency values are defined in NEMA MG 1 Table 12−12. Section 342(b)(2)(A) of EPCA, as amended, 42 U.S.C. 6313(b)(2)(A), essentially incorporates by reference NEMA MG 1 Table 12−12.

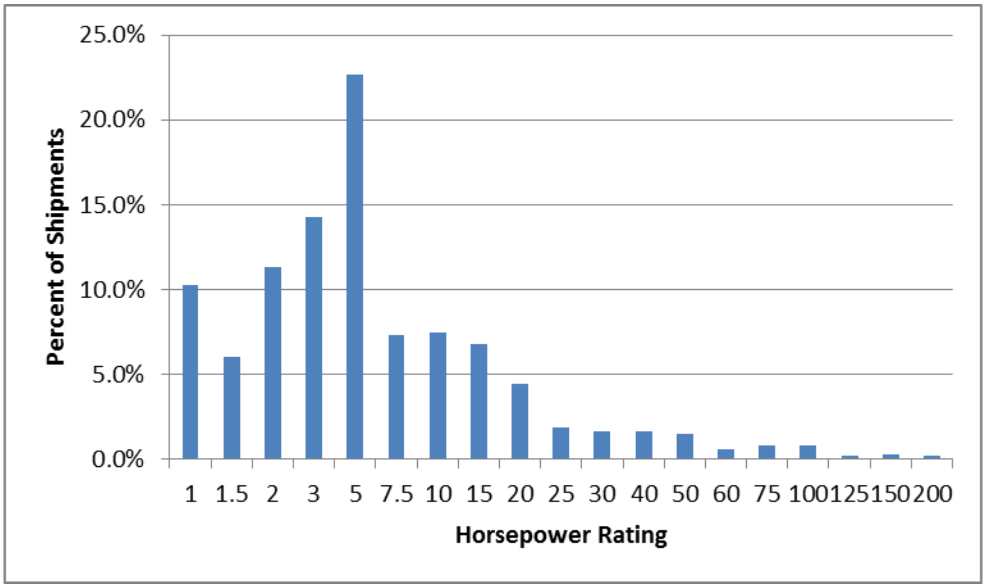

Figure 5.3 ECG 2 (NEMA Design C) Electric Motors Shipments by Horsepower Rating for 2012

5.2.3 Pole-Configuration

Pole-configuration is another important equipment class setting criterion which DOE had to consider when selecting its representative units. For the preliminary analysis, DOE selected 4-pole motors for all of its representative units. DOE maintained this approach in the NOPR analysis. DOE chose not to vary the pole configuration of the various representative units it analyzed because it believed that doing so would provide the strongest relationship upon which to base its scaling. By keeping as many design characteristics constant as possible, DOE could more accurately identify how design changes affect efficiency across horsepower ratings. For example, if DOE compared the NEMA Premium efficiencies of a 5-horsepower, 4-pole electric motor and 50-horsepower, 6-pole electric motor it would be difficult to determine how much of the difference was due to the change in horsepower rating and how much was due to the change of pole configuration. Additionally, DOE believes that the horsepower rating-versus-efficiency relationship is the most important (rather than pole configuration and enclosure-type versus efficiency) because there are significantly more horsepower ratings to consider. Finally, as illustrated in Figure 5.4, 4-pole electric motors constitute the largest fraction of the electric motors market. Electric motors built with 4-poles accounted for 69 percent of shipments in 2012, which was more than 2-pole, 6-pole, and 8-pole motor shipments combined.

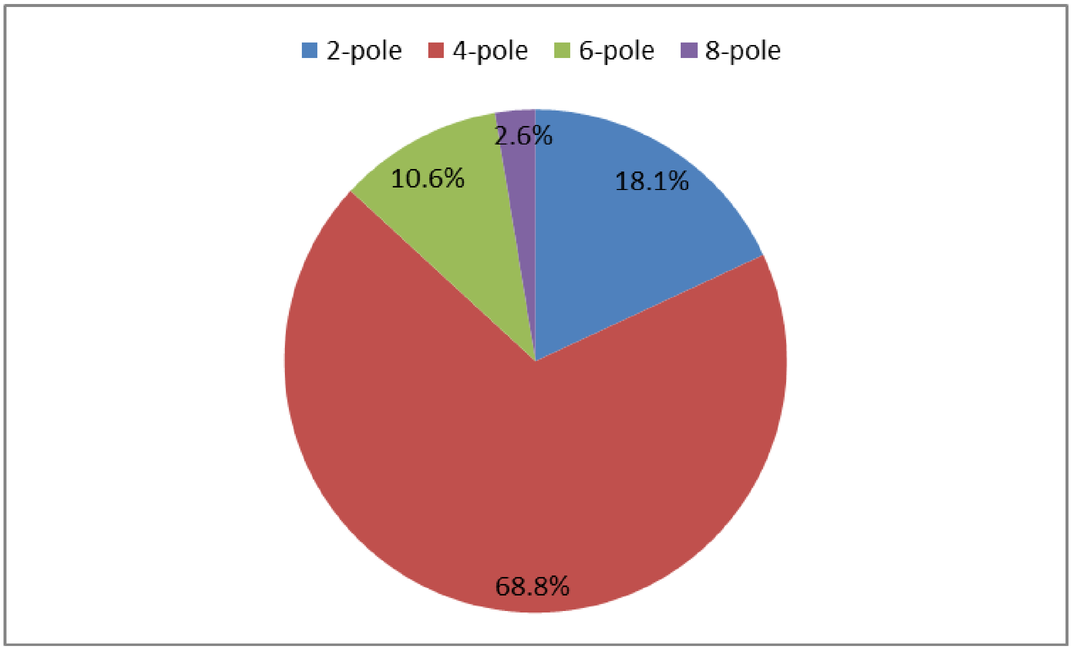

Figure 5.4 Electric Motor Shipments by Pole Configuration for 2012

5.2.4 Enclosure Type

The final equipment class setting criterion that DOE had to consider when selecting its representative units was enclosure type. For the NOPR, DOE elected to only analyze electric motors with totally enclosed, fan-cooled (TEFC) designs rather than open designs for all of its representative units. DOE selected TEFC motors because, as with pole configurations, DOE wanted as many design characteristics to remain constant as possible. Again, DOE believed that such an approach would allow it to more accurately identify the reasons for efficiency improvements. Finally, TEFC electric motors represented more than three times the shipment volume of open motors. Figure 5.5 shows the relative shipments of open and enclosed motors in the year 2012.

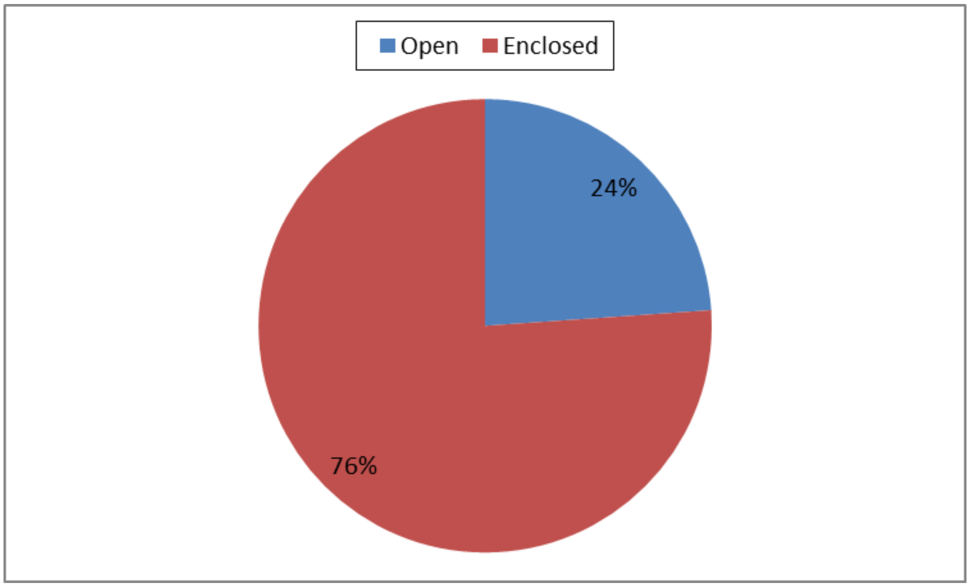

Figure 5.5 Electric Motor Shipments by Enclosure Type for 2012

As addressed above, when identifying which electric motors to evaluate, DOE considered equipment classes that represented motors with a significant volume of shipments. DOE also considered the necessity for scaling its engineering results. Therefore, DOE selected electric motors that would minimize any error that might be introduced through extrapolating between horsepower ratings, pole configurations, and enclosure types. As is discussed in section 5.7, DOE scaled the engineering analysis results of its analyzed representative units to all of the other, not-analyzed, equipment classes. Such scaling is necessary for the national impacts analysis (NIA). For more information on the NIA, please see TSD chapter 10. Table 5-2 presents the major design characteristics of the five representative units that DOE analyzed and will discuss in detail throughout this engineering analysis.

Table 5-2 Design Characteristics of the Five Representative Units Analyzed

Equipment Class Group Represented	Electric Motor Design Type	Horsepower Rating	Pole Configuration	Enclosure
1, 3, and 4	NEMA Design B	5	4	Totally Enclosed, Fan Cooled
1, 3, and 4	NEMA Design B	30	4	Totally Enclosed, Fan Cooled
1, 3, and 4	NEMA Design B	75	4	Totally Enclosed, Fan Cooled
2	NEMA Design C	5	4	Totally Enclosed, Fan Cooled
2	NEMA Design C	50	4	Totally Enclosed, Fan Cooled

5.2.5 Equipment Class Group 1 (NEMA Design A and B Electric Motors)

DOE decided to focus the analysis of NEMA Design A and NEMA Design B electric motors on three representative units. When selecting these representative units, DOE used the data in Figure 5.2 and Figure 5.12 to select three representative units with high shipping volume that also evenly cover the entire range of horsepower ratings in the scope of this analysis. The graph in Figure 5.12 shows the average efficiencies of 4-pole, enclosed electric motors versus horsepower rating. This data was based on DOE's electric motor database which was compiled from the most current electric motor manufacturer catalog data available. DOE analyzed this curve and segmented the graph into three primary sections.

5.2.6 Equipment Class Group 2 (NEMA Design C Electric Motors)

When selecting the representative units for equipment class group 2 (NEMA Design C electric motors), DOE referred to Figure 5.3 which represents the shipment volumes of NEMA Design C electric motors. Based on Figure 5.2, DOE selected a 5-horsepower electric motor again because of its high volume of shipments. To cover the higher horsepower ratings, DOE selected a 50-horsepower electric motor. DOE chose to base the analysis on the NEMA Design C equipment class group on two electric motors instead of three due to the smaller range of horsepower ratings as well as the lower production volumes of NEMA Design C electric motors and therefore somewhat limited equipment selection. DOE selected the 50-horsepower rating because it falls between the 30-horsepower and 75-horsepowerratings selected as representative units for equipment class group 1.

5.2.7 Equipment Class Group 3 (Fire Pump Electric Motors)

According to National Fire Protection Association (NFPA) 20, *Standard for the Installation of Stationary Pumps for Fire Protection,* electric motors (as covered under this rulemaking) used with a fire pump system must comply with NEMA Standards Publication MG 1, *Motors and Generators*, (MG 1) requirements , comply with NEMA Design B requirements, and be listed for fire pump service. So, with a few exceptions, fire pump electric motors are very similar to NEMA Design B electric motors. Namely, fire pump electric motors are not required to shut off if they are overheating, and they require more rigorous start/stop capabilities than general purpose NEMA Design B electric motors. Aside from these operating differences, fire pump electric motors are electromechanically similar to NEMA Design B electric motors. Therefore, DOE decided to base the analysis of fire pump electric motors on the engineering data produced from the representative units chosen for equipment class group 1.

5.2.8 Equipment Class Group 4 (Brake Motors)

Equipment class group 4, consisting of brake electric motors, is also based on equipment class group 1 because DOE is only aware of brake motors being built to NEMA Design B specifications. Although these motor types will be in their own ECG and subject to their own energy conservation levels, DOE is basing the analysis of brake motors on the analysis of the representative units for ECG 1. DOE makes this decision after observing catalog data and finding that brake motors only appear to be offered in the NEMA Design B motor type.

5.3 BASELINE AND CANDIDATE STANDARD LEVELS OF EFFICIENCY

For each representative unit selected, DOE identified a specific baseline electric motor as a fundamental design against which it would apply design changes to improve the electric motor's efficiency. DOE chose the baseline electric motors to represent the typical characteristics of electric motors in the equipment class of the corresponding representative unit. The baseline efficiency level is used to determine energy savings and changes in price associated with moving to higher efficiency levels. Efficiency levels (ELs) are intended to help characterize the cost-efficiency relationship. Table 5-3 shows the baseline efficiency levels for each of DOE's selected representative units.

Table 5-3 Baseline Efficiency Ratings of Representative Units

Basic Characteristics of Electric Motors Analyzed	Baseline Efficiency %	Equipment Class Group
Design B, 5-horsepower, 4-pole, enclosed frame	82.5	1*
Design B, 30-horsepower, 4-pole, enclosed frame	89.5	1*
Design B, 75-horsepower, 4-pole, enclosed frame	93.0	1*
Design C, 5-horsepower, 4-pole, enclosed frame	87.5	2
Design C, 50-horsepower, 4-pole, enclosed frame	93.0	2

*Analysis of equipment class groups 3 and 4 will be based on these representative units. However, the baseline for equipment class group 3 is slightly higher (equivalent to NEMA MG 1 Table 12-11) because fire pump electric motors have conservation standards set by the Energy Independence and Security Act of 2007 (EISA 2007) while equipment class group 1 includes electric motors with no existing conservation standards.

As discussed in chapters 2 and 3, DOE intends to expand the scope of energy conservation standards to include electric motors that were not previously covered by regulation. Those motor types not previously covered and that are now within the scope of coverage are listed in chapter 3 of the TSD. DOE used a motor database of efficiencies and up-to-date manufacturer motor catalogs to find motors with the lowest market efficiency. Since the expanded scope of energy conservation standards includes motors not previously subject to efficiency standards, DOE selected motors whose baseline efficiencies were below the lowest energy conservation levels currently enforced for any motors (levels most recently prescribed by EISA 2007). DOE observed NEMA Design B vertical, hollow-shaft motors, currently outside the scope of regulation, with efficiency levels listed in Table 5-3. For the NEMA Design C equipment class group, DOE selected NEMA MG 1 Table 12-11 values as baseline efficiency levels. This approach is based on the lowest efficiency values DOE observed in motor catalogs for NEMA Design C motors. The NEMA Design C representative motors with the lowest observed efficiencies are also listed in Table 5-3.

Should DOE not find any economic justification for amended energy conservation standards above the baseline efficiency level, subtype I and subtype II motors would remain subject to the same conservation standards (i.e., different from each other) mandated by EISA 2007. Additionally, DOE notes that although the efficiencies in Table 5-3 represent the baseline, DOE's efficiency distribution for equipment class group 1 shows a significant portion of motors already above the baseline efficiency level.

5.3.1 Efficiency Levels (ELs)

NEMA MG 1-2011 contains a table of standardized "nominal" full load efficiency values, Table 12-10, from which manufacturers may choose a value to label and market their electric motors. NEMA uses these standardized values of efficiency to characterize the efficiency of a population of electric motors because of the variability in performance due to materials used in electric motors, such as electrical steel and copper, and the laboratory to laboratory test variation that can occur. Because of these possible sources of performance variation, NEMA and its members in industry use these standardized values of efficiencies, with associated guaranteed minimum values of efficiencies, to represent a specific electric motor model's efficiency with a "band" of efficiency. The standardized values of NEMA nominal efficiencies found in Table 12-10 of NEMA MG 1-2011 are fairly evenly spaced in terms of motor losses.[b] Each higher, incremental level of nominal efficiency represents a reduction in motor losses of roughly 10 percent. DOE followed a similar pattern when developing its higher ELs (i.e., those above NEMA MG 1-2011 Table 12-11 and Table 12-12).

As mentioned earlier, DOE selected a baseline model for each representative unit as a reference point against which to measure changes that may result from increasing an electric motor's efficiency. Each increase in efficiency over the baseline level that DOE analyzed was assigned an EL number. For the NOPR, DOE based its baseline efficiency level, or EL 0, on the

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[b] Motor losses (watts) are calculated with the formula $P\left(\frac{1}{\eta} - 1\right)$, where *P* represents the motor's rated power in watts, and η represents the value of efficiency.

lowest efficiency levels observed in motor catalog data for the electric motors DOE plans on including in the expanded scope of conservation standards. DOE selected four additional incremental ELs for equipment class group 1 and two additional incremental ELs for equipment class group 2 based on other industry specifications, market data, and software modeling.

Table 5-4 shows the ELs for equipment class group 1 that DOE used for electric motors during the analysis. DOE based its first incremental EL (EL 1) on NEMA MG 1-2011, Table 12-11 and Table 20-A[c], which specify the nominal efficiency levels for motors that NEMA classifies as "energy efficient." Table 12-11 is equivalent to the EPACT 1992 levels for 1 to 200 horsepower NEMA Design B electric motors and the EISA 2007 levels for NEMA Design B electric motors with a horsepower rating greater than 200. EISA 2007 also mandated that general purpose electric motors (subtype I) from 1 to 200 horsepower meet efficiency levels that correspond to NEMA MG 1-2011, Table 12-12 (i.e., equivalent to NEMA Premium levels). However, equipment class group 1 includes motors that are considered general purpose electric motors (subtype II). For these electric motors, EISA 2007 mandated efficiency standards equivalent to Table 12-11, which is why DOE believes Table 12-11 is the appropriate EL 1 to represent equipment class group 1.

Table 5-4 Candidate Standard Levels for ECG 1

EL Number	EL Name	NEMA MG 1-2011 Table	Note
0	Baseline	—	Lowest observed efficiency under expanded scope
1	Standard	12-11 & 20-A	EPACT 1992 requirement, with additional efficiency levels added in NEMA MG 1-2011
2	Premium	12-12 & 20-B	EISA 2007 requirement for general purpose electric motors (subtype I), with additional efficiency values added in NEMA MG 1-2011
3	Best-in-Market	—	One NEMA nominal efficiency level improvement relative to the Premium level
4	Maximum Technology	—	One NEMA nominal efficiency level improvement relative to the Best-in-Market

DOE based its second incremental EL (EL 2) on the NEMA Premium efficiency levels, found in NEMA MG 1 Tables 12-12 and 20-B. These tables typically represent a two or three NEMA band improvement above the previously mandated EPACT 1992 levels displayed in NEMA MG 1 Table 12-11. The third incremental EL (EL 3) is based on motors with the highest efficiencies observed in DOE's motor database and up-to-date motor catalogs. Therefore EL 3 motors have the "best-in-market" efficiencies for equipment class group 1 (ECG 1). This level was generally one NEMA band above the NEMA Premium level, or EL 2. This level represents the best or near best efficiency level at which current manufacturers are producing electric motors. EL 4 represents an incremental level between the maximum available efficiency and the

[c] NEMA MG 1-2011 Table 20-A includes efficiency levels for 6- and 8-pole motors at higher horsepower ratings (between 300 and 500 horsepower) that are omitted from Table 12-11. Table 20-A is a new addition to NEMA MG 1-2011, and therefore the efficiency levels it specifies are not part of the most recent conservation standards set by EISA 2007.

maximum technology ("max-tech") EL. EL 4 represents the maximum technologically available or "max-tech" efficiency level. EL 4 is based on a motor which incorporates a combination of the best materials potentially available for high-production motor manufacturing. This includes low-loss electrical steel and copper rotor motor technology. DOE based its value of efficiencies for EL 4 on a physical electric motor, computer-modeled designs and subject matter expert (SME) feedback.

Table 5-5 shows the ELs for equipment class group 2 (NEMA Design C motors), which were selected differently than for equipment class group 1. For equipment class group 2, DOE selected the NEMA MG 1 Table 12-11 values as the baseline efficiency level. This approach is based on the lowest efficiency values DOE observed in manufacturer catalogs for NEMA Design C motors, which are the EPACT 1992 equivalent efficiency levels (as mandated by EISA 2007 under 'general purpose electric motor (subtype II)'). Further ELs for ECG 2 were selected based on computer modeling results, and are displayed in Table 5-6.

Table 5-5 Candidate Standard Levels for ECG 2

EL Number	EL Name	NEMA MG 1-2011 Table	Note
0	Baseline	12-11	Lowest observed efficiency under expanded scope (EPACT 1992 requirement)
1	Premium	12-12	EISA 2007 requirement for general purpose electric motors (subtype I)
2	Maximum Technology	—	One NEMA nominal efficiency level improvement relative to the Premium level

Table 5-6 shows the nominal efficiency values for each representative unit and each EL. Cells with a '†' indicate a physical electric motor that DOE purchased and tore down. Cells with a '*' indicate the efficiency levels are from software modeling data gathered from DOE's SME which were derived using various technology, material, and geometry changes. Cells with a '—' indicate that DOE was not able to further increase efficiency levels for these representative units and still keep an electric motor design within the proper specifications.

Table 5-6 Efficiency Levels for each Representative Unit

Efficiency Level (EL)	5-Horsepower Design B Efficiency (%)	30-Horsepower Design B Efficiency (%)	75-Horsepower Design B Efficiency (%)	5-Horsepower Design C Efficiency (%)	50-Horsepower Design C Efficiency (%)
0	82.5†	89.5†	93.0†	87.5†	93.0†
1	87.5†	92.4†	94.1†	89.5*	94.5*
2	89.5†	93.6†	95.4†	91.0*	95.0*
3	90.2†	94.1†	95.8†	—	—
4	91.0†	94.5*	96.2*	—	—

†Indicates the efficiency of a purchased and physically torn-down electric motor
*Indicates the efficiency of a software-modeled electric motor

5.4 ENGINEERING ANALYSIS METHODOLOGY

As stated, the engineering analysis estimates the cost increment for the efficiency improvement potential of individual design options or combinations of design options that pass the four criteria in the screening analysis. DOE uses this cost-efficiency relationship, developed in the engineering analysis, in the LCC analysis.

DOE can use three methodologies to generate the manufacturing costs needed for the engineering analysis. These methods are:

1. the design-option approach — reporting the incremental costs of adding design options to a baseline model;

2. the efficiency-level approach — reporting relative costs of achieving improvements in energy efficiency; and

3. the reverse engineering or cost assessment approach — involving a "bottom up" manufacturing cost assessment based on a detailed bill of materials derived from electric motor teardowns.

Because DOE targeted certain nominal efficiency levels when improving baseline efficiencies and relied on tear-downs of electric motors, DOE's analysis for the electric motor rulemaking is a combination of the efficiency-level approach and the reverse engineering approach. DOE created baseline costs from bills of materials of electric motor tear-downs and then determined the costs of increasing efficiency levels based on material or technology changes.

5.4.1 Subcontractor Tear-downs

Due to limited manufacturer feedback concerning cost data and production costs, DOE derived its production and material costs by having a professional motor laboratory[d] disassemble

[d] The Center for Electromechanics University of Texas at Austin, a 140,000 sq. ft. lab with 40 years of operating experience with teardowns overseen by Dr. Angelo Gattozzi, an electric motor expert with previous industry experience. In addition, some teardowns were performed at Advanced Energy, an independent test lab with NVLAP (National Voluntary Laboratory Accreditation Program) certification located in North Carolina.

and inventory the physical electric motors purchased. DOE performed tear-downs on the electric motors representing EL 0 through 3 for equipment class group 1 as well as electric motors representing EL 0 for equipment class group 2. These tear-downs provided DOE the necessary data to construct a bill of materials, which DOE could normalize using a standard cost model and markup to produce a projected manufacturer selling price (MSP). DOE used the MSP derived from the engineering tear-down paired with the corresponding nameplate nominal efficiency to report the relative costs of achieving improvements in energy efficiency. DOE derived material prices from a consensus of current, publicly available data, manufacturer feedback, and conversations with its subject matter experts. DOE supplemented the findings from its tests and tear-downs through: (1) a review of data collected from manufacturers about prices, efficiencies, and other features of various models of electric motors, and (2) interviews with manufacturers about the techniques and associated costs used to improve efficiency.

DOE's engineering analysis documents the design changes and associated costs when improving electric motor efficiency from the baseline level up to a max-tech level. This includes considering improved electrical steel for the stator and rotor, using die-cast copper rotors, increasing stack length, and any other applicable design options remaining after the screening analysis. As each of these design options are added, the manufacturer's cost generally increases and the electric motor's efficiency improves.

5.4.2 Subcontractor Software Designs

DOE worked with technical experts to develop the highest efficiency levels (i.e., the max-tech levels) technologically feasible for each representative unit analyzed. DOE used a combination of electric motor software design programs and SME input. DOE retained an electric motor expert[e] with design experience and software, who prepared a set of designs with increasing efficiency. The design software DOE used is a proprietary software program called VICA.[f] The SME also checked his designs against tear-down data and calibrated his software using the relevant test results. As new designs were created, careful attention was paid to the critical performance characteristics defined in NEMA MG 1-2011 Tables 12-2, 12-3, 12-4, and paragraph 12.35.1, which define locked-rotor torque, breakdown torque, pull-up torque and maximum locked-rotor currents, respectively. This was done to ensure that the utility of the baseline unit was conserved as efficiency was improved through the application of various design options. Additionally, DOE limited its modeled stack length increases based on tear-down data and the maximum "C" dimensions found in manufacturer's catalogs.[g]

DOE limited the amount by which it would increase the stack length of its software-modeled electric motors to preserve the utility of the baseline model torn down. The maximum stack lengths used in the software-modeled ELs were determined by first analyzing the stack lengths and "C" dimensions of torn-down electric motors. Then, DOE analyzed the "C" dimensions of various electric motors in the marketplace conforming to the same design constraints as the representative units (same NEMA design letter, horsepower rating, NEMA

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[e] Dr. Howard Jordan, Ph.D, an electric motor design expert with over 40 years of industry experience.
[f] VICA stands for "Veinott Interactive Computer Aid."
[g] The "C" dimension of an electric motor is the length of the electric motor from the end of the shaft to the end of the opposite side's fan cover guard. Essentially, the "C" dimension is the overall length of an electric motor including its shaft extension.

frame series, enclosure type, and pole configuration). For each representative unit, DOE found the largest "C" dimension currently available on the marketplace and estimated a maximum stack length based on the stack length to "C" dimension ratios of motors it tore down. The resulting product was the value that DOE chose to use as the maximum stack length in its software modeled designs. Table 5-7 shows the stack lengths of torn down ELs and stack lengths used in the software modeled ELs. Table 5-8 shows the estimated maximum stack length that was used as an upper bound in the software modeled ELs. The efficiency levels of the software modeled ELs are displayed in Table 5-6.

Table 5-7 Stack Length Measurements of Torn Down and Modeled Motors

Representative Unit	EL	Stack Length (in)
5 HP, Design B	0	2.80*
	1	3.47
	2	5.14
	3	4.65
	4	5.02
30 HP, Design B	0	7.87*
	1	5.53
	2	8.02
	3	6.74
	4	7.00**
75 HP, Design B	0	8.15*
	1	10.23
	2	10.58
	3	11.33
	4	12.00**
5 HP, Design C	0	4.75
	1	4.25**
	2	5.32**
50 HP, Design C	0	8.67
	1	9.55**
	2	9.55**

*Represents stack length of a vertical, hollow-shaft motor.
**Represents stack length of a software modeled motor.

Table 5-8 Comparison of Maximum Stack Lengths Considered for Modeled Designs

Representative Unit	Estimated Maximum Stack Length (in.)	Maximum Stack Length of a Torn Down Motor (in.)	Maximum Stack Length Modeled (in.)
30 Horsepower Design B	8.87	8.02 (EL 2)	7.00
75 Horsepower Design B	13.06	11.33 (EL 3)	12.00
5 Horsepower Design C	5.80	4.75 (EL 0)	5.32
50 Horsepower Design C	9.55	8.67 (EL 0)	9.55

5.5 COST MODEL

DOE uses a standard method of cost accounting to determine the costs associated with manufacturing. This methodology is illustrated in Figure 5.6, where production costs and non-production costs are combined to determine the full cost of a product.

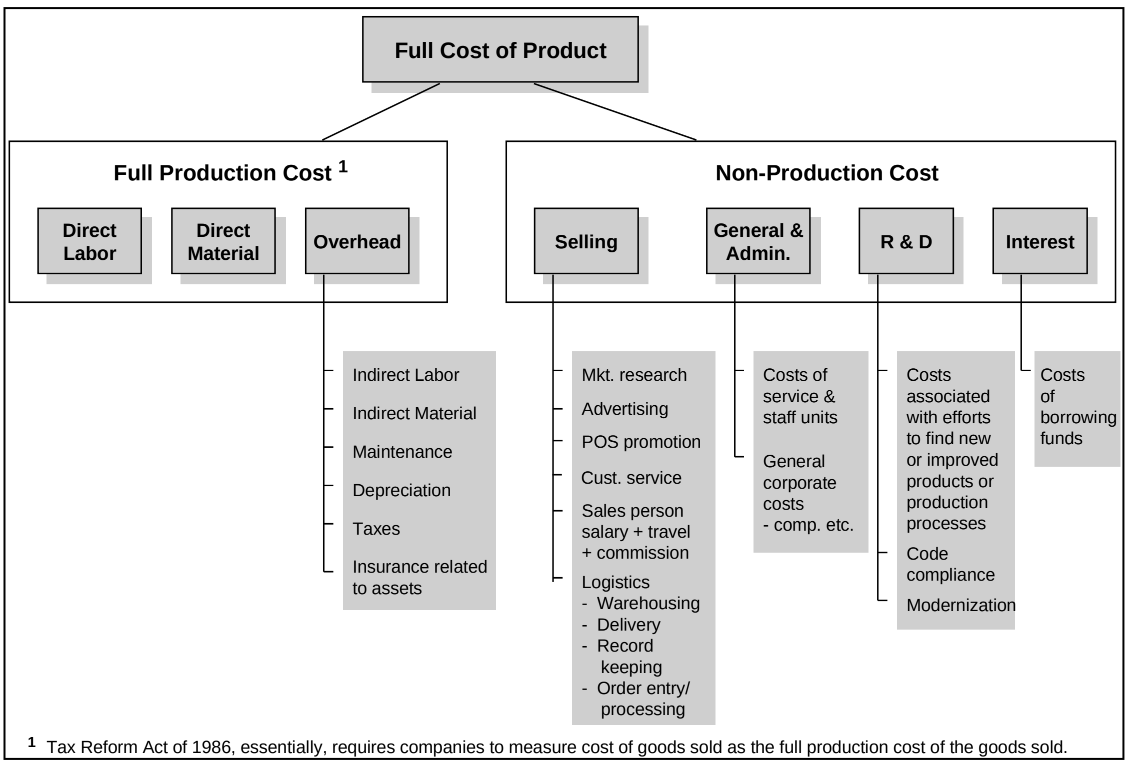

Figure 5.6 Standard Method of Cost Accounting for Standards Rulemaking

DOE developed estimates of some of the cost multipliers shown in Figure 5.6 by reviewing Security and Exchange Commission (SEC) SEC-10K reports from electric motor manufacturers, and examining previous, relevant, rulemakings, and through conversations with industry experts. Together, the full production cost and the non-production costs equal the full cost of the product. Full production cost is a combination of direct labor, direct materials, and overhead. The overhead contributing to full production cost includes indirect labor, indirect material, maintenance, depreciation, taxes, and insurance related to company assets. Non-production costs include the cost of selling (market research, advertising, sales representatives, logistics), general and administrative costs, research and development, interest payments and profit factor (not shown in the figure).

After the designs examined by DOE's motor experts were completed or the electric motors were torn down and the parts were inventoried, the next step was applying a consistent cost model to all of them. A standard bill of materials (BOM) was constructed that includes direct material costs. From this BOM, labor time estimates (along with associated costs) were added and various manufacturer markups were applied to create an MSP. DOE presents a summary of the production costs and non-production costs for each of the representative units analyzed in Appendix 5A.

5.5.1 Constructing a Bill of Materials

The BOM calculated for each design contained three types of material costs: variable, insulation, and hardware. The variable costs considered are those portions of the BOM that vary based on the cost of the material and the amount of that material used in the design. For example, stator and rotor lamination costs are variable costs because the material price for the different steel grades changes as does the volume of steel needed for each design. The insulation cost was aggregated due to the difficulty in pricing out all components of the insulation system. Based on SME feedback, DOE assumed increased efficiency does not incur notable increases in insulation system costs. Therefore, insulation costs increase as representative unit horsepower increases, but remain constant across all ELs for each representative unit. The total price for insulation was also derived from SME input. Finally, hardware costs are an aggregate cost for all electric motor hardware components. This includes nuts, bolts, gaskets, washers and other miscellaneous hardware components. As with the insulation costs, the hardware cost was aggregated due to the difficulty of pricing individual components. DOE believes hardware costs account for a small percentage of the total material costs of an electric motor and therefore does not believe this aggregation method will have a detrimental impact on the accuracy of the MSP. The aggregate hardware cost, which is unique for each horsepower rating, was also derived based on SME input and information received about the teardowns.

Each item in the BOM is organized by the type of cost (i.e., variable, insulation, and hardware) and the component of the electric motor to which they apply. The variable costs portion of the BOM includes the following subheadings, each with an itemized parts list: stator assembly, rotor assembly, and other major costs. The insulation cost section of the BOM includes subheadings for each individual component identified during teardown, however they are not priced out individually. As discussed above, an aggregate price is used to cover this entire section. This aggregate price is unique for different horsepower ratings. The hardware cost section of the BOM includes subheadings for individual hardware items identified during the teardown, but again like the insulation costs, they are not individually priced. There is one aggregate price used that covers all of the hardware components. This aggregate price is unique for each horsepower rating.

The subheadings that have an itemized list of components include the stator assembly, rotor assembly, and other major costs. The stator assembly's itemized lists include prices for steel laminations and copper wire. The rotor assembly portion of the BOM includes prices for laminations, rotor conductor material, (either aluminum or copper) and shaft extension material. The other major costs heading contains items for the frame material and base, terminal housing components, bearing-type, and end-shield material.

DOE presents a detailed BOM for one design from each of the electric motor categories analyzed in Appendix 5B. The discussion below describes the level of detail contained in the bill of materials presented in the appendix.

5.5.2 Labor Costs and Assumptions

Due to the varying degree of automation used in manufacturing electric motors, labor costs differ for each representative unit. DOE analyzed teardown results to determine which electric motors were machine wound and which electric motors were hand wound and based on this analysis, DOE applied a higher labor hour amount for the hand-wound electric motors. For the max-tech software modeled electric motors, DOE always assumed hand-winding and therefore a higher labor hour amount. Labor hours for each of the representative units were based on SME input and manufacturer interviews.

DOE used the same hourly labor rate for all electric motors analyzed. The base hourly rate was developed from the 2007 Economic Census of Industry,[h] published by the U.S. Census Bureau, as well as manufacturer and SME input. The base hourly rate is an aggregate rate of a foreign labor rate and a domestic labor rate. DOE weighed the foreign labor rate more than the domestic labor rate due to manufacturer feedback indicating off-shore production accounts for a majority of electric motor production by American-based companies. Several markups were applied to this hourly rate to obtain a fully burdened rate which was intended to be representative of the labor costs associated with manufacturing electric motors. Table 5-9 shows the markups that were applied, their corresponding markup percentage, and the new burdened labor rate.

[h] U.S. Census Bureau, 2007 Economic Census of Industry

Table 5-9 Labor Markups for Electric Motor Manufacturers

Item description	Markup percentage	Rate per hour
Labor cost per hour*		$ 10.87
Indirect Production**	33 %	$ 14.46
Overhead***	30 %	$ 18.79
Fringe†	24 %	$ 23.40
Assembly Labor Up-time††	43 %	$ 33.46
Cost of Labor Input to Spreadsheet		**$ 33.46**

* Cost per hour is an aggregate number drawn from U.S. Census Bureau, *2007 Economic Census of Industry,* published December 2010 and foreign labor rate estimates based on manufacturer feedback.
** Indirect Production Labor (Production managers, quality control, etc.) as a percent of direct labor on a cost basis. Navigant Consulting, Inc. (NCI) estimate.
*** Overhead includes commissions, dismissal pay, bonuses vacation, sick leave, and social security contributions. NCI estimate.
† Fringe includes pension contributions, group insurance premiums, workers compensation. Source: U.S. Census Bureau, *2007 Economic Census of Industry,* published December 2010. Data for NAICS code 335312 "Electric Motor and Generator Manufacturer" total fringe benefits as a percent of total compensation for all employees (not just production workers).
†† Assembly labor up-time is a factor applied to account for the time that workers are not assembling product and/or reworking unsatisfactory units. The markup of 43 percent represents a 70 percent utilization (multiplying by 100/70). NCI estimate.

5.5.3 Manufacturer Markups

DOE used the three markups described below to account for non-production costs that are part of each electric motor leaving a manufacturer's facility. Handling and scrap factor, overhead, and non-production markups will vary from manufacturer to manufacturer because their profit margins, overheads, prices paid for goods, and business structures vary. DOE prepared estimates for these three non-production cost manufacturer markups from Securities and Exchange Commission (SEC) Form 10K annual reports, and conversations with manufacturers and experts.

- Handling and scrap factor: 2.5 percent markup. This markup was applied to the direct material production costs of each electric motor. It accounts for the handling of material (loading into assembly or winding equipment) and the scrap material that cannot be used in the production of a finished electric motor (e.g., lengths of wire too short to wind).

- Factory overhead: 17.5 percent markup. Factory overhead includes all the indirect costs associated with production, indirect materials and energy use, taxes, and insurance. DOE applies factory overhead to the sum of direct material production costs (including the handling and scrap factor) and the direct labor costs. The overhead increases to 18.0 percent when copper die-casting is used in the rotor. This accounts for additional energy, insurance, and other indirect costs associated with the copper die-casting process.

- Non-production: 37 – 45 percent markup. This markup reflects costs including sales and general administrative, research and development, interest payments, and profit factor. DOE applies the non-production markup to the sum of the direct material production, the direct labor, the factory overhead, and the product conversion costs. For the analyzed electric motors at or below 30-horsepower this markup was 37 percent and for electric motors above 30-horsepower this markup was 45 percent. This increase accounts for the extra profit margin manufacturers may receive on larger electric motors that are sold in smaller volumes.

5.5.4 Conversion Costs

DOE understands that even without new conservation standards, manufacturers will be expending resources on research and development, capital equipment replacement, and testing and certification for new products in the normal course of their day-to-day business operations. However, DOE also realizes that some of the conservation standards under consideration may require significant levels of investment, in time and dollars, by manufacturers above and beyond their typical operational levels. To account for the additional investments that manufacturers will have to make to reach certain ELs, DOE included a conversion cost adder in the cost model. This reflects the additional cost passed along to the consumer by manufacturers attempting to recover the costs incurred from having to redevelop their product lines as a result of higher energy conservation standards. The conversion costs incurred by manufacturers include capital investment (i.e., new tooling and machinery), product development (i.e., reengineering each motor design offered), and testing and certification costs.

The conversion cost adder was only applied to ELs above NEMA Premium based on manufacturer feedback on conversion costs at each EL. For background, most manufacturers now offer NEMA Premium motors for a significant portion of their product line as a result of EISA 2007. Many manufacturers also offer certain ratings with efficiency levels higher than NEMA Premium. However, DOE is not aware of any manufacturer with a complete product line above NEMA Premium. Consequently, DOE believes that energy conservation standards above NEMA Premium would result in manufacturers incurring significant conversion costs as they bring their product offerings up to the higher standard.

DOE developed the various conversion costs from data collected during manufacturer interviews that were conducted for the Manufacturer Impact Analysis (MIA). For more information on the MIA, see chapter 12 of the TSD. DOE used the manufacturer supplied data to estimate industry-wide capital conversion costs and product conversion costs for each EL above NEMA Premium. DOE then assumed that manufacturers would markup their motors to recover the total conversion costs over a seven year period. By dividing industry-wide conversion costs by seven years of expected industry-wide revenue, DOE obtained a percentage estimate of how much each motor would be marked up by manufacturers:

- 1 NEMA band above NEMA Premium: $\frac{\$841,468,452}{\$20,404,723,108} = 4.1\%$ (Conversion costs as a percentage of 7 year revenue)
- 2 NEMA bands above NEMA Premium: $\frac{\$1,320,413,562}{\$20,404,723,108} = 6.5\%$ (Conversion costs as a percentage of 7 year revenue)

The percentage markup was then applied to the full production cost (direct material + direct labor + overhead) at the NEMA Premium levels to derive the per unit adder for levels above NEMA Premium (see Table 5-10).

Table 5-10 Conversion Cost Adder for ELs above NEMA Premium.

Representative Unit	Per Unit Adder for 1 Band Above NEMA Premium	Per Unit Adder for 2 Bands Above NEMA Premium
5 HP, Design B	$11.06	$17.36
30 HP, Design B	$32.89	$51.61
75 HP, Design B	$66.18	$103.86
5 HP, Design C	$10.68	$16.75
50 HP, Design C	$60.59	$95.08

5.6 RESULTS OF ENGINEERING ANALYSIS

DOE used the five representative units to develop five manufacturer selling price versus nominal full-load efficiency curves, three for equipment class group 1 (also used for equipment class group 3), and two for equipment class group 2. Figure 5.7 through Figure 5.11 provide the manufacturer selling price versus efficiency curves and Table 5-11 through Table 5-22 present the tabulated results.

5.6.1 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.7 presents the relationship between MSP and nominal full-load efficiency for the 5-horsepower, Design B, 4-pole, enclosed electric motor that was analyzed. Using the tear-down results for ELs 0 to 3, DOE determined that the manufacturer of these electric motors increased the stack length and used various combinations of increasing the stator copper, electrical steel, or rotor conductor, as well as design changes, to improve the electric motor's efficiency.

DOE increased the efficiency level of these representative units and all other representative units by employing a combination of changing the slot fill, increasing stator copper or electrical steel amounts, changing the type or amount of rotor conductor material, and changing specifications of the motor design such as rotor cage geometry or rotor skew. For EL 4, which is the max-tech efficiency level, DOE used a die-cast copper rotor electric motor in lieu of a software modeled design.

Material cost increases, such as low loss electrical steel and increased stator copper, contribute to the relatively large increase in MSP from EL 3 to EL 4. Additionally, DOE observed a hand-wound stator for EL 4 which adds to the relatively large jump in MSP when moving to EL 4. All of the motors torn down and used for ELs 0 through 3 were observed to have machine-wound stators.

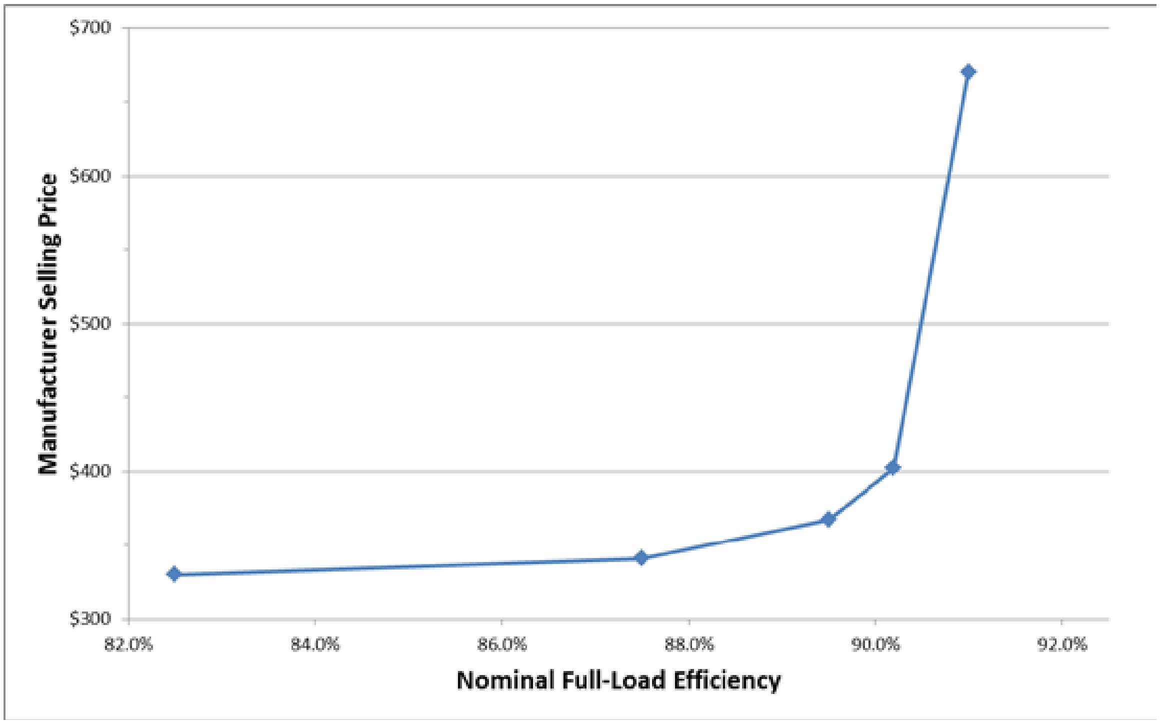

Figure 5.7 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Electric Motor Engineering Analysis Curve

Table 5-11 presents the same engineering analysis results in tabular form, including the nominal full-load efficiency values and the MSPs. From EL 0 through EL 3, MSP increases by amounts varying up to 10 percent. When moving from EL 3 to 4, MSP increases by $260, or about 65 percent, for a loss reduction of roughly 10 percent. The large price increase when moving to EL 4 is largely a result of the use of increased labor hours and die-cast copper conductor in the rotor. At the time of publishing, copper was approximately 3.9 times more expensive than aluminum per pound and is three times denser.

Table 5-11 Efficiency and Manufacturer Selling Price Data for the NEMA Design B, 5-Horsepower Motor

EL	Nominal Full-Load Efficiency (%)	MSP ($)
0	82.5	330
1	87.5	341
2	89.5	367
3	90.2	402
4	91.0	670

Table 5-12 presents some of the design and performance specifications associated with the five 5-horsepower NEMA Design B electric motors presented above including stator copper weight, rotor conductor weight, and electrical steel weight.

Table 5-12 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	EL 0	EL 1	EL 2	EL 3	EL 4
Efficiency	**%**	82.5	87.5	89.5	90.2	91.0
Line Voltage	**V**	460	460	460	460	460
Full Load Speed	**RPM**	1,745	1,745	1,750	1,755	1,770
Full Load Torque	**Nm**	20.3	20.3	20.4	20.3	20.1
Current	**A**	6.9	6.5	6.6	6.2	6.5
Steel	**-**	M56	M47	M47	M47	M15
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	38.7%	51.7%	70.0%	54.4%	53.3%
Stator Wire Gauge	**AWG**	19	19	19	20	20.5
Stator Copper Weight	**lbs**	8.4	10.1	10.1	12.2	13.4
Rotor Conductor Weight	**lbs**	2.63	2.87	2.64	3.42	9.8
Stack Length	**In**	2.8	3.47	5.14	4.65	5.02
Housing Weight	**lbs**	8	15.4	22	20.6	21.4

5.6.2 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.8 presents the relationship between the MSP and nominal full-load efficiency for the 30-horsepower, Design B, 4-pole, enclosed electric motor analyzed. Using tear-down results for ELs 0, 1, 2 and 3, DOE determined that the manufacturer of these motors used a combination of material grade, material quantities, and design changes to increase the electric motor's efficiency.

DOE also used software modeling to develop EL4. For this design DOE used a copper rotor and low-loss electrical steel to achieve efficiencies higher than the purchased electric motors. Using a die-cast copper conductor in the rotor also reduced the stack length of EL 4 compared to the other 30 horsepower ELs analyzed. Shortening the stack length helps lower the cost of this max-tech design. EL 4's primary cost increases arise from an increased labor hour amount based on a hand-wound labor assumption as well as other material quantity increases.

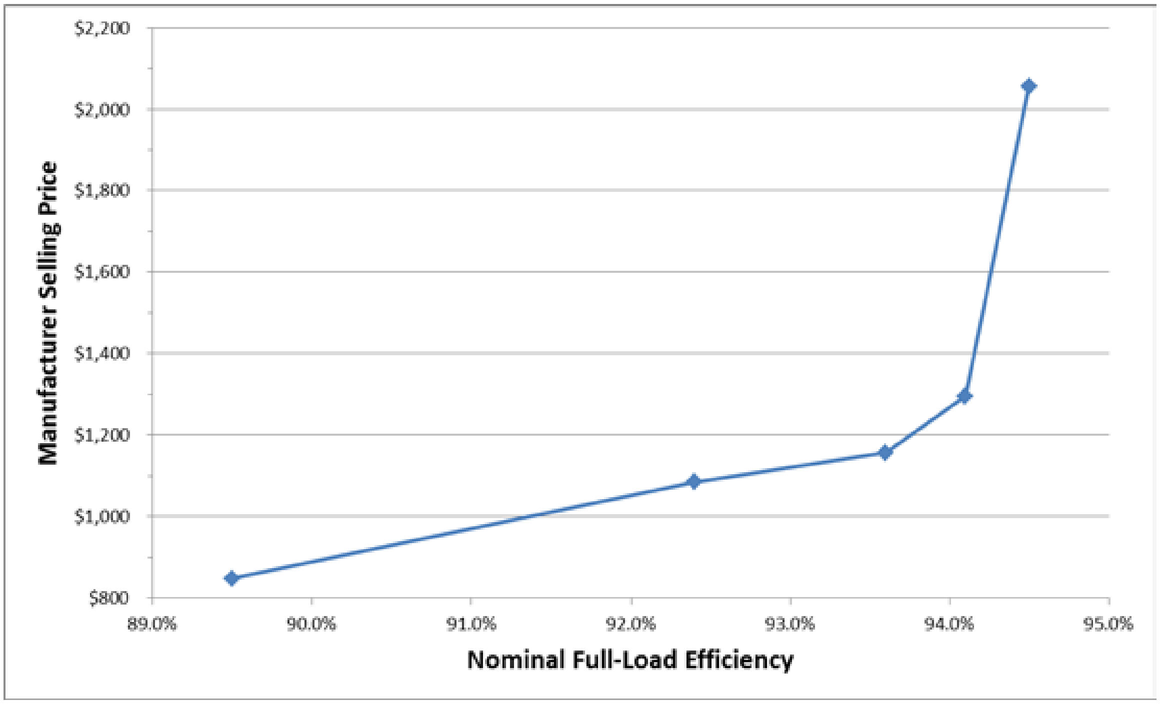

Figure 5.8 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Electric Motor Engineering Analysis Curve

Table 5-13 presents the engineering analysis results in a tabular form, including the full-load efficiency values and the MSPs. From EL 0 to 3, DOE found that the full-load efficiency would increase 4.6 nominal percentage points over the baseline, EL 0, which represents about a 47 percent reduction in electric motor losses. The increase in MSP to move from EL 0 to EL 3 is $435, or about a 51 percent increase in MSP over EL 0. Moving from EL 0 to EL 4 provides a 51 percent reduction in electric motor losses for a MSP increase of $1,169 or about a 138 percent MSP increase over EL 0.

Table 5-13 Efficiency and Manufacturer Selling Price Data for the NEMA Design B, 30-Horsepower Motor

EL	Nominal Full-Load Efficiency (%)	MSP ($)
0	89.5	848
1	92.4	1,085
2	93.6	1,156
3	94.1	1,295
4	94.5	2,056

Table 5-14 presents some of the design and performance specifications associated with the five 30-horsepower designs presented above, including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5-15 shows the NEMA MG 1 Design B performance criteria as well as those design parameters for the software modeled electric motor.

Table 5-14 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	EL 0	EL 1	EL 2	EL 3	EL 4*
Efficiency	**%**	89.5	92.4	93.6	94.1	94.5
Line Voltage	**V**	460	460	460	575	460
Full Load Speed	**RPM**	1,755	1,765	1,770	1,773	1,784
Full Load Torque	**Nm**	121.6	120.9	120.0	120.7	119.6
Current	**A**	37	37	37.5	29.2	37
Steel	**-**	M56	M56/M47	M47	M47	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	47.5	64.8	50.9	70.0	83.2
Stator Wire Gauge	**AWG**	18	17	18	18	18
Stator Copper Weight	**lbs**	20.2	43.5	49.4	47.4	74.5
Rotor Conductor Weight	**lbs**	8.25	9.5	16.84	13.66	42.6
Stack Length	**In**	7.88	5.53	8.02	6.74	7.00
Housing Weight	**lbs**	21	121	28.3	147	153

* Software modeled motor

Table 5-15 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design B Limit	EL 4
Efficiency	%	-	94.5
Breakdown Torque	% of full-load	200 (min.)	202
Pull-up Torque	% of full-load	105 (min.)	139
Locked Rotor Torque	% of full-load	150 (min.)	154
Locked Rotor Current	A	217.5(max.)	208

5.6.3 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.9 presents the relationship between the MSP and nominal full-load efficiency for the 75-horsepower, Design B, 4-pole enclosed electric motor analyzed. Using tear-down results for ELs 0 through 3, DOE determined that the manufacturer of these electric motors increased the stack length and other material amounts to increase the electric motor’s efficiency levels from 93.0 percent to 95.8 percent. The torn-down electric motor representing EL 3 used increased rotor aluminum and stator copper as well as an increased stack length to achieve 95.8 percent efficiency.

DOE used software modeling to develop the max-tech efficiency level, EL 4. For this design, DOE used a die-cast copper conductor in the rotor and low-loss electrical steel in the rotor and stator to achieve efficiencies higher than commercially available electric motors. The assumption of manual-labor hour amounts and the use of die-cast copper conductors in EL 4’s rotor accounts for the larger-than-typical price increase between EL 3 and EL 4 for the 75-horsepower Design B representative unit.

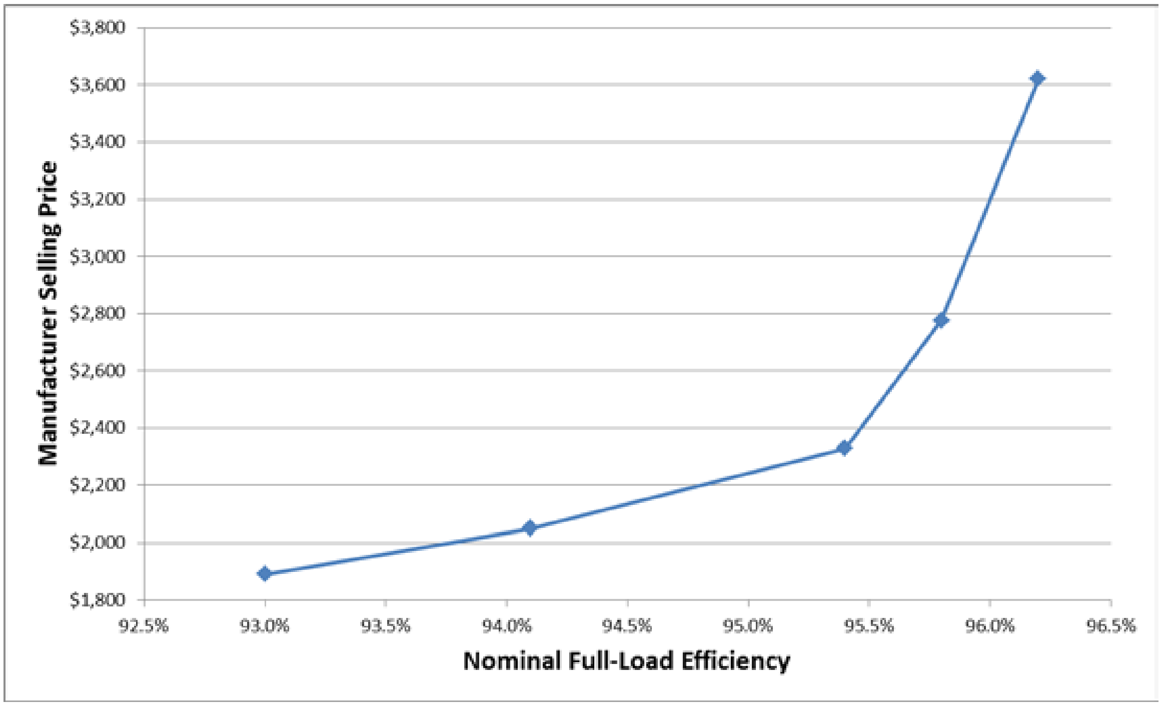

Figure 5.9 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Motor Engineering Analysis Curve

Table 5-16 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from EL 0 to EL 3, DOE found that the full-load efficiency would increase 2.4 nominal percentage points over the baseline, EL 0, which represents about a 42 percent reduction in electric motor losses. The increase in MSP to move from EL 0 to EL 3 is about $860 or about a 45 percent increase in MSP over EL 0. Moving from EL 0 to the max-tech efficiency level of EL 4 provides a 48 percent reduction in electric motor losses for a MSP increase of $1,520, which constitutes an 87 percent MSP increase over the EL 0 electric motor.

Table 5-16 Efficiency and Manufacturer Selling Price Data for the NEMA Design B, 75-Horsepower Motor

EL	Nominal Full-Load Efficiency (%)	MSP ($)
0	93.0	1,891
1	94.1	2,048
2	95.4	2,327
3	95.8	2,776
4	96.2	3,620

Table 5-17 presents some of the design and performance specifications associated with the five 75-horsepower designs presented above, including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5-18 shows the NEMA MG 1 Design B performance criteria as well as those design parameters for the software modeled electric motor.

Table 5-17 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	EL 0	EL 1	EL 2	EL 3	EL 4*
Efficiency	**%**	93.0	94.1	95.4	95.8	96.2
Line Voltage	**V**	460	460	460	460	460
Full Load Speed	**RPM**	1,775	1,785	1,775	1,785	1,788
Full Load Torque	**Nm**	300.6	299.6	299.6	299.6	299.6
Current	**A**	88	91.5	85	85.5	89.8
Steel	**-**	M56	M47	M27	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	50.9	35.0	70.0	70.0	85.1
Stator Wire Gauge	**AWG**	17	12	15	16	14
Stator Copper Weight	**lbs**	77.8	71	82	136	127
Rotor Conductor Weight	**lbs**	30.9	20.7	27.3	38.5	78.9
Stack Length	**In**	8.15	10.23	10.58	11.33	12.00
Housing Weight	**lbs**	127	79	168	180	190

* Software modeled motor

Table 5-18 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design B Limit	EL 4
Efficiency	%	-	96.2
Breakdown Torque	% of full-load	200 (min.)	218.2
Pull-up Torque	% of full-load	100 (min.)	135
Locked Rotor Torque	% of full-load	140 (min.)	163.8
Locked Rotor Current	A	542.5(max.)	530.7

5.6.4 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.10 presents the relationship between the MSP and nominal full-load efficiency for the 5-horsepower, NEMA Design C, 4-pole, enclosed electric motor analyzed. DOE purchased only one 5-horsepower NEMA Design C electric motor for its tear-down analysis. The remaining two ELs were based on software modeled electric motors. Therefore, discussion of the NEMA Design C revolves around the design changes DOE's software modeling expert chose to implement to increase the efficiency levels of the electric motors.

DOE achieved the EL 1 efficiency level by using a lower loss grade of electrical steel and increasing the slot fill higher than that of the EL 0 electric motor. The EL 1 electric motor also boasts a smaller stack length than the EL 0 electric motor. DOE achieved the max-tech efficiency level of the EL 2 motor design by switching to a die-cast copper rotor and increasing the stack length to the maximum stack length calculated via the methodology described in section 5.4.2. This increased the amount of electrical steel and stator copper material by 25 and 29 percent, respectively.

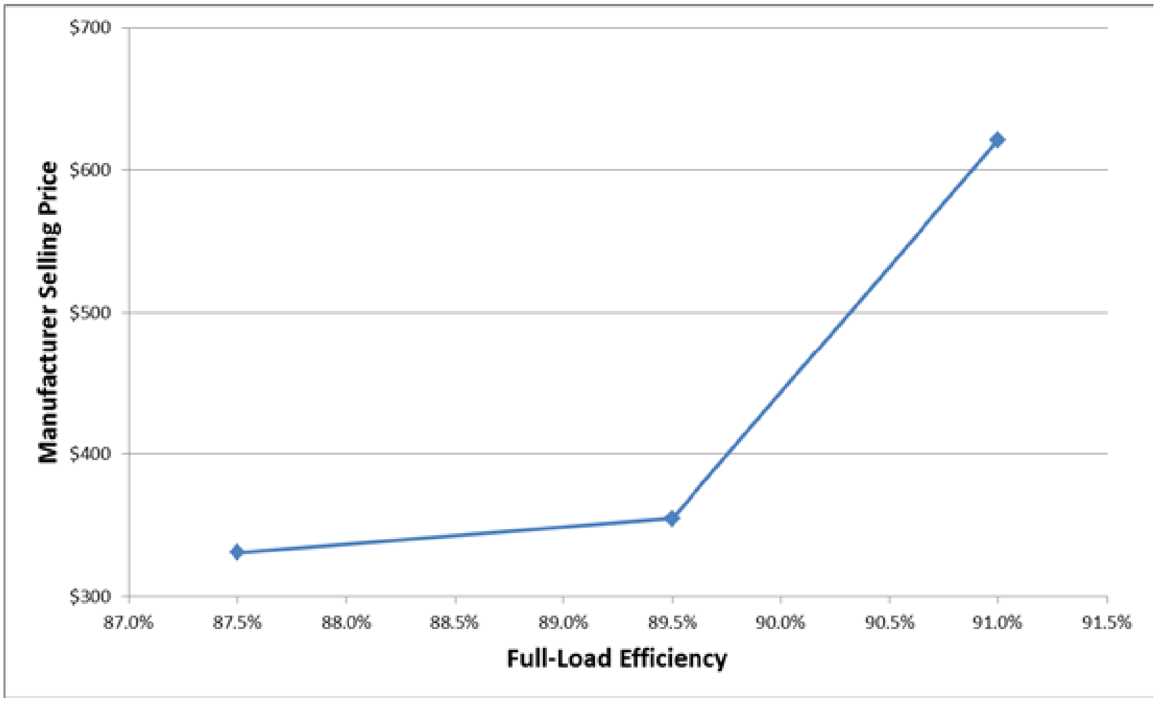

Figure 5.10 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Motor Engineering Analysis Curve

Table 5-19 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from EL 0 to EL 2, DOE found that the full-load nominal efficiency would increase 3.5 percentage points over the baseline, EL 0, which represents a 31 percent reduction in electric motor losses. The increase in MSP to move from EL 0 to EL 2 is $278, or about an 84 percent increase in MSP over EL 0.

Table 5-19 Efficiency and Manufacturer Selling Price Data for the NEMA Design C, 5-Horsepower Motor

EL	Nominal Full-Load Efficiency (%)	MSP ($)
0	87.5	331
1	89.5	355
2	91.0	621

Table 5-20 presents some of the design and performance specifications associated with the three NEMA Design C, 5-horsepower electric motors presented above. The table includes stator copper weight, rotor conductor weight, and electrical steel weight. Table 5-21 shows the NEMA MG 1 Design C performance requirements as well as the resulting design parameters for the two software modeled electric motors.

Table 5-20 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	EL 0	EL 1	EL 2
Efficiency	**%**	87.5	89.5	91.0
Line Voltage	**V**	460	460	460
Full Load Speed	**RPM**	1,750	1,762	1,776
Full Load Torque	**Nm**	20.3	20.2	20.1
Current	**A**	7.1	8.4	6.5
Steel	**-**	M47	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	53.3	79.9	82.9
Stator Wire Gauge	**AWG**	18	18	18
Stator Copper Weight	**lbs**	10	9.9	12.8
Rotor Conductor Weight	**lbs**	2.2	2.0	7.8
Stack Length	**in**	4.75	4.25	5.32
Frame Weight	**lbs**	12	11	14

Table 5-21 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design C Limit	EL 1	EL 2
Efficiency	%	-	89.5	91.0
Breakdown Torque	% of full-load	200 (min.)	293	260.8
Pull-up Torque	% of full-load	180 (min.)	283.9	260.8
Locked Rotor Torque	% of full-load	255 (min.)	344.1	260.8
Locked Rotor Current	A	46 (max.)	38.5	41.7

5.6.5 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.11 presents the relationship between the MSP and nominal full-load efficiency for the 50-horsepower, NEMA Design C, 4-pole, enclosed electric motor analyzed. DOE purchased only one NEMA Design C electric motor for its tear-down analysis. The remaining two ELs were based on software-modeled electric motors. Therefore, discussion of the NEMA Design C revolves around the design changes DOE's software modeling expert chose to implement to increase the efficiency levels of the electric motors.

DOE achieved the EL 1 efficiency level by using a higher slot fill, higher grade electrical steel and the maximum-calculated stack length found by using the method discussed in section 5.4.2. DOE then increased the efficiency level to EL 2 by switching to a die-cast copper rotor and using a higher grade electrical steel.

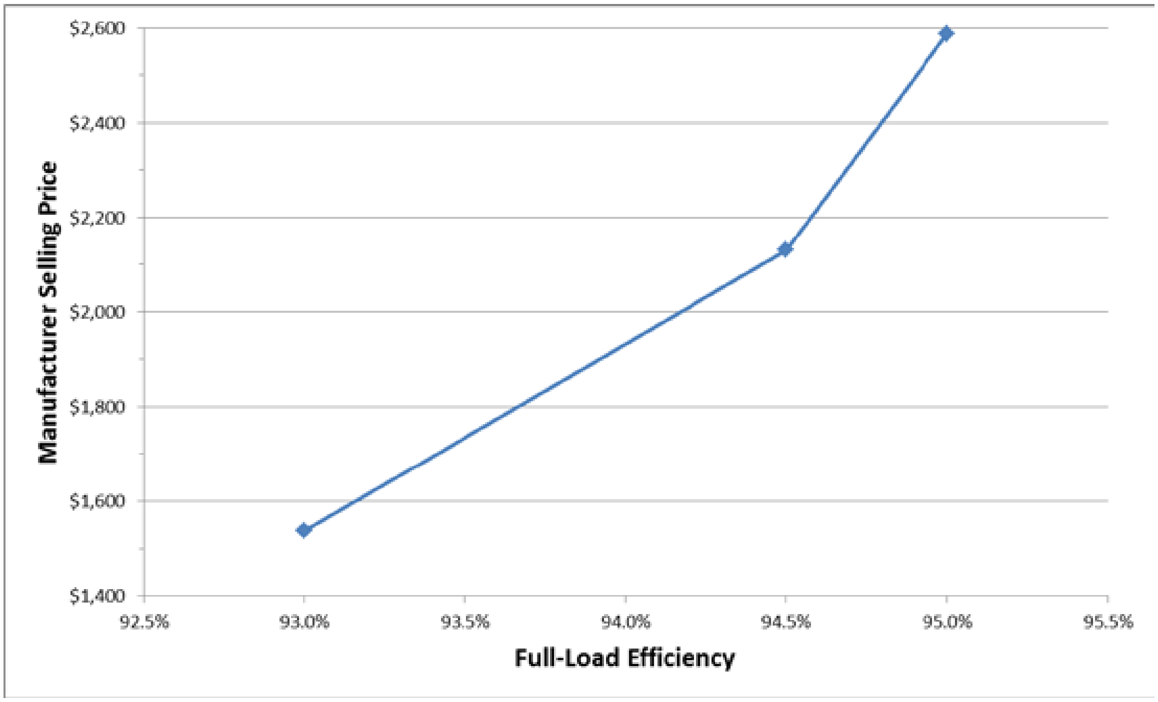

Figure 5.11 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Motor Engineering Analysis Curve

Table 5-22 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from the EL 0 to EL 2, DOE found that the nominal full-load efficiency would increase 2.0 nominal percentage points over the baseline, EL 0, which represents about a 30 percent reduction in electric motor losses. The increase in MSP to move from EL 0 to EL 2 is $976, or about a 64 percent increase in MSP over EL 0.

Table 5-22 Efficiency and Manufacturer Selling Price Data for the NEMA Design C, 50-Horsepower Motor

EL	Nominal Full-Load Efficiency (%)	MSP ($)
0	93.0	1,537
1	94.5	2,130
2	95.0	2,586

Table 5-23 presents some of the design and performance specifications associated with the three NEMA Design C, 50-horsepower electric motor designs presented above including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5-24 shows the NEMA MG 1 Design C performance requirements as well as the resulting design parameters for the software modeled electric motors.

Table 5-23 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	EL 0	EL 1	EL 2
Efficiency	**%**	93.0	94.5	95.0
Line Voltage	**V**	460	460	460
Full Load Speed	**RPM**	1,770	1,775	1,782
Full Load Torque	**Nm**	200.7	200.6	199.8
Current	**A**	59	63.8	61.3
Steel	**-**	M47	M36	M19
Rotor Conductor Material	**-**	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	62.5	85.3	81.3
Stator Wire Gauge	**AWG**	17	17	17
Stator Copper Weight	**lbs**	66	90	85
Rotor Conductor Weight	**lbs**	16.5	13.5	36.6
Stack Length	**In**	8.67	9.55	9.55
Frame Weight	**lbs**	125	138	138

Table 5-24 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design C Limit	EL 1	EL 2
Efficiency	%	-	94.5	95.0
Breakdown Torque	% of full-load	190 (min.)	193.5	233.5
Pull-up Torque	% of full-load	150 (min.)	165.1	202.9
Locked Rotor Torque	% of full-load	200 (min.)	258.6	202.9
Locked Rotor Current	A	362.5 (max.)	356.2	359.6

5.7 SCALING METHODOLOGY

Due to the large number of equipment classes, DOE was not able to perform a detailed engineering analysis on each one. Instead, DOE focused its analysis on three NEMA Design B equipment classes and two NEMA Design C equipment classes. From these results, DOE scaled to other equipment classes not directly analyzed in the engineering analysis. DOE considered two methods of scaling, one based on the incremental improvement of motors losses and one that develops a set of power law equations based on the relationships found in the NEMA "Energy Efficient" and NEMA "Premium Efficient"[i] tables of efficiency. Ultimately, DOE did not find a large discrepancy between the two methods and elected to use the, simpler, incremental improvement of motor losses approach.

5.7.1 Scaling Approach Using Incremental Improvements of Motor Losses

Scaling electric motor efficiencies is a complicated proposition that has the potential to result in efficiency standards that are not evenly stringent across all equipment classes. Among DOE's four ECGs, there are several hundred combinations of horsepower rating, pole

[i] NEMA MG 1-2011 specifies that motors classified as "energy efficient" shall meet or exceed the efficiency values listed in Table 12-11 (or Table 20-A for certain larger horsepower ratings). Motors classified as "premium efficiency" shall meet or exceed the efficiency values listed in Table 12-12 (or Table 20-B for certain larger horsepower ratings).

configuration, and enclosure. Within these combinations there is a large number of standardized frame number series. Given this sizable number of frame number series, DOE cannot feasibly analyze all of these variants — hence, the need for scaling. Scaling across horsepower ratings, pole configurations, enclosures, and frame number series is a necessity. For DOE's first approach to scaling, it relied on a relatively simple method of analyzing the motor losses of each of its representative units from EL to EL and applying those same losses to various segments of the market.

As discussed previously, DOE based the first four of its ELs for ECG 1 on torn-down motors. As these motors were marketed and sold with NEMA nominal efficiencies, DOE used those values to denote each of those ELs. Consequently, the efficiency levels that DOE scaled to for the non-representative units were also selected from the NEMA nominal efficiency levels. DOE also used the NEMA nominal efficiency values for the ELs that were achieved for the representative units using software modeling.

For EL 1 and EL 2, DOE had to do minimal scaling. EL 1 is based on NEMA MG 1-2011 Tables 12-11 and 20-A, which were left unchanged for all electric motors. However, Table 12-11 does not specify an efficiency level for 1 horsepower, 2 pole, open motors. DOE scaled the missing value by using the same efficiency level as that of 1 horsepower, 2 pole, enclosed motors. By observing that 1 horsepower, 2 pole, both open and enclosed motors had the same Table 12-12 efficiency levels, DOE inferred that a 1 horsepower, 2 pole, open configuration could also meet the Table 12-11 efficiency level of its enclosed counterpart.

EL 2 is based on NEMA MG 1-2011 Tables 12-12 and 20-B, which specify the nominal efficiencies of electric motors that NEMA classifies as "Premium Efficiency." The 2011 version of NEMA MG 1 omits NEMA Premium efficiency levels for 6-pole motors at 300- and 350-horsepower, leaving a gap in the NEMA Premium efficiency tables where there was no gap in the 2009 version of NEMA MG 1. To keep EL 2 continuous from 1- to 500-horsepower, DOE scaled the missing values from then next closest horsepower ratings (250- and 400-horsepower). Conveniently, the NEMA Premium efficiency levels for 6-pole motors at 250- and 400-horsepower are equivalent, so DOE assumed that 6-pole motors at 300- and 350-horsepower are also at the same efficiency level (i.e., 250-, 300-, 350-, and 400-horsepower all have the same efficiency).

For the higher ELs, namely 3 and 4, DOE's conservation of motor losses approach relies on NEMA MG 1-2011's table of nominal efficiencies and the relative improvement in motor losses of the representative units. As has been discussed, each incremental improvement in NEMA nominal efficiency (or NEMA band) corresponds to roughly a 10 percent reduction in motor losses. After ELs 3 and 4 were developed for each representative unit, DOE applied the same reduction in motor losses (or the same number of NEMA band improvements) to various segments of the market based on the representative units. DOE assigned a segment of the electric motors market, based on horsepower ratings, to each representative unit analyzed. DOE's assignments of these segments of the markets were in part based on the standardized NEMA frame number series that NEMA MG 1 assigns to horsepower and pole configuration combinations. That segmentation of the market is shown in Figure 5.12.

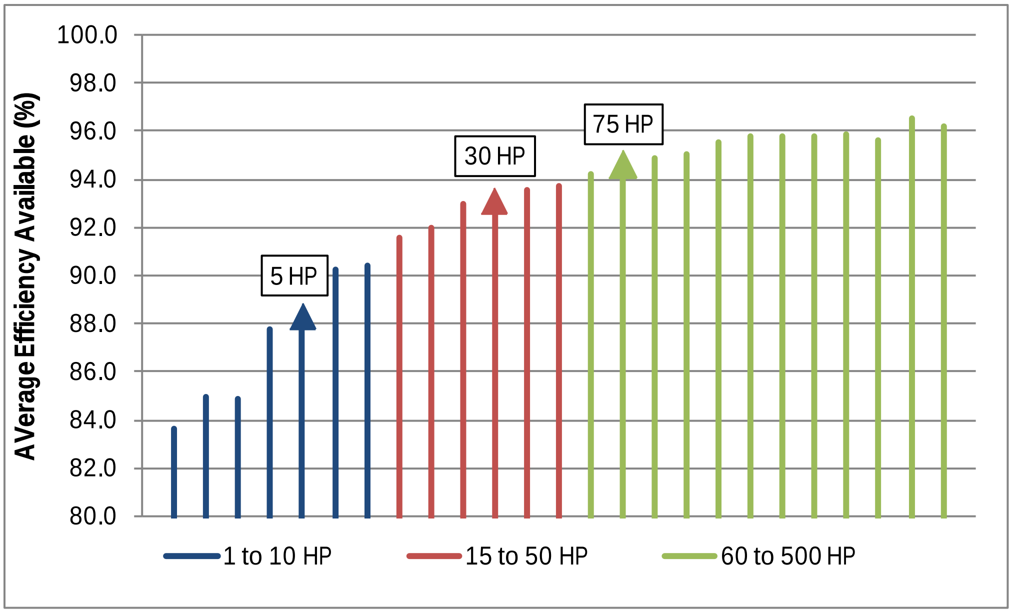

Figure 5.12 Segmentation of Electric Motor Market for Representative Units

The first section, shaded blue in Figure 5.12, consists of smaller frame electric motors whose efficiencies increase at a quicker rate than larger frame electric motors. A 5-horsepower electric motor was selected to represent the electric motors on this section of the graph based on high shipment volume and the fact that this electric motor's efficiency is in middle of this steep section of the graph. The electric motors whose analysis is based on the 5-horsepower electric motor are electric motors between 1-horsepower and 10-horsepower.

DOE then analyzed the mid-section of the graph, or electric motors whose efficiencies do not change as drastically as the blue-shaded region and determined that a 30-horsepower electric motor falls in the middle of this region of the graph. Consequently, DOE selected the 30-horsepower rating to analyze for the red shaded region of the graph, which represents electric motors from 15-horsepower to 50-horsepower.

For the third section, DOE observed the electric motor efficiencies exhibited a fairly "flat" characteristic as frame sizes increase beyond 60-horsepower. DOE selected a 75-horsepower electric motor to represent the electric motors on the final part of the graph because it was large enough to represent electric motors in this horsepower range yet small enough to facilitate various aspects of the engineering analysis, such as physical teardowns of the electric motor. The 75-horsepower electric motor represents electric motors on the large end of the scope of coverage, from 60-horsepower to 500-horsepower.

In the end, for ECG 1, each EL above EL 2 was one NEMA band above the previous EL for each representative unit — i.e., EL 3 exceeded Table 12-12 by one band, and EL 4 by two. The following bulleted line items summarize each EL for ECG 1:

- EL 0: Lowest-in-scope efficiencies for all equipment classes
- EL 1: NEMA MG 1-2011 Tables 12-11 and 20-A for all equipment classes
- EL 2: NEMA MG 1-2011 Tables 12-12 and 20-B for all equipment classes

- EL 3: One NEMA band above EL 1 for all equipment classes
- EL 4: One NEMA band above EL 2 for all equipment classes

The scaling results for ECG 2 were slightly different. As discussed, there is limited equipment selection of NEMA Design C motors, and EL 0 was the only EL based on tear-down results. Consequently, ELs 1 through 2 were modeled using a computer software program. Relative to the baseline EL (NEMA MG 1 Table 12-11) DOE was able to achieve a max-tech efficiency level that corresponded to an improvement of four NEMA bands for both representative units. Each incremental EL above EL 1 corresponded to a one NEMA band improvement, totaling four NEMA bands of improvement relative to the baseline at EL 2. The following bullets summarize each EL for ECG 2.

- EL 0: NEMA MG 1-2011 Table 12-11 for all equipment classes
- EL 1: NEMA MG 1-2011 Table 12-12 for all equipment classes
- EL 2: One NEMA band above EL 1 for all equipment classes

5.7.2 Scaling Approach Using Regression Equations

DOE developed a second approach for scaling to EL 3 and EL 4 which relied on regression equations to predict electric motor losses. The first step DOE took in this approach was to create a model that describes electric motor losses as a function of the electric motor's rated horsepower. To do this, DOE examined the standards adopted by EISA 2007. For polyphase general-purpose electric motors built in a three digit frame size EISA adopted the NEMA Premium Standards, shown in NEMA MG 1-2006 in Table 12-12, as the minimum efficiency levels. This table has standards for electric motors ranging in horsepower from 1 to 200-horsepower, in two-, four-, and six-pole configurations, and in open and enclosed constructions. DOE plotted this data to observe any trends:

- Electric motor losses (calculated as $\frac{1}{efficiency} - 1$) versus horsepower

When plotted on logarithmic scales, DOE observed that as horsepower increased, electric motor losses decreased following a power law function, as shown in Figure 5.13. That is:

- $MotorLosses(HP) = a \times HP^{-b}$, where *a* and *b* vary by pole configuration and electric motor category combination.

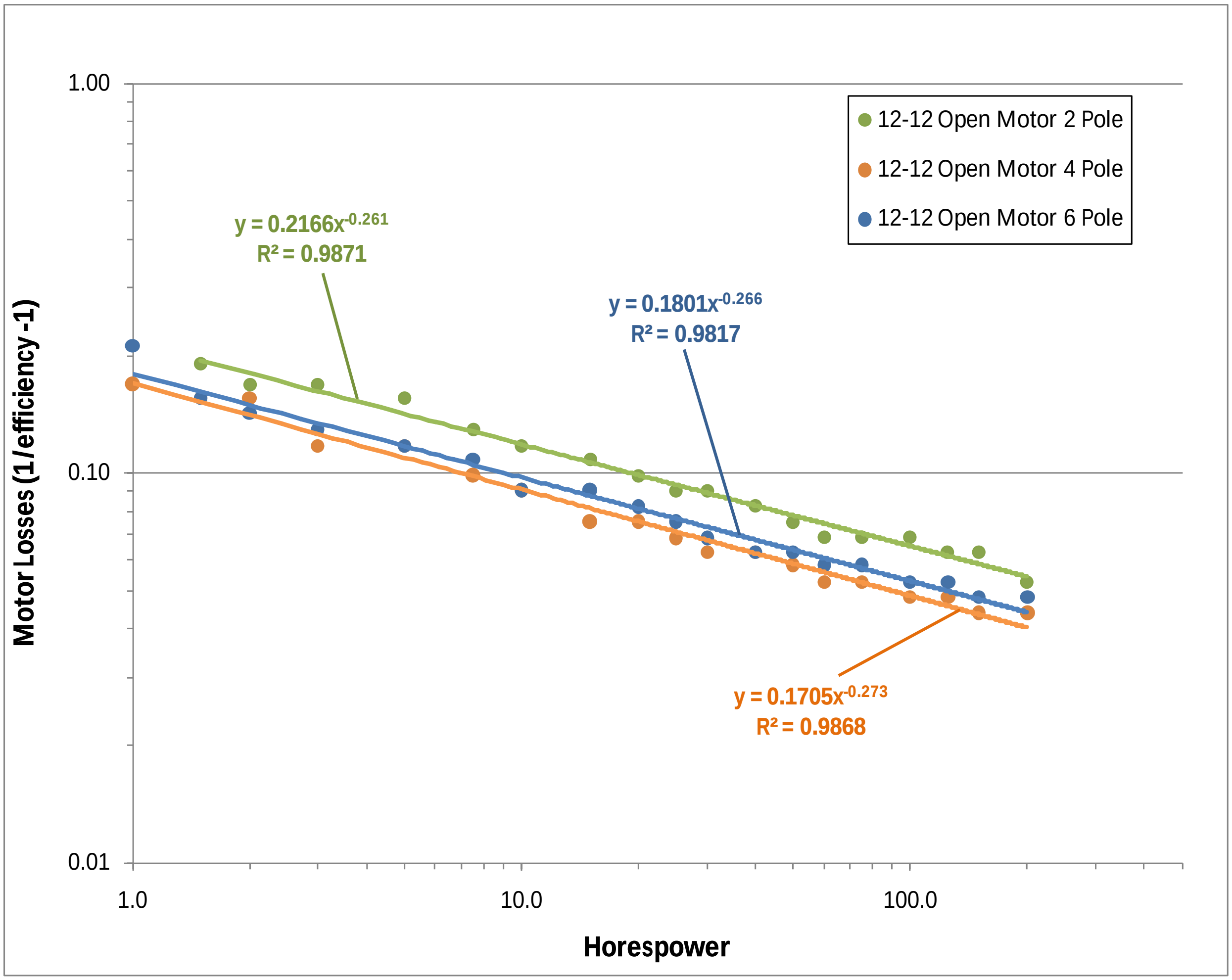

Figure 5.13 NEMA Premium Motor Losses versus Horsepower Rating

As mentioned in section 5.3, for ECG 1 EL 3 represents a best-in-market efficiency level, and EL 4 represents the maximum technology efficiency level. For the representative units, the efficiency levels at EL 3 and EL 4 were already known, either through purchased electric motors or software modeling. Therefore, DOE scaled the ELs from the representative units to the equipment classes that were not analyzed. This was done by using the power law function observed in Figure 5.13. Since DOE directly analyzed three horsepower ratings (5-horsepower, 30-horsepower and 75-horsepower), the electric motor losses continuum was split up into three ranges: 1- to 10-horsepower, 15- to 50-horsepower, and 60- to 500-horsepower (as shown in Figure 5.12). A power law function was derived for EL 1 and EL 2 for each range in the representative ECGs as shown in Figure 5.14.

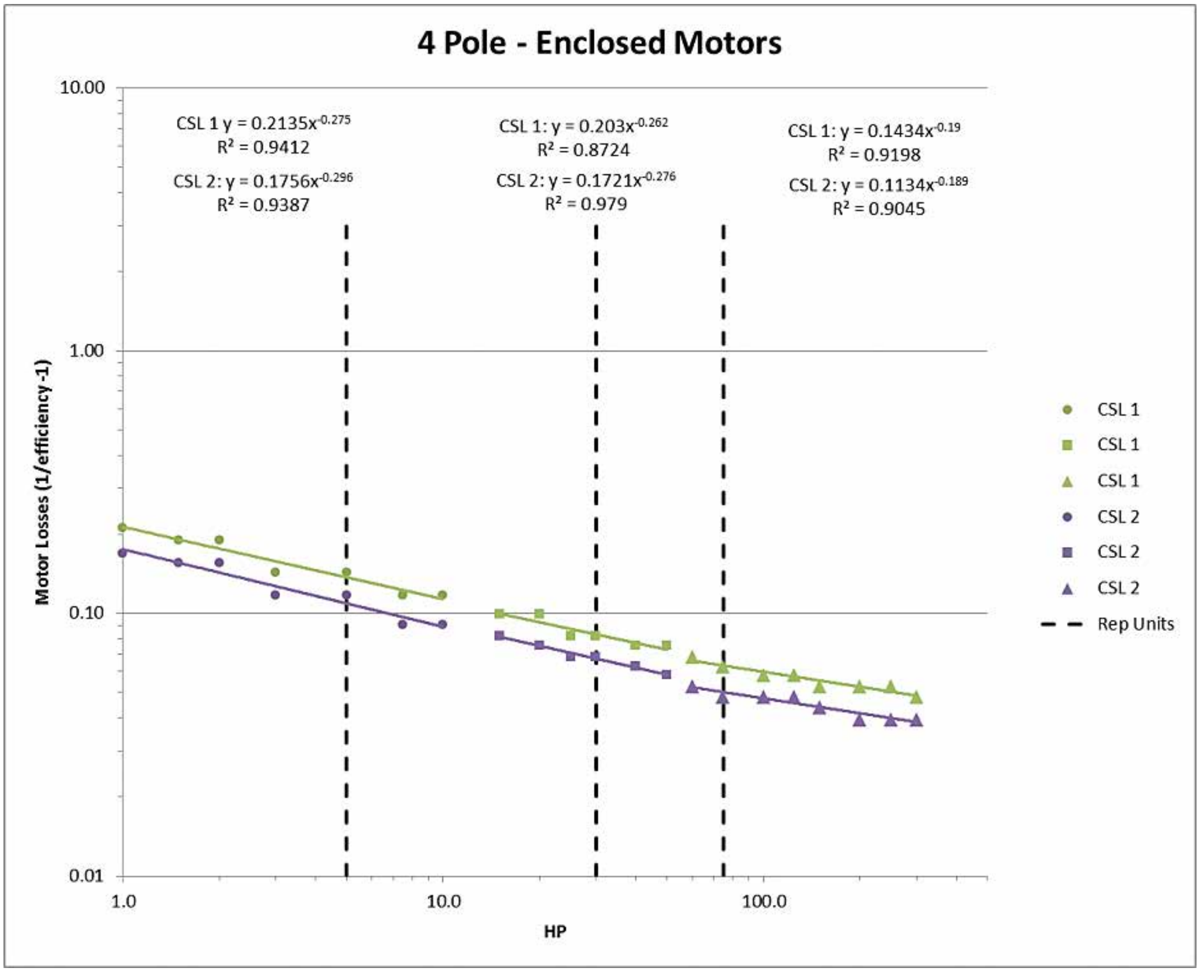

Figure 5.14 Function of Electric Motor Losses with Horsepower for 4-Pole, Enclosed Electric Motors

For each range, the exponents of EL 1 and EL 2 were averaged to derive the following three power law equations:

$$MotorLosses(HP) = a' \; HP^{-.286} \textit{ for 1 horsepower to 10-horsepower}$$

$$MotorLosses(HP) = a' \; HP^{-.269} \textit{ for 15-horsepower to 50-horsepower}$$

$$MotorLosses(HP) = a' \; HP^{-.190} \textit{ for 60-horsepower and greater}$$

where '*a*' is a constant that that differs for EL 3 and EL 4. As previously mentioned, the efficiency values for EL 3 and EL 4 are known at 5-horsepower, 30-horsepower and 75-horsepower as they are the efficiency levels of the representative equipment classes. The value of '*a*' for EL 3 and EL 4 can be solved for using these known efficiency values. With the constants and exponents derived for the EL 3 and EL 4 power functions, the equations can be used to derive the EL 3 and EL 4 efficiency levels for the horsepower ratings not analyzed. The results of this calculation are shown in Figure 5.15.

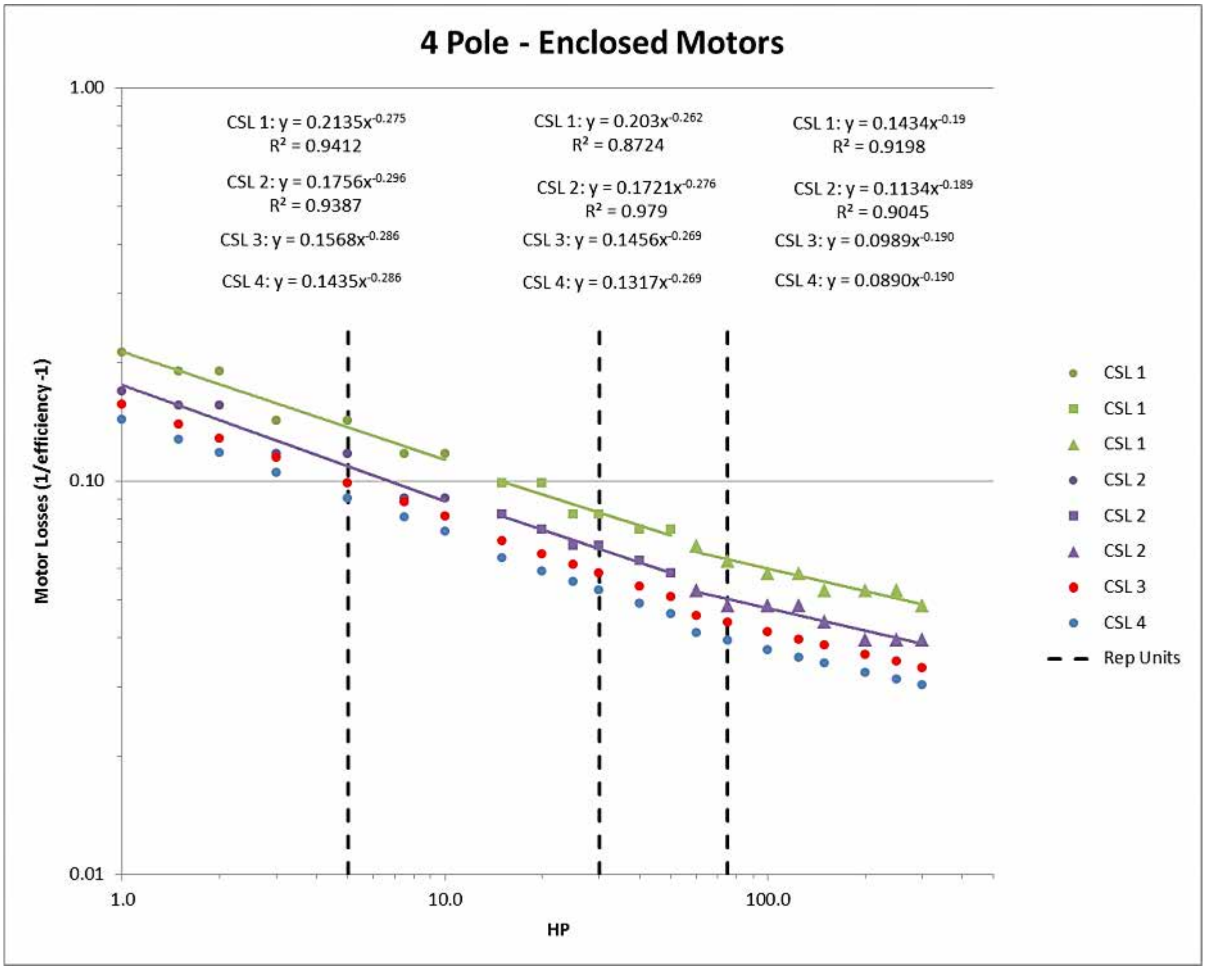

Figure 5.15 Function of Electric Motor Losses with Horsepower Derived for EL 2 and EL 3 for 4-Pole, Enclosed Electric Motors of NEMA Design A & B

With EL 3 and EL 4 determined for the 4-pole enclosed electric motors, DOE then had to scale these ELs to the other electric motor pole configurations and enclosures. To do this, DOE compared the efficiencies, at a given horsepower rating, of the 4-pole enclosed motors with the efficiencies of other pole configurations and enclosures at the Table 12-12 levels. The ratio of those efficiencies was multiplied by the scaled efficiency (at EL 3 or 4) of the 4-pole enclosed electric motor efficiency. The resulting product was a scaled efficiency, at a given horsepower rating, of the equipment class not analyzed. To do this, DOE had to assume that the ratio of efficiencies of different equipment classes at EL 2 stayed constant for EL 3 and EL 4. The following equation was used to derive the scaled efficiencies:

$$Efficiency(hp) = \frac{Efficiency_{NP}(hp)}{Efficiency_{NP4E}(hp)} Efficiency_{4E}(hp)$$

where

- *Efficiency*- is the resulting scaled efficiency of the desired equipment class at the new EL (3, 4, or 5).
- $Efficiency_{NP}$-is the NEMA Premium efficiency of the desired equipment class.
- $Efficiency_{NP4E}$-is the NEMA Premium efficiency of a 4-pole enclosed electric motor.
- $Efficiency_{4E}$- is the scaled efficiency of a 4-pole enclosed electric motor at the EL being scaled to (3, 4, or 5).

HP	Enclosed Frame									
	4 Pole					6 Pole				
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4
7.5	84.0	89.5	91.7	92.4	93.0	82.5	89.5	91.0		
10	86.5	89.5	91.7	92.4	93.0	84.0	89.5	91.0		Result
15	86.5	91.0	92.4	93.0	94.1	88.5	90.2	91.7	92.3	
20	87.5	91.0	93.0	93.6	94.1	87.5	90.2	91.7		
25	89.5	92.4	93.6	94.1	94.5	91.7	91.7	93.0		

Efficiency derived from power law equation

Unknown efficiency

Figure 5.16 Scaling Across Electric Motor Configurations

For example, in order to calculate the efficiency of a 15-horsepower, 6-pole, enclosed electric motor at EL 3, see the equation below along with Figure 5.16.

$$Efficiency(15) = \frac{Efficiency_{NP}(15)}{Efficiency_{NP4E}(15)} Efficiency_{4E}(15) = \frac{91.7}{92.4} \times 93.0 = 92.3$$

As shown above, this method results in an efficiency level of 92.3 percent for a 6-pole NEMA Design A or B electric motor of enclosed construction. However, 92.3 percent falls just short of the NEMA nominal efficiency (see NEMA MG 1-2011 Table 12-10) of 92.4 percent. Therefore, it would have to be “rounded” down to the closest NEMA nominal efficiency level which in this case is 91.7 percent. By having to convert the calculated scaled efficiency levels to NEMA nominal efficiency levels, DOE observed that some of the efficiency levels that were scaled were the same efficiency as the lower EL. For instance, in the example above EL 2 and EL 3 would be equal to each other at 15-horsepower since the 92.3 percent efficiency would have to be rounded down to the closest NEMA nominal efficiency level. As a result, DOE elected not to use this as the primary methodology for scaling the efficiency levels of its representative units.

CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

This chapter of the technical support document (TSD) presents the U.S. Department of Energy's (DOE's) method for deriving electric motor prices. The objective of the equipment price determination is to estimate the price paid by the customer or purchaser for an installed electric motor. Purchase price and installation cost are necessary inputs to the life-cycle cost (LCC) and payback period (PBP) analyses. Chapter 8 presents the LCC calculations; section 8.2.1 describes how the LCC uses purchase price and installation cost as inputs.

Purchase prices for electric motors are not generally known. Electric motors are often sold as part of a project, sometimes custom-built with unlisted prices. The engineering analysis (chapter 5) provides the manufacturer selling prices (MSPs) for the representative units included in the LCC analysis. DOE derived a set of prices, for each electric motor representative unit produced by the engineering analysis, by applying markups to the manufacturer selling price in the form of markup equations.

6.1.1 Distribution Channels

The appropriate markups for determining the end-user equipment price depend on the type of distribution channels through which equipment moves from manufacturers to purchasers. At each point in the distribution channel, companies mark up the price of the equipment to cover their business costs and profit margin.

Distribution channels vary depending on the size of the electric motor. Because smaller electric motors used as components in larger pieces of equipment constitute the majority of the market, much of the market passes through original equipment manufacturers (OEMs) who design, assemble, and brand equipment that contains electric motors. OEMs in turn obtain their motors either directly from the motor manufacturers or from manufacturers via distributors. For motors with larger horsepowers (more than 50 horsepower), direct sales to the end-user and sales to contractors become more significant.

Based on market research[1] and input from interested parties, DOE identified six main distribution channels for electric motors and estimated their respective shares of shipments per electric motor horsepower range. The six channels are from the manufacturer to:

(1) OEMs and then to end-users (50 percent of sales);
(2) distributors to end-users (24 percent of sales);
(3) distributors to OEM and then to end-users (23 percent of sales);
(4) contractors and then to end-users (less than one percent of sales);
(5) distributors to end-users through contractors (less than one percent of sales); and
(6) end-users (less than two percent of sales).

Other distribution channels exist (*e.g.*, from manufacturer to OEMs to end-users through distributors) but are estimated to account for a minor share of motor sales (less than one percent).

In addition to these distribution chain markups, DOE estimated the shipping costs of the motors and added these to the end-user equipment prices. These costs are a significant factor, because more-efficient motors are often larger and heavier than less efficient motors, so this is a cost that needs to be included in an accurate cost analysis.

6.2 MARKUP CALCULATION METHODOLOGY

As addressed previously, at each point in the distribution channel, companies mark up the price of the equipment to cover their business costs and profit margins. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (CGS). Inputs for calculating the gross margin are all corporate costs, including: overhead costs (sales, general, and administration), research and development (R&D), interest expenses, depreciation, taxes, and profits. For sales of equipment to contribute positively to company cash flow, the markup of the equipment must be greater than the corporate gross margin. Individual pieces of equipment may command a lower or higher markup, depending on their perceived added value and the competition they face from similar equipment in the market.

In developing markups for OEMs and distributors, DOE obtained data about the revenue, CGS, and expenses of firms that produce and sell the equipment of interest. DOE determined that markups are neither fixed-dollar nor proportional to all direct costs, which means that the selling price of a piece of equipment may not be strictly proportional to the purchase price of the equipment. Using the available data, DOE has found measurable differences between incremental markups on direct equipment costs and the average aggregate markup on direct business costs. Additionally, DOE discovered significant differences between average and incremental markups for electric motor OEMs and distributors. Section 6.3 and Section 6.4 further discusses the differences between average and incremental markups.

The main reason that the selling price of a piece of equipment may not be strictly proportional to the purchase price of the equipment is that businesses incur a wide variety of costs. When the purchase price of equipment and materials increases, only a fraction of the business expenses increases, while the remainder of the business expenses stays relatively constant. For example, if the unit price of an electric motor increases by 30 percent, it is unlikely that the cost of secretarial support in an administrative office will increase by 30 percent also. Certain business expenses are uncorrelated with the cost of equipment or cost of goods.

DOE's approach categorizes the expenses into two categories: invariant costs (IVC), which are those costs that are not expected to vary in proportion to the change in manufacturer selling price, and variant costs (VC), which are the costs that scale with the change in manufacturer selling price. Together, IVC and VC represent the gross margin.

For each step in equipment distribution, DOE estimated both a baseline markup and an incremental markup. For electric motors, DOE understands that no increase in distribution labor is necessary for the distribution of more-efficient equipment, while the non-labor-scaling cost does increase with increasing equipment costs. This allowed DOE to estimate the incremental markup given a breakdown of distribution and manufacturing business expenses for a particular industry.

6.2.1 Assumptions

DOE derived the OEM and motor distributor markups from three key assumptions about the costs associated with motor-related industrial series. DOE used the financial data from the 2007 U.S. Economic Census's manufacturing industrial series and 2007 Business Expenses Survey to determine OEM and motor distributor markups, respectively. These income statements break down the components of all costs incurred by firms that assemble and distribute electric motors. The key assumptions used to estimate markups using these financial data are:

1. The firm income statements faithfully represent the various average costs incurred by firms designing, assembling, and distributing electric motors.

2. These costs can be divided into two categories: (1) costs that vary in proportion to the MSP of electric motors (variant costs); and (2) costs that do not vary with the MSP of electric motors (invariant costs).

3. Overall, OEM and distributor sales prices vary in proportion to OEM and distributor costs that are included in the balance sheets.

In support of the first assumption, the income statements itemize firm costs into a number of expense categories, including CGS, operating labor and occupancy costs, and other operating costs and profit. Although OEMs and motor distributors tend to handle multiple commodity lines, these data provide the most accurate indication that is available of the expenses associated with electric motors.

In the following discussion, DOE assumes a division of costs between those that do not scale with the manufacturer price (labor and occupancy expenses), and those that do (operating expenses and profit). This division of costs led to the estimate of incremental markups addressed in the next section.

In support of the third assumption, the wholesaler industries are relatively competitive, and end-user demand for motors and equipment with motors is relatively inelastic—*i.e.*, the demand is not expected to decrease significantly with a relatively small increase in price. Following standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[2]

6.3 APPROACH FOR ORIGINAL EQUIPMENT MANUFACTURER MARKUPS

Using the previous assumptions, DOE developed baseline and incremental markups for OEMs using the firm income statement from several manufacturing industries which design, assemble, and brand equipment that contain electric motors. The *2007 Economic Census Manufacturing Industry Series* reports the payroll (production and total), cost of materials, capital expenditures and total value of shipments, and miscellaneous operating costs for manufacturers of various types of machinery. DOE collected these data for 25 types of OEMs, including:

- farm machinery and equipment manufacturing;
- construction machinery manufacturing;
- mining machinery and equipment manufacturing;
- oil and gas field machinery and equipment manufacturing;
- sawmill and woodworking machinery manufacturing;
- plastics and rubber industry machinery manufacturing;
- paper industry machinery manufacturing;
- textile machinery manufacturing;
- printing machinery and equipment manufacturing;
- food product machinery manufacturing;
- semiconductor machinery manufacturing;
- other industrial machinery manufacturing;
- air-purification equipment manufacturing;
- industrial and commercial fan and blower manufacturing;
- heating equipment (except warm-air furnaces) manufacturing;
- air conditioning and warm-air heating and commercial and industrial refrigeration equipment manufacturing;
- machine-tool (metal-cutting types) manufacturing;
- machine-tool (metal-forming types) manufacturing;
- rolling mill machinery and equipment manufacturing;
- pump and pumping equipment manufacturing;
- air and gas compressor manufacturing;
- elevator and moving stairway manufacturing;
- conveyor and conveying equipment manufacturing;
- packaging machinery manufacturing; and
- fluid-power pump and motor manufacturing.

DOE used the baseline markups, which cover all of the OEM's costs (both variant and invariant costs), to determine the sales price of baseline models. Variant costs were defined as costs that vary in proportion to the change in MSP induced by increased efficiency standards; in contrast, invariant costs were defined as costs that do not vary in proportion to the change in MSP due to increased efficiency standards. The baseline markup relates the MSP to the OEM selling price. For each of the 25 OEMs identified above, DOE calculated the OEM baseline markup as follows:

$$\frac{SALES}{PAY + MAT + CAP} = MU_{BASE}$$

Where:

SALES =	value of shipments,
PAY =	payroll expenses,
MAT =	material input expenses,
CAP =	capital expenses, and
MU_{BASE} =	baseline markup.

The baseline markups range between 1.32 (machine-tool manufacturing) and 1.63 (semiconductor machinery manufacturing), with the sales-weighted average of 1.44.

Incremental markups are coefficients that relate the change in the MSP of more-efficient models, or that equipment that meets the requirements of new energy conservation standards, to the change in the OEM selling price. Incremental markups cover only those costs that scale with a change in the manufacturer's sales price (variant costs). DOE calculated the incremental markup (MU_{INCR}) for each of the 25 OEMs using the following equation:

$$MU_{INCR} = \frac{CGS_{OEM} + VC_{OEM}}{CGS_{OEM}}$$

Where:

MU_{INCR} =	incremental OEM markup,
CGS_{OEM} =	OEM's cost of goods sold, and
VC_{OEM} =	OEM's variant costs.

The incremental markups range between 1.27 (machine-tool manufacturing) and 1.56 (pump and pumping equipment manufacturing), with the sales-weighted average of 1.39.

6.4 APPROACH FOR MOTOR DISTRIBUTOR MARKUPS

The type of financial data used to estimate markups for OEMs is also available for distributors. DOE based its distributor markups on financial data from the *2007 U.S. Census Business Expenses Survey* (BES). DOE organized the financial data into income statements that break down cost components incurred by firms that sell equipment with electric motors or replacement motors, "Electrical Goods Merchant Wholesalers" (NAICS 4236).[a]

Using the previously described assumptions, DOE developed baseline and incremental markups and applied them in calculating end-user equipment prices from manufacturer sales prices. The BES provides gross margin (GM) as percent of sales for the electrical goods merchant wholesalers industry; therefore, baseline markups can be derived with the following equation:

$$\mathrm{MU}_{\mathrm{BASE}} = \frac{Sales(\%)}{Sales(\%) - GM(\%)}$$

DOE used financial data from the BES for the categories "Electrical Goods Merchant Wholesalers" to calculate incremental markups used by wholesalers of motors. Incremental markups are coefficients that relate the change in the MSP of higher efficiency models to the change in the wholesaler selling price. Hence, incremental markups cover only those costs that scale with a change in the manufacturer's sales price (*i.e.*, variant costs). DOE considers higher efficiency models to be equipment sold under market conditions with new efficiency standards. It calculated the incremental markup (MU_{INCR}) for distributors using the following equation:

$$MU_{INCR} = \frac{CGS_{DISTRIBUTOR} + VC_{DISTRIBUTOR}}{CGS_{DISTRIBUTOR}}$$

Where:

MU_{INCR} = incremental wholesaler markup,
$CGS_{DISTRIBUTOR}$ = distributor's cost of goods sold, and
$VC_{DISTRIBUTOR}$ = distributor's variant costs.

Table 6.4-1 shows the data from the BES and the markups DOE estimated using the procedures described previously.

Table 6.4-1 Business Expenses Survey Data Used to Calculate Distributor Markups

Items	Amount ($1,000,000)
Sales	348,960
Cost of goods sold (CGS)	258,579
Gross Margin	90,381
Total Operating Expenses	55,785
Labor & Occupancy Expenses	**Amount ($1,000,000)**
Annual payroll	26,785
Employer costs for fringe benefit	5,008

[a] The distributors to whom these financial data refer handle multiple commodity lines.

Contract labor costs including temporary help	894
Purchased utilities, total	628
Cost of purchased repair and maintenance services	691
Cost of purchased management consulting administrative services and other professional services	1,863
Purchased communication services	790
Lease and rental payments	2,164
Taxes and license fees (mostly income taxes)	707
Other Operating Expenses & Profit	**Amount ($1,000,000)**
Expensed computer related supplies	335
Cost of purchased packaging and containers	335
Other materials and supplies not for resale	644
Lease and rental payments for machinery and equipment	347
Cost of purchased transportation, shipping and warehousing services	2,486
Cost of purchased advertising and promotional services	1,890
Expense purchases of software	353
Cost of data processing and other purchased computer services, except communications	268
Depreciation and amortization charges	2,170
Commissions paid	1,444
Other Operating Expenses	6,004
Net profit before taxes	34,575
Baseline Markup=(CGS+GM)/CGS	1.350
Incremental Markup=(CGS+Total Other Operating Expenses and Profit)/CGS	1.197

Source: 2007 Business Expenses Survey, Electrical Goods Merchant Wholesalers (NAICS 4236)

6.5 CONTRACTOR OR INSTALLER MARKUP

DOE used information from RSMeans *Electrical Cost Data*[3] to estimate markups used by contractors in the installation of equipment with small motors or replacement motors. RSMeans *Electrical Cost Data* estimates material expense markups for electrical contractors as 10 percent, leading to a markup factor of 1.10. DOE recognizes that contractors are not used in all installations, as some firms have in-house technicians who would install equipment or replace a motor. However, DOE has no information on the extent to which this occurs, so it applied a markup of 1.10 in all cases.

6.6 SALES TAXES

The sales tax represents state and local sales taxes that are applied to the end-user equipment price. The sales tax is a multiplicative factor that increases the end-user equipment price.

DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[4] These data represent weighted averages that include county and city rates. DOE then derived population-weighted average tax values for each Census division and large state, as shown in Table 6.6-1 below. This provides a national average tax rate of 7.13 percent, which DOE used for each distribution channel.

Table 6.6-1 Average Sales Tax Rates by Census Division and Large State

Census Division/State	2011 Population	Tax Rate (2011) %
New England	14,492,360	5.64
Middle Atlantic	21,564,041	6.62
East North Central	46,519,084	6.84
West North Central	20,639,751	6.86
South Atlantic	41,167,090	6.30
East South Central	18,553,961	8.01
West South Central	11,304,323	8.51
Mountain	22,373,411	6.73
Pacific	12,799,425	5.30
New York	19,465,197	8.40
California	37,691,912	8.40
Texas	25,674,681	7.95
Florida	19,057,542	6.65
Population Weighted Average		7.13

6.7 OVERALL MARKUP

The overall markup for each distribution channel is the product of the relevant markups, as well as the sales tax. DOE used the overall baseline markup to estimate the end-user equipment price of baseline models, given the MSP of the baseline models. As stated previously, DOE considers baseline models to be equipment sold under existing market conditions (*i.e.*, without new energy efficiency standards).

DOE used the overall incremental markup to estimate changes in the end-user equipment price, given changes in the manufacturer cost above the baseline model cost resulting from a standard to raise equipment efficiency. The total end-user equipment price for higher efficiency models is composed of two components: the end-user equipment price of the baseline model and the change in end-user equipment price associated with the increase in manufacturer cost to meet the new efficiency standard. The following equation shows how DOE used the overall incremental markup to determine the end-user equipment price for higher efficiency models (*i.e.,* models meeting new efficiency standards).

$$\begin{aligned} EQP_{STD} &= MSP_{MFG} \times MU_{OVERALL\_BASE} + \Delta MSP_{MFG} \times \left(MU_{INCR} \times Tax_{SALES} \right) \\ &= EQP_{BASE} + \Delta MSP_{MFG} \times MU_{OVERALL\_INCR} \end{aligned}$$

Where:

EQP_{STD} = end-user equipment price for models meeting new efficiency standards,
EQP_{BASE} = end-user equipment price for baseline models,
MSP_{MFG} = manufacturer selling price for baseline models,
ΔMSP_{MFG} = change in manufacturer selling price for higher efficiency models,
MU_{INCR} = incremental OEM or distributor markup,
Tax_{SALES} = sales tax,
$MU_{OVERALL\_BASE}$ = baseline overall markup (product of manufacturer markup, baseline OEM or distributor markup, and sales tax), and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental OEM or distributor markup, and sales tax).

Table 6.7.1 summarizes the markups and the overall baseline and incremental markups for each of the three main identified channels. Weighting the values by the respective shares of each channel yields an average overall baseline markup of 1.63 and an overall incremental markup of 1.50.

Table 6.7.1 Summary of Markups for Three Primary Distribution Channels for Electric Motors

Markup	OEM to End-User (50%)		Distributor to End-User (24%)		Distributor to OEM to End-User (23 %)	
	Baseline	Incremental	Baseline	Incremental	Baseline	Incremental
Distributor	-	-	1.35	1.20	1.35	1.20
OEM	1.44	1.39	-	-	1.44	1.39
Contractor/Installer	-	-	-	-	-	-
Sales Tax	1.0713	1.0713	1.0713	1.0713	1.0713	1.0713
Overall	1.54	1.49	1.45	1.29	2.08	1.79

6.8 SHIPPING COSTS

DOE examined freight shipping costs to evaluate the impact of increased motor weight on installed cost. DOE collected quoted shipping costs from 16 freight shipment companies for single shipments by “less than truckload” (LTL) ground service weighing between 50 and 2,600 pounds and over shipping distances of between 350 and 3,000 miles. Marginal shipment costs per pound varied from 7.1 cents to $1.44, depending on the total weight, distance shipped, and guaranteed delivery times. DOE used a median marginal shipment cost of 65 cents per pound.

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CHAPTER 7. ENERGY USE CHARACTERIZATION

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CHAPTER 7. ENERGY USE CHARACTERIZATION

7.1 INTRODUCTION

A key component of the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8 is the savings in operating costs that customers would realize from more energy-efficient equipment. Energy costs are the most significant component of customer operating costs. The U.S. Department of Energy (DOE) uses annual energy use, along with energy prices, to establish energy costs at various energy efficiency levels. This chapter describes how DOE determined the annual energy use of electric motors.

The analysis focuses on ten representative units identified in the engineering analysis (chapter 5) and for which engineering analysis outputs were obtained. (Table 7.1.1)

Table 7.1.1 Representative Units

Representative Unit	Equipment class Group	Specifications	Horsepower
1	NEMA Designs A & B	NEMA Design B, T-frame, enclosed, 4-pole	5
2			30
3			75
4	NEMA Design C	NEMA Design C, T-frame, enclosed, 4-pole	5
5			50
6	Fire Pump Electric Motor	Uses engineering outputs derived from units 1, 2, and 3	5
7			30
8			75
9	Brake motor	Uses engineering outputs derived from units 1, 2, and 3	5
10			30

7.2 ENERGY USE ANALYSIS FOR ELECTRIC MOTORS

7.2.1 Introduction

The energy use by electric motors is derived from three components: energy converted to useful mechanical shaft power, motor losses, and reactive power. Motor losses consist of I^2R losses (both stator and rotor), core losses, stray load losses, and friction and windage losses.[1] Core losses and friction and windage losses are relatively constant with variations in motor loading, while I^2R losses increase with the square of the motor loading. Stray load losses are also dependent upon loading. DOE models the I^2R losses and stray load losses as load-dependent losses.

7.2.2 Motor Losses

For each representative unit, DOE obtained data on part-load motor losses from test data developed in the engineering analysis (chapter 5). Based on the test data, DOE modeled the motor losses as a function of loading using a third degree polynomial equation[2]:

$$Loss(L) = A + B \times L + C \times L^2 + D \times L^3$$

Where:

Loss(L)	=	the losses of the motor at loading *L* in watts,
L	=	motor load as a fraction of rated power in percent, and
A/B/C/D	=	polynomial equation coefficients.

Table 7.2.1 presents the polynomial equation coefficients for modeling losses as a function of load for the ten representative units at each efficiency level analyzed by DOE. These efficiency levels correspond to the efficiency levels (ELs) analyzed in the engineering analysis (chapter 5).

Table 7.2.1 Polynomial Equation Coefficients for Losses vs. Load relationship

Representative Unit	EL	A	B	C	D
1	0	364.9	103.8	191.9	130.5
	1	169.6	51.2	208.8	103.4
	2	158.0	77.8	68.3	133.6
	3	141.7	24.0	186.1	53.3
	4	118.1	14.6	183.8	52.5
2	0	903.3	-401.9	2462.5	-338.3
	1	863.1	-14.8	856.3	136.1
	2	422.1	97.8	654.7	355.7
	3	489.0	79.3	601.6	233.3
	4	444.6	228.4	358.3	271.3
3	0	1487.9	190.3	2066.7	466.3
	1	1599.4	91.3	1581.4	236.0
	2	870.8	280.9	1037.9	508.1
	3	1123.5	-13.0	1156.9	185.7
	4	765.9	247.6	690.2	506.3
4	0	220.3	62.5	159.7	90.3
	1	200.1	39.2	142.5	55.8
	2	180.6	31.8	121.0	35.5
5	0	1177.8	106.3	1240.8	282.6
	1	922.8	178.6	886.5	183.0
	2	767.2	204.1	573.1	418.7

6	0	169.6	51.2	208.8	103.4
	1	158.0	77.8	68.3	133.6
	2	141.7	24.0	186.1	53.3
	3	118.1	14.6	183.8	52.5
7	0	863.1	-14.8	856.3	136.1
	1	422.1	97.8	654.7	355.7
	2	489.0	79.3	601.6	233.3
	3	444.6	228.4	358.3	271.3
8	0	1599.4	91.3	1581.4	236.0
	1	870.8	280.9	1037.9	508.1
	2	1123.5	-13.0	1156.9	185.7
	3	765.9	247.6	690.2	506.3
9	0	364.9	103.8	191.9	130.5
	1	169.6	51.2	208.8	103.4
	2	158.0	77.8	68.3	133.6
	3	141.7	24.0	186.1	53.3
	4	118.1	14.6	183.8	52.5
10	0	903.3	-401.9	2462.5	-338.3
	1	863.1	-14.8	856.3	136.1
	2	422.1	97.8	654.7	355.7
	3	489.0	79.3	601.6	233.3
	4	444.6	228.4	358.3	271.3

To determine the annual energy losses E_{loss} in kilowatt-hours (kWh), DOE converts the full-load losses into part-load losses using the estimate of the motor's load and multiplies by the annual operating hours. Annual energy losses are represented by the following equation:

$$E_{loss} = H_{op} \times Loss(L)$$

Where:

E_{loss}	=	annual energy consumed by motor losses in watts per hour, and
H_{op}	=	the annual operating hours, in hours.

7.2.2.1 Impact of Higher Operating Speeds

DOE is aware that the installation of a more efficient motor could lead to less energy savings than anticipated. According to stakeholder comments, a more efficient motor typically has less slip than a less efficient motor, an attribute that can result in a higher operating speed and a potential overloading of the motor.

DOE acknowledges that the cubic relation between speed and power requirement in many variable torque applications can affect the benefits gained by efficient motors, which have a lower slip. DOE did not obtain sufficient data to incorporate this effect into the LCC analysis. Instead, DOE incorporated this effect as a sensitivity analysis in the LCC spreadsheet, allowing the user to consider this effect following a scenario described in Appendix 7-A of the technical support document (TSD).

7.2.3 Reactive Power

In an alternating current power system, the reactive power is the root mean square (RMS) voltage times the RMS current, multiplied by the sine of the phase difference between the voltage and the current. Reactive power occurs when the inductance or capacitance of the load shifts the phase of the voltage relative to the phase of the current. While reactive power does not consume energy directly, it can increase losses and costs for the electricity distribution system. Motors tend to create reactive power, because the windings in the motor coils have high inductance.

Alternating-current power flow has three components: real power (P), measured in watts (W); apparent power (S), measured in volt-amperes (VA); and reactive power (Q), measured in reactive volt-amperes (VAr). The power factor is defined as P/S. In the case of a perfectly sinusoidal waveform, P, Q, and S can be expressed as vectors that form a vector triangle such that: $S^2 = P^2 + Q^2$. This implies that the formula for reactive power as a function of real power and power factor is as follows:

$$Q = P * (1/PF^2-1)$$

Where:

Q	=	reactive power in reactive volt-amperes,
P	=	real power in watts, and
PF	=	the motor's power factor.

DOE used data on motor power factor as a function of motor loading from test data developed in the engineering analysis (chapter 5) to develop a relationship between power factor and motor load. This relationship is expressed as a third degree polynomial:

$$PF(L) = A + B \times L + C \times L^2 + D \times L^3$$

Table 7.2.2 presents the polynomial equation coefficients developed to estimate power factor for all representative units at each efficiency level analyzed by DOE.

Table 7.2.2 Polynomial Equation Coefficients for Power Factor vs. Load relationship

Representative Unit	EL	A	B	C	D
1	0	0.042	2.035	-1.883	0.636
	1	0.034	2.053	-1.858	0.592
	2	0.033	1.835	-1.554	0.476
	3	0.035	2.311	-2.289	0.783
	4	0.006	1.957	-1.722	0.544
2	0	0.039	2.716	-2.963	1.068
	1	0.032	2.126	-1.975	0.636
	2	0.005	2.344	-2.346	0.796
	3	0.033	2.188	-2.108	0.698
	4	0.048	2.333	-2.386	0.795
3	0	0.044	3.182	-3.823	1.467
	1	0.146	1.765	-1.557	0.467
	2	0.225	1.827	-1.781	0.578
	3	0.160	1.814	-1.663	0.519
	4	0.052	2.812	-3.202	1.147
4	0	0.033	1.612	-1.276	0.381
	1	0.040	0.860	-0.269	-0.012
	2	0.077	1.746	-1.453	0.420
5	0	0.040	2.616	-2.835	1.029
	1	0.043	1.925	-1.703	0.516
	2	0.051	2.402	-2.504	0.851
6	0	0.034	2.053	-1.858	0.592
	1	0.033	1.835	-1.554	0.476
	2	0.035	2.311	-2.289	0.783
	3	0.006	1.957	-1.722	0.544
7	0	0.032	2.126	-1.975	0.636
	1	0.005	2.344	-2.346	0.796
	2	0.033	2.188	-2.108	0.698
	3	0.048	2.333	-2.386	0.795
8	0	0.146	1.765	-1.557	0.467
	1	0.225	1.827	-1.781	0.578
	2	0.160	1.814	-1.663	0.519
	3	0.052	2.812	-3.202	1.147
9	0	0.042	2.035	-1.883	0.636
	1	0.034	2.053	-1.858	0.592
	2	0.033	1.835	-1.554	0.476
	3	0.035	2.311	-2.289	0.783
	4	0.006	1.957	-1.722	0.544
10	0	0.039	2.716	-2.963	1.068
	1	0.032	2.126	-1.975	0.636
	2	0.005	2.344	-2.346	0.796
	3	0.033	2.188	-2.108	0.698
	4	0.048	2.333	-2.386	0.795

7.2.4 Motor Applications

The annual operating hours and loading of motors depend on the sector (*i.e.*, industry, agriculture, and commercial), motor size (in horsepower), and end-use application (*e.g.*, pump). DOE estimated the share of motors in each type of application depending on the National Electrical Manufacturers Association (NEMA) Design and size of the motor and used a distribution of motors across sectors by motor size. DOE drew upon several data sources to develop a model of the applications for which motors covered in this analysis are used.

Six motor applications (air compressors, fans, pumps, material handling, fire pumps, and others) were selected as representative applications based on a previous DOE study (DOE-ITP study)[3]. In order to derive distributions of motors across applications, DOE used data from more than five hundred field assessments aggregated in two databases: (1) a database of motor nameplate and field data compiled by the Washington State University (WSU) Extension Energy Program, Applied Proactive Technologies (APT), and New York State Energy Research and Development Authority (NYSERDA)[4] ("WSU/NYSERDA database")[a]; (2) a database of motor nameplate and field data compiled by the Industrial Assessment Center (IAC) at Oregon University (OSU) ("Northwest Industrial Motor Database")[b,5].

Table 7.2.3 summarizes the sector-specific distributions of NEMA Design A and B motors across applications by horsepower range. Table 7.2.4 summarizes the distribution of NEMA Design C motors across applications by horsepower range in all sectors. For Design C motors, insufficient data were available to develop similar estimates in the commercial or agricultural sector and, instead, the estimates in the industrial sector were used as an approximation. **Error! Reference source not found.** represents the sector-specific distribution of integral brake motors across applications by horsepower range. To account for the fact that integral brake motors are typically not used in air compressor, pump, and fan applications, these distributions were derived from information on NEMA Design A and B motors distributions across material handling and other applications.

Table 7.2.3 Distribution of Motors by Application for NEMA Design A and B Motors

(%)	Air Compressor	Fan	Pump	Material Handling	Other
Industry					
1-5hp	5.1	14.0	10.6	41.7	28.6
6-20hp	6.3	23.4	17.1	23.2	30.0
21-50hp	12.1	20.2	17.5	19.5	30.7
51-100hp	17.1	20.9	16.1	14.3	31.6
101-200hp	19.0	21.4	14.8	6.6	38.2

[a] The motors database is composed of information gathered by WSU and APT during 123 industrial motor surveys or assessments: 11 motor assessments were conducted between 2005 and 2011 and occurred in industrial plants; 112 industrial motor surveys were conducted between 2005 and 2011 and were funded by NYSERDA and conducted in New York State.
[b] The Northwest Industrial Motor Database provides information on motors collected by the Industrial Assessment Center (IAC) at Oregon State University (OSU). The database includes more than 22,000 records, each with detailed motor application and field usage data.

201-500hp	23.5	13.6	15.6	7.2	40.1
Commercial					
1-5hp	5.0	36.7	26.7	3.6	27.9
6-20hp	3.1	28.9	35.0	1.7	31.3
21-50hp	2.8	55.9	20.7	3.6	17.1
51-100hp	8.1	58.5	25.2	0.8	7.3
101-200hp	3.3	43.3	43.3	0.0	10.0
201-500hp	7.1	14.3	78.6	0.0	0.0
Agriculture					
1-5hp	0.1	50.1	13.2	20.6	15.9
6-20hp	1.3	23.5	18.8	39.8	16.6
21-50hp	6.3	8.7	37.0	27.6	20.5
51-100hp	11.3	12.4	48.5	17.5	10.3
101-200hp	5.3	2.6	59.2	7.9	25.0
201-500hp	12.8	28.2	33.3	5.1	20.5

Table 7.2.4 Distribution of Motors by Application for NEMA Design C Motors

(%)	Air Compressor	Fan	Pump	Material Handling	Other
All Sectors					
1-5hp	-	25.0	-	25.0	50.0
6-20hp	-	11.1	-	11.1	77.8
21-50hp	-	0.0	-	20.0	80.0
51-100hp	-	11.1	-	11.1	77.8
101-200hp	-	11.1	-	14.8	74.1

Table 7.2.5 Distribution of Motors by Application for Brake motors

(%)	Air Compressor	Fan	Pump	Material Handling	Other
Industrial					
1-5hp	-	-	-	24.8	75.2
6-20hp	-	-	-	43.6	56.4
21-30hp	-	-	-	38.9	61.1
Commercial					
1-5hp	-	-	-	11.4	88.6
6-20hp	-	-	-	5.3	94.7
21-30hp	-	-	-	17.5	82.5
Agriculture					
1-5hp	-	-	-	56.4	43.6
6-20hp	-	-	-	70.6	29.4
21-30hp	-	-	-	57.4	42.6

The distribution of motors across sectors by motor size was extracted from an Easton Consultants report,[6] which provides the distribution of AC integral motors by horsepower across various sectors (Table 7.2.6).

Table 7.2.6 Distribution across Sector by Motor Size

Horsepower range *hp*	Industry	Agriculture	Commercial
1-50	26.11	0.11	73.78
51-100	63.27	6.98	29.75
101-200	76.03	3.35	20.62
201-500	69.09	3.03	27.88

7.2.5 Load

To calculate the annual energy consumption at each efficiency level for each equipment class, DOE used the efficiencies and losses from the engineering analysis, along with estimates of motor operating hours and average load. Because the losses of a motor depend on the motor load, DOE estimated average motor load in order to look up the motor losses from the losses-versus-load curves from the engineering analysis (Table 7.2.1). The average motor load mainly depends on the motor's end-use application (*e.g.*, fan, pump) and sector (*e.g.* industrial). The DOE-ITP study shows that motor load does not vary significantly across horsepower ranges for a specific application. DOE assumed that the motor load distribution took the form of a normal distribution, centered on the average value, and estimated application-specific average load and standard deviation values from approximately 21,500 field measurements provided by the WSU/NYSERDA and the Northwest Industrial Motor databases. **Error! Reference source not found.** presents the average motor load by application in the industrial sector. Because sufficient data were not available, the same average load values and statistical distribution were used for the commercial and agricultural sectors.

Table 7.2.7 Average Motor Load

Application	Load
Air compressors	72.1
Fans	69.6
Pumps	67.0
Material Handling	58.9
Other	62.0
Fire Pumps	67.0

7.2.6 Motor Annual Hours of Operation

DOE estimated average annual operating hours by sector, application, and horsepower ranges and developed statistical distributions to use in its Monte Carlo analysis. (The Monte Carlo analysis is described in chapter 8.)

For the industrial sector, DOE combined data from the WSU/NYSERDA database and the Northwest Industrial Motor database to determine average annual operating hours by application and horsepower ranges and statistical distributions. For example, Figure 7.2.1 shows the cumulative form of the discrete distributions for motors of between 21 and 50 horsepower in various applications.

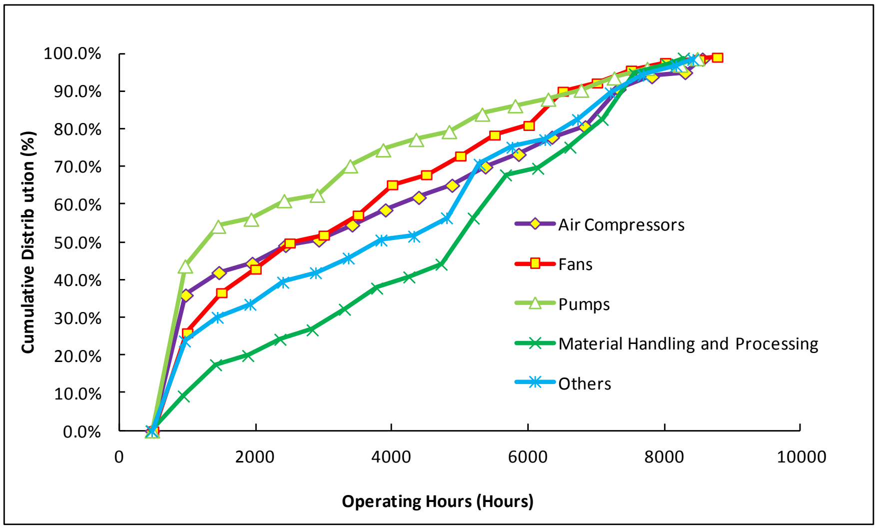

Figure 7.2.1 Cumulative Distribution for 21-50 Horsepower Motors by Applications in Industry Sector

For the commercial and agricultural sectors, DOE derived estimates of average operating hours by application and horsepower range from various sources: the 2007 Census of Agriculture Farm and Ranch Irrigation Survey[7], an article by Michael Gallaher *et al*.[8], the Regional Technical Forum[9], DOE's own analysis on classification and evaluation of electric motors and pump[10], an EPRI report[11], and a DOE report by Arthur D. Little[12]. For fire pumps, DOE assumed a uniform distribution between 0.5 hours and up to 6 hours.

Table 7.2.8 displays the average hours of motor operation by application and motor sizes for the industrial, commercial, and agricultural sectors.

Table 7.2.8 Average Motor Operating Hours by Application and Horsepower Range

	Horsepower range *hp*					
	1-5	6-20	21-50	51-100	101-200	201-500
Industry						
Air Compressors	5,729	5,568	5,986	6,440	6,398	6,023
Fans	5,932	6,332	6,469	6,538	6,590	6,817
Pumps	5,936	6,347	6,883	6,848	7,076	7,518
Material Handling	4,902	4,577	4,681	5,488	6,431	5,990
Other	5,289	5,416	5,544	5,377	5,442	5,456
Fire Pump	3.25	3.25	3.25	3.25	3.25	3.25
Commercial						
Air Compressors	1,000	1,200	1,500	1,500	1,500	1,500
Fans	3,000	3,300	3,600	3,900	4,200	4,500
Pumps	1,500	1,650	1,800	1,950	2,100	2,250
Material Handling	1,959	2,165	2,380	2,567	2,753	2,939
Other	1,959	2,165	2,380	2,567	2,753	2,939
Fire Pump	3.25	3.25	3.25	3.25	3.25	3.25
Agriculture						
Air Compressors	1,500	1,500	1,500	1,500	1,500	1,500
Fans	1,500	1,500	1,500	1,500	1,500	1,500
Pumps	1,009	1, 009	1, 009	1, 065	1, 121	1, 121
Material Handling	1,500	1,500	1,500	1,500	1,500	1,500
Other	1,500	1,500	1,500	1,500	1,500	1,500
Fire Pump	3.25	3.25	3.25	3.25	3.25	3.25

7.3 ANNUAL ENERGY USE

Depending on the hours of operation, the loading, and the efficiency of the motor (which varies with the standard level), the annual energy use varies both by efficiency level and from motor to motor. The annual energy use is calculated using the following expression:

$$E = \frac{HP \times L}{\eta} \times H_{op}$$

Where:

E = energy use,
HP = horsepower of the motor, or motor capacity,
η = operating efficiency, and
H_{op} = motor operating hours.

Table 7.3.1 shows the results of the energy use analysis for the eight representative units at each considered energy efficiency level. Results are given for baseline units (EL 0) and the higher efficiency levels (ELs) being considered for motors.

Table 7.3.1 Average Annual Energy Consumption by Efficiency Level for Representative Units

Rep. Unit	Description	*kilowatt-hours per year*				
		EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
1	Design B, T-frame, 5 hp*, 4 poles, enclosed	8,977	8,287	8,138	8,062	7,969
2	Design B, T-frame, 30 hp, 4 poles, enclosed	61,611	60,164	58,778	58,698	58,511
3	Design B, T-frame, 75 hp, 4 poles, enclosed	195,566	194,167	190,458	190,392	188,997
4	Design C, T-frame, 5 hp, 4 poles, enclosed	8,376	8,206	8,078	-	-
5	Design C, T-frame, 50 hp, 4 poles, enclosed	79,551	78,276	77,653	-	-
6	Fire pump electric motor , 5 hp, 4 poles, enclosed	9.24	9.08	9.00	8.89	-
7	Fire pump electric motor, 30 hp, 4 poles, enclosed	53.47	52.22	52.17	52.01	-
8	Fire pump electric motor, 75 hp, 4 poles, enclosed	130.24	127.77	127.75	126.81	-
9	Brake motor, 5 hp, 4 poles, enclosed	8,079	7,430	7,290	7,219	7,132
10	Brake motor, 30 hp, 4 poles, enclosed	48,394	47,178	45,999	45,934	45,777

* hp = horsepower.

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

This chapter of the technical support document (TSD) presents the Department of Energy (DOE)'s life-cycle cost (LCC) and payback period (PBP) analysis. It describes the method DOE used for analyzing the economic impacts of possible standards on consumers. The effect of standards on consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The LCC and PBP analysis produces two basic outputs to describe the effect of standards on consumers:

- **LCC** is the total (discounted) cost that a consumer pays over the lifetime of the equipment, including purchase price, installation cost, and operating expenses.

- **PBP** measures the amount of time it takes consumers to recover the estimated higher purchase expense of more energy-efficient equipment through lower operating costs.

This chapter presents inputs and results for the LCC and PBP analysis, as well as key variables, current assumptions, and computational equations. DOE performed the calculations discussed here using Microsoft Excel spreadsheets, which are accessible on DOE's website (*http://www.eere.energy.gov/buildings/appliance_standards/*). Inputs to the LCC and PBP are discussed in sections 8.2 and 8.3, respectively, of this chapter. Results for the LCC and PBP are presented in section 8.4, with sensitivity results in section 8.5. Details regarding and instructions for using the spreadsheets are discussed in Appendix 8-A.

8.1.1 General Approach for Life-Cycle Cost and Payback Period Analysis

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analysis by modeling both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. DOE developed LCC and PBP spreadsheet models incorporating both Monte Carlo simulation and probability distributions by using a Microsoft Excel spreadsheet combined with Crystal Ball (a commercially available add-on program).

In addition to characterizing several of the inputs to the analysis with probability distributions, DOE also developed sector-specific samples of end-use applications for each of the ten representative units. These end-use applications determine the use profile of the motor and the economic characteristics of the motor owner (see chapter 7 for details).

In each Monte Carlo iteration, for each representative unit, the sector (*i.e.*, industrial, agricultural, and commercial) and the Census region are identified by sampling from distributions, and they determine the energy price used in the LCC calculation in each simulation. DOE used Energy Information Administration (EIA) data on electricity prices in 2010 for different customer classes and data from the DOE and the U.S. Department of Agriculture to establish the variability in energy pricing by Census region.

Further, one of the applications is identified by sampling from a sector-specific distribution of applications for that representative unit. The selected application within a sector determines the number of operating hours per year as well as the motor loading. The operating hours and the motor loading for the application are used in the energy use calculation (see chapter 7).

Also, the sector to which the motor belongs determines the discount rate used in the LCC calculation in each simulation.

DOE also used data from the literature and field assessments[1] on motor loading and motor application characteristics to estimate the variability of annual energy use. Due to the large range of applications and motor use characteristics considered in the LCC and PBP analysis, the range of annual energy use and energy prices can be quite large. Thus, although the annual energy use and energy pricing are known for each sampled motor, their variability across all motors contributes to the range of LCCs and PBPs calculated for any particular standard level.

Results presented at the end of this chapter are based on 10,000 samples per Monte Carlo simulation run. DOE displays the LCC and PBP results as distributions of impacts compared to the base case without standards.

8.1.2 Overview of Life-Cycle Cost and Payback Period Inputs

DOE categorizes inputs to the LCC and PBP analysis as follows: (1) inputs for establishing the initial expense, otherwise known as the total installed cost, and (2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer selling price*: The price at which the manufacturer sells the baseline equipment, which includes the costs incurred by the manufacturer to produce equipment meeting existing standards.
- *Manufacturer selling price increases*: The change in manufacturer selling price associated with producing equipment to meet a particular standard level.
- *Markups and sales tax*: The markups and sales tax associated with converting the manufacturer cost to a consumer equipment price. The markups and sales tax are described in detail in chapter 6, Markups Analysis.
- *Installation cost*: The cost to the consumer of installing the equipment. The installation cost represents all costs required to install the equipment other than the marked-up consumer equipment price. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer equipment price plus the installation cost.

The primary inputs for calculating the operating cost are:

- *Equipment energy consumption and reactive power*: The equipment energy consumption is the site energy use associated with operating the equipment. Reactive power is power that is reflected back to the electrical system by a change in the phase of alternating current power. Chapter 7, Energy Use Characterization, details how DOE determined the equipment energy consumption based on various data sources.

- *Equipment efficiency:* The equipment efficiency dictates the energy consumption associated with standard-level equipment (*i.e.*, equipment with efficiencies greater than baseline equipment). Chapter 7, Energy Use Characterization, details how energy and reactive power change with increasing equipment efficiency and how equipment efficiency relates to actual equipment energy use.

- *Energy prices*: Energy prices are the prices paid by end-users for energy (i.e., electricity). DOE determined current energy prices based on data from the EIA.

- *Energy price trends*: DOE used the EIA *Annual Energy Outlook 2012* (*AEO2012*)[2] to forecast energy prices into the future. For the results presented in this chapter, DOE used the reference case of *AEO2012* to forecast future energy prices.

- *Repair and maintenance costs*: Repair costs are associated with repairing or replacing components that have failed. Maintenance costs are associated with maintaining the operation of the equipment.

- *Lifetime*: The age at which the equipment is retired from service.

- *Discount rate*: The rate at which DOE discounted future expenditures to establish their present value.

Figure 8.1-1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP. In the figure below, the yellow boxes indicate the inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate the final outputs (the LCC and PBP).

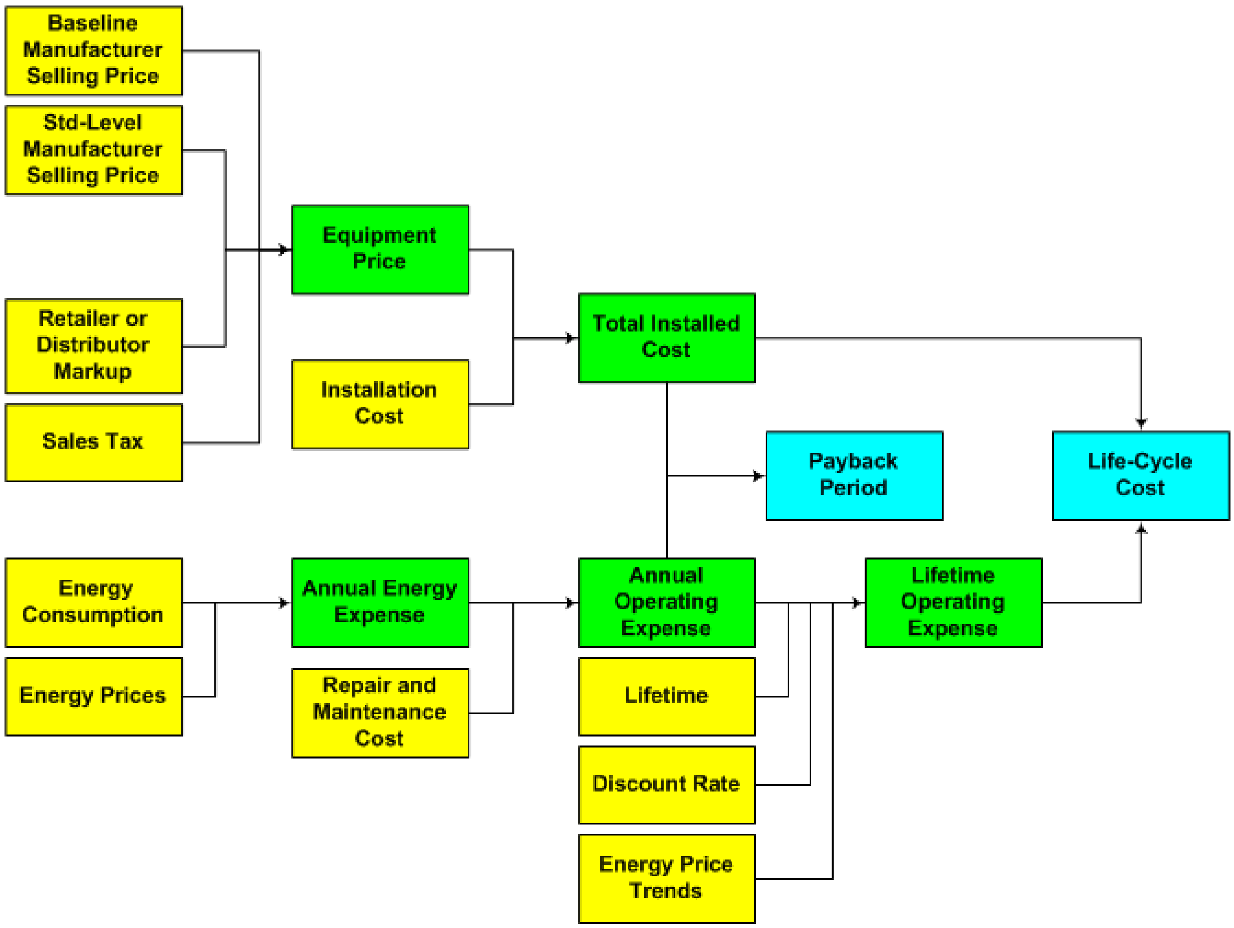

Figure 8.1-1 Flow Diagram of Inputs for the Determination of Life-Cycle Cost and Payback Period

Table 8.1.1Table 8.1.1 summarizes the input values that DOE uses to calculate the LCC and PBP for electric motors and lists how these inputs changed from the preliminary analysis to the notice of proposed rulemaking (NOPR) analysis.. Each row summarizes the total installed cost inputs and operating costs, including the lifetime, discount rate, and electricity price trend. DOE characterizes several of the inputs with probability distributions that capture the input's uncertainty, variability, or both in the Monte Carlo analysis.

Table 8.1.1 Summary Information of Inputs for the Life-Cycle Cost and Payback Period Analyses

Inputs	Preliminary Analysis	Changes for the Proposed Rule
Manufacturer Selling Price	From the engineering analysis	No change.
Markups	Considered various distribution channel pathways.	No change.
Sales Tax	Derived weighted-average tax values for each Census division and large State from data provided by the Sales Tax Clearinghouse.	Updated the sales tax using the latest information from the Sales Tax Clearinghouse.
Installation Cost	Assumed to remain constant across efficiency levels.	No change.
Maintenance Cost	Assumed to remain constant across efficiency levels.	No change.
Repair Costs	Based on Vaughen's 2011 data.	Updated to Vaughen's 2013 data.
Repair frequency	Determined for each motor horsepower range and sector based on multiple data sources.	Used same methodology with additional data sources. See chapter 8 of the TSD for details.
Unit Energy Consumption	Determined for each application based on sampled sector and applications which in turns determined loading points and usage profile.	Used same methodology with additional data sources. See chapter 7 of the TSD for details.
Electricity Prices	Price: Based on EIA's 2010 Form EIA-861 data. Variability: Regional energy prices determined for 4 regions.	Price: Updated with 2011 Form EIA-861 data. Variability: No change.
Electricity Price Trends	Forecasted with EIA's *Annual Energy Outlook Early Release 2011*.	Updated with EIA's *Annual Energy Outlook 2013*.
Discount Rate	Derived discount rates using the cost of capital of publicly-traded firms based on data from Damodaran Online, the Value Line Investment survey, and the Office of Management and Budget (OMB) Circular No. A-94.	DOE updated the risk-free rate to use a 40-year average return on 10-year treasury notes, as reported by the U.S. Federal Reserve. DOE updated the equity risk premium.
Base Case Market Efficiency Distribution	All market efficiency distributions were derived for each equipment class group and by horsepower range. Distributions were derived from model counts derived from catalog data and assumed to remain constant over time.	Used same methodology to develop the efficiency distribution in 2012 and updated to account for the revised efficiency levels. Added efficiency trends for equipment class groups 1 and 4 to derive efficiency distributions in the compliance year

8.2 LIFE-CYCLE COST INPUTS

Life-cycle cost is the total customer expense over the life of a piece of equipment, including purchase expense and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase and sums them over the lifetime of the equipment. DOE defines LCC by the following equation:

$$LCC = IC + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t}$$

Where:

LCC = life-cycle cost in dollars,

IC =	total installed cost in dollars,
$\sum$ =	sum over the lifetime, from year 1 to year N,
N =	lifetime of appliance in years,
OC =	operating cost in dollars,
r =	discount rate, and
t =	year for which operating cost is being determined.

DOE gathered most of its data for the LCC and PBP analysis in 2010, 2011, and 2012 and updated its inputs to 2012$ using appropriate measures of inflation where necessary. Throughout this TSD, DOE expresses dollar values in 2012$.

8.2.1 Total Installed Cost Inputs

DOE defines the total installed cost, IC, using the following equation:

$$IC = EQP + INST$$

Where:

EQP =	equipment price (*i.e.*, customer cost for the equipment only), expressed in dollars, and
INST =	installation cost or the customer price to install equipment (*i.e.*, the cost for labor and materials), also in dollars.

The equipment price is based on how the customer (end-user) purchases the equipment. As discussed in chapter 6, Markups for Equipment Price Determination, DOE defined markups and sales taxes for converting manufacturing selling prices into customer equipment prices.

Table 8.2.1 summarizes the inputs for the determination of total installed cost.

Table 8.2.1 Inputs for Total Installed Cost

Baseline Manufacturer Selling Price
Manufacturer Selling Price Increase
Markups and Sales Tax
Installation Cost

The *baseline manufacturer selling price* is the price charged by the manufacturer to produce equipment for the current market. *Manufacturer selling price increase* is the change in manufacturer price associated with producing equipment at a standard level. *Markups and sales tax* convert the manufacturer selling price to a consumer equipment price. The *installation cost* is the cost to the consumer of installing the equipment and represents all costs required to install the equipment other than the marked-up consumer equipment price. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer equipment price plus the installation cost. DOE calculated the total installed cost for baseline products based on the following equation:

$$
\begin{aligned}
IC_{BASE} &= EQP_{BASE} + INST_{BASE} \\
&= MSP_{MFG} \times MU_{OVERALL\_BASE} + INST_{BASE}
\end{aligned}
$$

Where:

IC_{BASE} = baseline total installed cost,
EQP_{BASE} = consumer equipment price for baseline models,
$INST_{BASE}$ = baseline installation and shipping cost,
MSP_{MFG} = manufacturer selling price for baseline models, and
$MU_{OVERALL\_BASE}$ = baseline overall markup (product of manufacturer markup, baseline retailer or distributor markup, and sales tax).

DOE calculated the total installed cost for standard-level products based on the following equation:

$$
\begin{aligned}
IC_{STD} &= EQP_{STD} + INST_{STD} \\
&= \left(EQP_{BASE} + \Delta EQP_{STD}\right) + \left(INST_{BASE} + \Delta INST_{STD}\right) \\
&= \left(EQP_{BASE} + INST_{BASE}\right) + \left(\Delta EQP_{STD} + \Delta INST_{STD}\right) \\
&= IC_{BASE} + \left(\Delta MSP_{MFG} \times MU_{OVERALL\_INCR} + \Delta INST_{STD}\right)
\end{aligned}
$$

Where:

IC_{STD} = standard-level total installed cost,
EQP_{STD} = consumer equipment price for standard-level models,
$INST_{STD}$ = standard-level installation cost,
EQP_{BASE} = consumer equipment price for baseline models,
ΔEQP_{STD} = change in equipment price for standard-level models,
$INST_{BASE}$ = baseline installation and shipping cost,
$\Delta INST_{STD}$ = change in installation and shipping cost for standard-level models,
IC_{BASE} = baseline total installed cost,
ΔMSP_{MFG} = change in manufacturer selling price for standard-level models, and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental retailer or distributor markup, and sales tax).

DOE found no evidence that installation costs would increase with higher motor energy efficiency. Thus, DOE did not incorporate changes in installation costs for motors that are more efficient than baseline products. In addition, motor installation cost data from *RS Means Electrical Cost Data 2013*[3] show a variation in installation costs according to the motor horsepower (for three-phase electric motors), but not according to efficiency. Therefore, in the preliminary analysis, DOE assumed there is no variation in installation costs between a baseline efficiency motor and a higher efficiency motor.

The remainder of this section provides information about each of the input variables that DOE used to calculate the total installed cost for electric motors.

8.2.1.1 Projection of Future Product Prices

To derive a price trend for electric motors, DOE obtained historical Producer Price Index (PPI) data for integral horsepower motors and generators manufacturing spanning the time period 1969-2012 from the Bureau of Labor Statistics' (BLS).[a] The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for integral horsepower motors and generators manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index and is presented in 2012 dollar values in Figure 8.2-1.

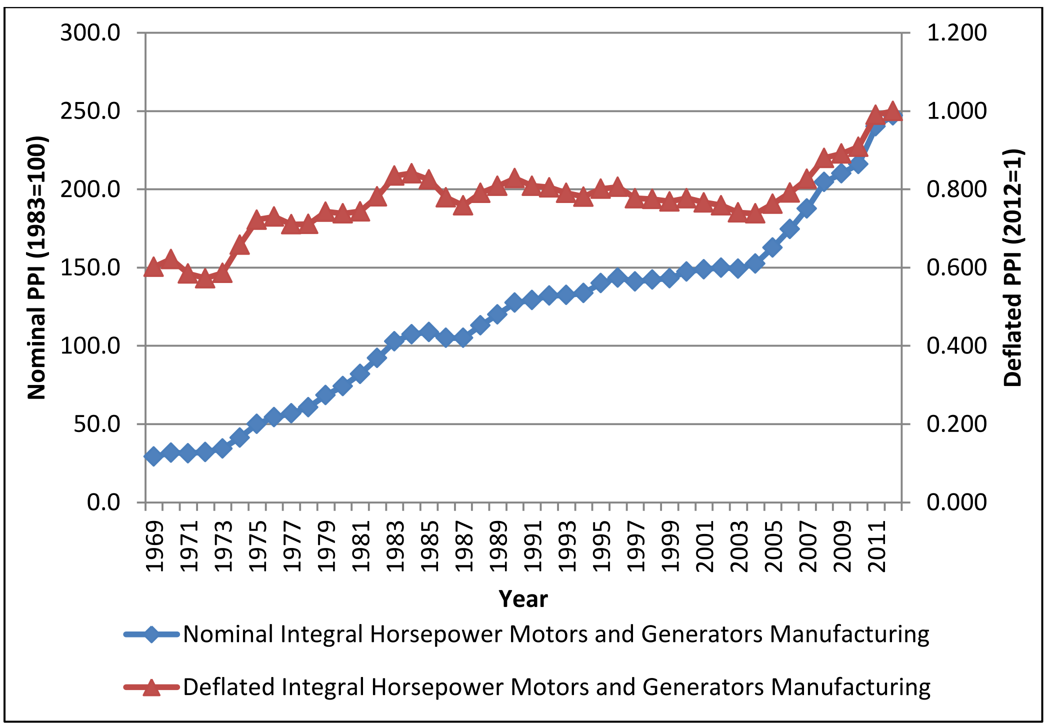

Figure 8.2-1 Historical Nominal and Deflated Producer Price Indexes for Integral Horsepower Motors and Generators Manufacturing

From the mid-1970s to 2005, the deflated price index for electric motors was roughly flat. Since then, the index has risen sharply, primarily due to rising prices of copper and steel products that go into motors (see Figure 8.2-2). The rising prices for copper and steel products were primarily a result of strong demand from China and other emerging economies. Given the slowdown in global economic activity in 2011, DOE believes that the extent to which the trends

[a] Series ID PCU3353123353123; http://www.bls.gov/ppi/

of the past five years will continue is very uncertain. DOE performed an exponential fit on the deflated price index for electric motors, but the R^2 was relatively low (0.58). DOE also considered the experience curve approach, in which an experience rate parameter is derived using two historical data series on price and cumulative production, but the time series for historical shipments was not long enough for a robust analysis.

Given the above considerations, DOE decided to use a constant price assumption as the default price factor index to project future motor prices. Thus, prices forecast for the LCC and PBP analysis are equal to the 2011 values for each efficiency level in each equipment class.

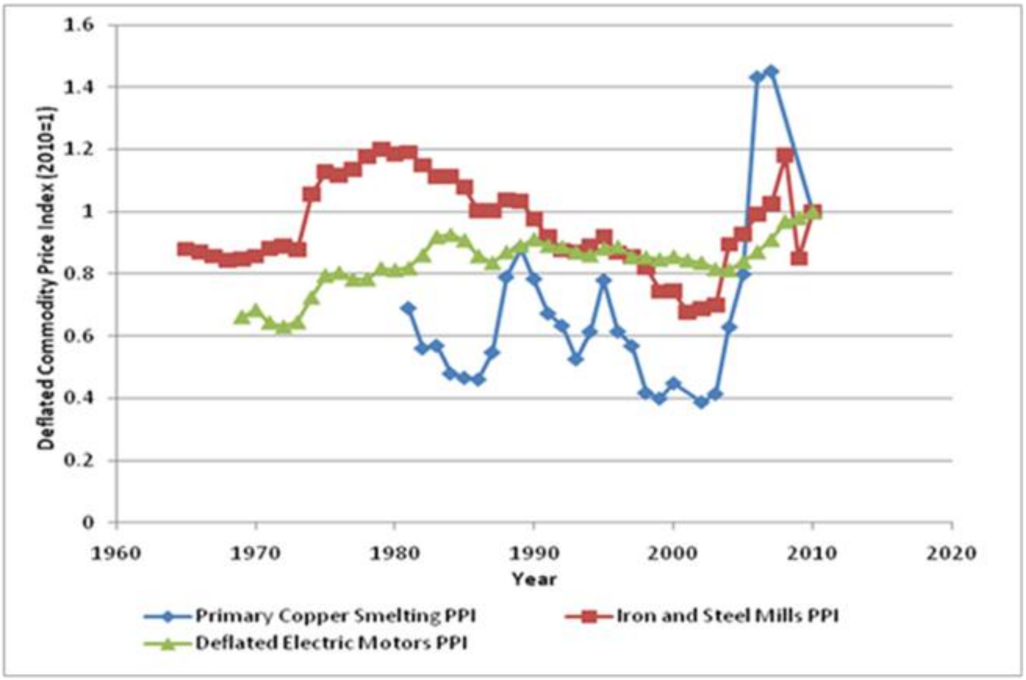

Figure 8.2-2 Historical Deflated Producer Price Indexes for Copper Smelting, Steel Mills Manufacturing and Integral Horsepower Motors and Generators

8.2.1.2 Baseline Manufacturer Selling Price

The engineering analysis provides a baseline manufacturer selling price (MSP) that includes all manufacturer markups (see TSD chapter 5). Table 8.2.2 presents the baseline MSP and the associated energy efficiency for each representative unit analyzed in the engineering analysis.

Table 8.2.2 Engineering Baseline Manufacturer Selling Price

Representative Unit		Baseline Efficiency *%*	Baseline MSP *2012$*
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	82.5	330
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	89.5	848
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	93.0	1,891
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	87.5	331
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	93.0	1,537
6	Fire pump electric motor, 5 hp , 4 poles, enclosed	87.5	341
7	Fire pump electric motor, 30 hp, 4 poles, enclosed	92.4	1,085
8	Fire pump electric motor, 75 hp, 4 poles, enclosed	94.1	2,048
9	Brake motor, T-frame, 5 hp, 4 poles, enclosed	82.5	330
10	Brake motor, T-frame, 30 hp, 4 poles, enclosed	89.5	848

DOE determined the MSP associated with motors produced at increasing energy efficiency levels (ELs) for electric motors in the engineering analysis (see TSD chapter 5). Table 8.2.3 presents the MSP, along with the associated energy efficiency, for representative units 1 through 10.

Table 8.2.3 Efficiency and Manufacturer Selling Price Data by Representative Unit:

Representative Unit		Energy Efficiency Level	Efficiency *%*	MSP *2012$*
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	Baseline	82.5	330
		1	87.5	341
		2	89.5	367
		3	90.2	402
		4	91.0	670
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	Baseline	89.5	848
		1	92.4	1,085
		2	93.6	1,156
		3	94.1	1,295
		4	94.5	2,056
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	Baseline	93.0	1,891
		1	94.1	2,048
		2	95.4	2,327
		3	95.8	2,776
		4	96.2	3,620
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	Baseline	87.5	331
		1	89.5	355
		2	91.0	621

5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	Baseline	93.0	1,537
		1	94.5	2,130
		2	95.0	2,586
6	Fire pump electric motor, 5 hp , 4 poles, enclosed	Baseline	87.5	341
		1	89.5	367
		2	90.2	402
		3	91.0	670
7	Fire pump electric motor, 30 hp, 4 poles, enclosed	Baseline	92.4	1,085
		1	93.6	1,156
		2	94.1	1,295
		3	94.5	2,056
8	Fire pump electric motor, 75 hp, 4 poles, enclosed	Baseline	94.1	2,048
		1	95.4	2,327
		2	95.8	2,776
		3	96.2	3,620
9	Brake motor, T-frame, 5 hp, 4 poles, enclosed	Baseline	81.5	330
		1	86.5	341
		2	88.5	367
		3	89.5	402
		4	90.2	670
10	Brake motor, T-frame, 30 hp, 4 poles, enclosed	Baseline	88.5	848
		1	91.7	1,085
		2	93.0	1,156
		3	93.6	1,295
		4	94.1	2,056

Table 8.2.4 shows the baseline and incremental markups estimated for each point in the electric motor supply chain. The overall baseline and incremental markups shown are weighted averages based on the share of shipments in each distribution channel. Refer to TSD chapter 6 for details.

Table 8.2.4 Weighted Average Markups for Electric Motors Covered in this Analysis

Point in Supply Chain	**Baseline***	**Incremental***
Wholesale	1.17	1.10
OEM	1.32	1.29
Contractor/Installer	1.00	1.00
Markup before Tax	1.52	1.40
Sales Tax	1.0713	
Overall	1.63	1.50

* Weighted average of the three distribution channels.

Total Installed Cost: The total installed cost is the sum of the end-user equipment price and the installation cost. Refer back to section 8.2.1 to see the equations that DOE used to calculate the total installed cost for various energy efficiency levels. Table 8.2.5 through Table 8.2.9 present the end-user equipment price, shipping cost, and total installed cost for representative units 1 through 10.

Table 8.2.5 Representative Unit 1: NEMA Design B, T-Frame, 5 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	**Efficiency *%***	**Equipment Price *2012$***	**Shipping Cost *2012$***	**Total Installed Cost *2012$***
Baseline	82.5	539	64	603
1	87.5	555	68	623
2	89.5	595	79	674
3	90.2	647	82	729
4	91.0	1,050	102	1,152

Table 8.2.6 Representative Unit 2: NEMA Design B, T-Frame, 30 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	**Efficiency *%***	**Equipment Price *2012$***	**Shipping Cost *2012$***	**Total Installed Cost *2012$***
Baseline	89.5	1,384	226	1,610
1	92.4	1,740	281	2,021
2	93.6	1,848	286	2,133
3	94.1	2,056	323	2,378
4	94.5	3,198	441	3,639

Table 8.2.7 Representative Unit 3: NEMA Design B, T-Frame, 75 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	93.0	3,088	488	3,576
1	94.1	3,323	538	3,860
2	95.4	3,742	601	4,344
3	95.8	4,416	665	5,082
4	96.2	5,683	778	6,461

Table 8.2.8 Representative Unit 4: NEMA Design C, T-Frame, 5 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	87.5	540	56	596
1	89.5	576	65	641
2	91.0	976	83	1,059

Table 8.2.9 Representative Unit 5: NEMA Design C, T-Frame, 50 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	93.0	2,509	431	2,941
1	94.5	3,401	510	3,910
2	95.0	4,085	525	4,610

Table 8.2.10 Representative Unit 6: Fire Pump Electric Motor, 5 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	87.5	556	68	625
1	89.5	596	79	676
2	90.2	649	82	731
3	91.0	1,051	102	1,153

Table 8.2.11 Representative Unit 7: Fire Pump Electric Motor, 30 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	92.4	1,772	281	2,052
1	93.6	1,879	286	2,164
2	94.1	2,087	323	2,410
3	94.5	3,230	441	3,670

Table 8.2.12 Representative Unit 8: Fire Pump Electric Motor, 75 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	94.1	3,343	538	3,881
1	95.4	3,763	601	4,364
2	95.8	4,437	665	5,102
3	96.2	5,703	778	6,482

Table 8.2.13 Representative Unit 9: Brake Motor, 5 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	82.5	539	64	603
1	87.5	555	68	623
2	89.5	595	79	674
3	90.2	647	82	729
4	91.0	1,050	102	1,152

Table 8.2.14 Representative Unit 10: Brake Motor, 30 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2012$*	Shipping Cost *2012$*	Total Installed Cost *2012$*
Baseline	89.5	1,384	226	1,610
1	92.4	1,740	281	2,021
2	93.6	1,848	286	2,133
3	94.1	2,056	323	2,378
4	94.5	3,198	441	3,639

8.2.2 Operating Cost Inputs

DOE defines the operating cost, OC, by the following equation:

$$OC = EC + RC + MC$$

Where:

EC = energy expenditure associated with operating the equipment,
RC = repair cost associated with component failure, and
MC = cost for maintaining equipment operation.

Table 8.2.15 shows the inputs for determining the operating costs. The inputs listed in Table 8.2.15 are also necessary for determining the present value of lifetime operating expenses, which include the energy price trends, equipment lifetime, discount rate, and effective date of the standard.

Table 8.2.15 Inputs for Operating Cost

Annual Energy Consumption
Energy Prices
Repair and Maintenance Costs
Energy Price Trends
Product Lifetime
Discount Rate
Effective Date of Standard

The *annual energy consumption* is the site energy use associated with operating the equipment. *Energy prices* are the prices paid by end-users for energy supply, including both energy and demand charges. Multiplying the annual energy and demand by the appropriate prices yields the annual energy cost. *Repair costs* are associated with repairing or replacing components that have failed, and *maintenance costs* are associated with maintaining the operation of the equipment. DOE used *energy price trends* to forecast energy supply prices into the future and, along with the equipment lifetime and discount rate, to establish the lifetime energy supply costs. The *equipment lifetime* is the age at which the equipment is retired from service. The *discount rate* is the rate at which DOE discounted future expenditures to establish their present value. DOE calculated the operating cost for the baseline equipment based on the following equation:

$$\begin{aligned} OC_{BASE} &= EC_{BASE} + RC_{BASE} + MC_{BASE} \\ &= AEC_{BASE} \times PRICE_{ENERGY} + RC_{BASE} + MC_{BASE} \end{aligned}$$

Where:

OC_{BASE} =	baseline operating cost,
EC_{BASE} =	energy expenditures associated with operating the baseline equipment, which may include reactive power costs,
RC_{BASE} =	repair cost associated with component failure for the baseline equipment,
MC_{BASE} =	cost for maintaining baseline equipment operation,
AEC_{BASE} =	annual energy consumption for baseline equipment, and
$PRICE_{ENERGY}$ =	energy price.

DOE calculated the operating cost for standard-level equipment based on the following equation:

$$\begin{aligned} OC_{STD} &= EC_{STD} + RC_{STD} + MC_{STD} \\ &= AEC_{STD} \times PRICE_{ENERGY} + RC_{STD} + MC_{STD} \\ &= \left(AEC_{BASE} - \Delta AEC_{STD}\right) \times PRICE_{ENERGY} + \left(RC_{BASE} + \Delta RC_{STD}\right) + \left(MC_{BASE} + \Delta MC_{STD}\right) \end{aligned}$$

Where:

OC_{STD} =	standard-level operating cost,
EC_{STD} =	energy expenditures associated with operating standard-level equipment,
RC_{STD} =	repair cost associated with component failure for standard-level equipment,
MC_{STD} =	cost for maintaining standard-level equipment operation,
AEC_{STD} =	annual energy consumption for standard-level equipment,
$PRICE_{ENERGY}$ =	energy price,
ΔAEC_{STD} =	decrease in annual energy consumption caused by standard-level equipment,
ΔRC_{STD} =	change in repair cost caused by standard-level equipment, and
ΔMC_{STD} =	change in maintenance cost caused by standard-level equipment.

The remainder of this section provides information about each of the above input variables that DOE used to calculate the operating costs for electric motors.

8.2.2.1 Annual Energy Consumption

Chapter 7, Energy Use Characterization, details how DOE determined the annual energy consumption for baseline and standard-level equipment and provides the average annual energy consumption by efficiency level for each representative unit. DOE captured the variability in energy consumption by estimating energy consumption for a variety of motor-using applications.

DOE used several assumptions to account for a possible decrease in efficiency each time the motor is repaired, which would increase the annual energy consumption. First, for the industrial and commercial sector, DOE assumed that 1 to 20 hp motors are not repaired; motors from 21 to 100 hp are repaired at half their lifetime; and motors from 101 to 500 hp are repaired at a third of their lifetime. For the agricultural sector, DOE did not find sufficient data to distinguish by horsepower range and assumed that motors are repaired on average at half of their lifetime. Based on the mechanical lifetime estimates (see section 8.2.3) and operating hours estimates (see chapter 7), this corresponds to a repair frequency of 48,600 hours in the industrial sector. DOE also assumed that fire pump electric motors are not repaired because of their low annual operating hours. Second, DOE assumed that 90% of repairs are performed following industry recommended practice and, therefore, do not affect the efficiency of the motor; that is, there is no degradation of efficiency after a repair[4]. In addition, DOE assumed that 10% of repairs do not follow good practice and that the repair results in a slight decrease in efficiency. This estimate of the number of repairs following industry recommended practices was based on the share of motor repair shops that are members of the Electrical Apparatus Service Association (EASA), assuming members of EASA follow the EASA recommended practices[5]. Lastly, for the cases in which good practices were not followed during repairs, DOE assumed the efficiency drops by 1 percent in the case of motors of less than 40 hp and by 0.5 percent in the case of larger motors[6].

8.2.2.2 Energy Prices

To estimate the energy prices faced by motor end-users throughout the United States, DOE uses sector-specific regional electricity prices, as well as a statistical distribution of motors across sectors and regions, to assign an appropriate electricity price to each motor end-user.

First, DOE distributed the motors across the three sectors using data from an Easton Consultants report[7] (see Table 8.2.16).

Table 8.2.16 Distribution Across Sector by Motor Size

Horsepower range (hp)	Industrial	Agricultural	Commercial
1-50	26.11	0.11	73.78
51-100	63.27	6.98	29.75
101-200	76.03	3.35	20.62
201-500	69.09	3.03	27.88

Then, for each sector, DOE distributed the motors in four Census regions based on the following indicators:

- industry electricity consumption by region from the *AEO2013* for the industrial sector[8];
- value of shipments of agricultural products from the U.S Census of Agriculture for the agricultural sector [9]; and
- commercial floor space from the Commercial Building Energy Consumption Survey for the commercial sector[10].

Table 8.2.17 shows the resulting distribution.

Table 8.2.17 Sector-Specific Share of Electric Motors by Census Region

Census Region	Agricultural *%*	Industrial *%*	Commercial *%*
Northeast	4.6	9.7	19.5
Midwest	42.8	29.3	25.3
South	29.5	44.6	37.3
West	23.1	16.4	17.9

For each sector, DOE then estimated weighted regional average prices using EIA Form 861 data.[11] These data are published annually and include annual electricity usage in kilowatt-hours (kWh), revenues from electricity sales, and number of consumers for the residential, commercial, and industrial sectors for every utility serving final consumers. The calculation used the most recent EIA data available at the time the analysis was conducted. Table 8.2.18 shows the average agricultural, industrial, and commercial electricity prices in 2011 for each Census region.

Table 8.2.18 Average Electricity Prices in 2011

Census Region	Average Agricultural Price *2012$/kWh*	Average Industrial Price *2012$/kWh*	Average Commercial Price *2012$/kWh*
Northeast	0.084	0.084	0.117
Midwest	0.081	0.081	0.089
South	0.076	0.076	0.098
West	0.081	0.081	0.117
Average (weighted)	0.080	0.080	0.104

8.2.2.3 Energy Price Trends

DOE used price forecasts by the EIA to estimate the trends in electricity prices for all sectors. To arrive at prices in future years, DOE multiplied the average prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO2013*. To estimate the trend after 2040, DOE followed past guidelines provided to the Federal Energy Management Program by the EIA and used the average rate of change during 2025–2040 for electricity prices.

As an example, Figure 8.2-3 shows the projected trends in industrial electricity prices based on the *AEO2013* reference case. For the LCC results presented in this chapter, DOE used only the energy price forecast from the *AEO2013* reference case.

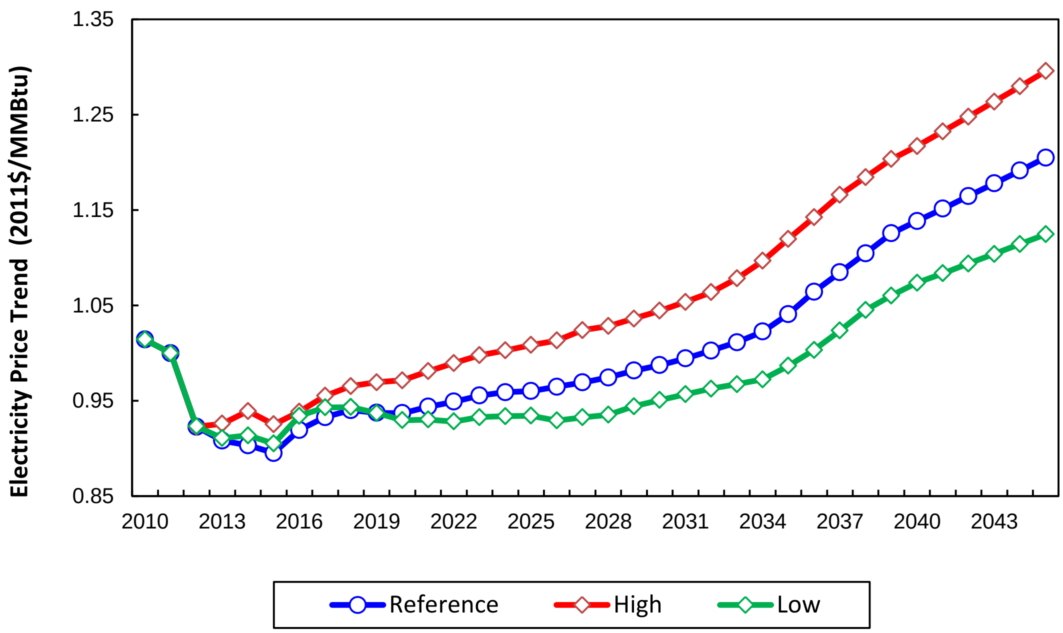

Figure 8.2-3 Industrial Electricity Price Trends

8.2.2.4 Repair and Maintenance Costs

DOE defined a motor repair as repair as including rewinding and reconditioning. DOE accounted for the differences in repair costs of a higher efficiency motor compared to a baseline efficiency motor. Based on data from Vaughen's[12], DOE derived a model to estimate repair costs by horsepower, enclosure, and pole for each efficiency level:

$$RepairCost = R(\hbar p, poles, encl, CSL),$$

$$R(\hbar p, poles, encl, CSL) = R'(\hbar p, poles) \cdot R''(encl) \cdot A(EL),$$

where:

$$R'(\hbar p, poles) = r_2(\hbar p, poles) + r_1(\hbar p, poles) + r_0(poles),$$

with:

$$r_2(hp, poles) = (-0.000005 \cdot poles) \cdot hp^2,$$

$$r_1(hp, poles) = (-0.00024 \cdot poles^2 + 0.00178 \cdot poles + 0.03859) \cdot hp,$$

$$r_0(poles) = (0.01886 \cdot poles^2 - 0.07154 \cdot poles + 0.89775),$$

and,

$$R''(encl) = \begin{cases} 1.0, & Open, \\ 1.2, & Enclosed, \end{cases}$$

and A(EL) is given by Table 8.2.19:

Table 8.2.19 Repair Cost Calculation Parameters

Efficiency level	**A(EL) by Equipment Class Group**			
	1 (NEMA Design A and B motors)	**2 (NEMA Design C motors)**	**3 (Fire pump electric motors)**	**4 (Brake motors)**
Baseline	0%	0%	0%	15%
EL 1	0%	15%	15%	15%
EL 2	15%	27%	27%	32%
EL 3	27%	n/a	39%	45%
EL 4	39%	n/a	n/a	60%

Table 8.2.20 shows the resulting repair cost estimates for all horsepower, enclosure, and pole combinations for equipment class group 1 motors (NEMA Design A and B) with baseline efficiency.

Table 8.2.20 Repair Cost Estimates at EL 0 (Equipment Class Group 1)

EL 0	Open				Enclosed			
hp	2 poles	4 poles	6 poles	8 poles	2 poles	4 poles	6 poles	8 poles
1	359	337	429	583	431	404	515	699
1.5	368	346	439	595	442	415	527	714
2	378	354	450	607	453	425	540	729
3	396	372	470	632	475	446	564	759
5	433	406	511	682	519	487	614	818
7.5	479	449	563	743	575	539	675	892
10	525	492	614	805	630	591	736	965
15	616	578	715	927	739	694	858	1,112
20	707	664	817	1,048	849	796	980	1,258
25	798	749	917	1,169	958	899	1,101	1,403
30	888	834	1,017	1,289	1,066	1,000	1,221	1,547
40	1,068	1,002	1,216	1,527	1,282	1,203	1,459	1,833
50	1,246	1,169	1,413	1,762	1,495	1,403	1,695	2,115
60	1,423	1,335	1,607	1,995	1,707	1,602	1,928	2,394
75	1,685	1,581	1,895	2,338	2,022	1,897	2,274	2,805
100	2,114	1,984	2,363	2,894	2,537	2,381	2,836	3,473
125	2,534	2,378	2,819	3,433	3,041	2,854	3,382	4,120
150	2,945	2,764	3,261	3,953	3,534	3,316	3,913	4,744
200	3,739	3,508	4,104	4,940	4,486	4,210	4,925	5,928
250	4,495	4,218	4,895	5,853	5,394	5,061	5,874	7,024
300	5,214	4,892	5,632	6,694	6,257	5,871	6,759	8,033
350	5,896	5,532	6,316	7,462	7,075	6,638	7,579	8,954
400	6,540	6,137	6,946	8,157	7,848	7,364	8,335	9,788
450	7,147	6,706	7,523	8,779	8,576	8,048	9,028	10,535
500	7,717	7,241	8,046	9,328	9,260	8,689	9,656	11,194

Table 8.2.21 summarizes the repair cost for representative units by efficiency level.

Table 8.2.21 Summary of Repair Cost for Each Representative Unit by Energy Efficiency Level ($2012)

	Representative Unit									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Baseline	487	1,000	1,897	487	1,403	487	1,000	1,897	561	1,150
EL 1	487	1,000	1,897	561	1,614	561	1,150	2,182	561	1,150
EL 2	561	1,150	2,182	617	1,775	617	1,265	2,400	645	1,323
EL 3	617	1,265	2,400	n/a	n/a	678	1,392	2,640	709	1,455
EL 4	678	1,392	2,640	n/a	n/a	n/a	n/a	n/a	780	1,601

For the maintenance costs, DOE did not find data indicating a variation in maintenance costs between baseline efficiency and higher efficiency motors. According to Vaughen's, the price of replacing bearings, which is the most common maintenance practice, is the same at all efficiency levels.

8.2.3 Motor Lifetime

Where data were available, DOE established sector-specific motor lifetime estimates to account for differences in maintenance practices and field usage conditions. DOE relied on several sources to inform its lifetime model: for the industrial sector, DOE consulted an industrial expert and obtained estimates of average mechanical lifetimes by horsepower range[13]; for the agricultural sector, DOE referred to an article by Michael Gallaher *et al*[14] for determining average motor lifetimes; and for the commercial sector, because DOE could not find sector-specific estimates, it used average motor lifetimes by horsepower range from the *Energy Efficient Motor Systems* handbook[15] instead.

DOE then converted all lifetimes into mechanical lifetimes in hours based on typical annual operating hours by horsepower range and sector (see chapter 6, Energy Use Characterization for operating hours). Table 8.2.22 presents the resulting lifetimes.

Table 8.2.22 Motor Lifetime by Horsepower Range and Sector

Lifetime	Horsepower Range	Industrial Sector*	Agricultural Sector**	Commercial Sector***
Mechanical ***Hours***	1 – 5	43,800	28,578	37,060
	6 – 20	43,800	27,966	44,248
	21 – 50	87,600	26,555	63,596
	51 – 100	87,600	25,870	88,675
	101 – 200	131,400	24,659	85,548
	201 – 500	131,400	27,597	73,018
Weighted Average Across Applications† ***Years***	1 – 5	8	20.0	17.1
	6 – 20	8	20.0	19.4
	21 – 50	15	20.0	21.8
	51 – 100	14	20.0	28.5
	101 – 200	21	20.0	28.0
	201 – 500	21	20.0	29.0

* Weighted average lifetimes in years were calculated based on the mechanical lifetime estimates and dividing by the weighted average annual operating hours across applications and equipment class groups. [13]
** Mechanical lifetimes were calculated based on an average 20-year lifetime estimate in agriculture and multiplying by the weighted average annual operating hours across applications and equipment class groups.[14]
*** Mechanical lifetimes were calculated based on average lifetime estimates by horsepower range and multiplying by the weighted average annual operating hours across applications and equipment class groups. [15]

In the LCC, DOE used a motor lifetime model that combines annual operating hours by application and sector with motor mechanical lifetime in hours to estimate the distribution of motor lifetimes in years. This model results in a negative correlation between annual hours of operation and motor lifetime; motors operated many hours per year are likely to be retired sooner than motors that are used for only a few hundred hours per year.

Further, motors that are smaller than 75 horsepower are typically embedded in other equipment (*i.e.*, "application") such as pumps or compressors. For each of these motors (less than 75 hp), DOE determined the lifetime in years by dividing the mechanical lifetime in hours by the annual hours of operation. DOE then compared this lifetime (in years) with the sampled application lifetime (also in years) and assumed that the motor would be retired at the younger of these two ages. For example, a pump motor with annual operating hours of 2,500 hours per year may have a mechanical lifetime of 30,000 hours (12 years) and an application lifetime of 10 years. DOE assumed the motor would retire in 10 years, when its application reached the end of its lifetime, even if the motor itself could run for two more years. If the pump motor were to run for 6,000 hours per year, with the same mechanical and application lifetimes, DOE would assume it would retire after 5 years due to motor failure upon reaching its mechanical lifetime of 30,000 hours.

Table 8.2.23 presents the average application lifetimes used in the LCC [16,17,18,19].

Table 8.2.23 Average Application Lifetime

Application	**Average Lifetime *Yr***
Air Compressor	15
Fans	15
Pumps	11
Material Handling	20
Other	15

The DOE's motor lifetime model relies on four distributions: (1) the annual operating hours distribution derived for use in the energy use analysis (see chapter 6); (2) the distribution of motor shipments into six application areas, each with its own distribution of annual hours of operation; (3) a Weibull distribution of mechanical motor lifetimes, expressed in total hours of operation before failure; and (4) a Weibull distribution of application lifetimes, expressed in years. DOE used its estimate of motor mechanical lifetime in hours and application lifetime in years to develop the parameters for the Weibull distributions for all represented units. DOE's Monte Carlo analysis of a motor's LCC selected an application, an appropriate number of hours of operation, a motor mechanical lifetime, and an application lifetime from these distributions in order to calculate the sampled motor's lifetime in years.

The national impact analysis (NIA) calculation uses average lifetimes in years by equipment class group, horsepower range, and sector. DOE used the application-specific annual operating hours and application distributions in order to convert the motor mechanical lifetimes into average lifetimes in years. Results are presented in Table 8.2.24 by equipment class group, horsepower range, and sector. Further, based on a literature review,[20,21,22] DOE assumed that the maximum motor lifetime in years is 30 years.

Table 8.2.24 Weighted Average Lifetime by Equipment Class Groups and Sector

Horsepower Range *hp*	Equipment Class Group	Weighted Average Lifetime Across Applications *Yr*		
		Industrial	**Commercial**	**Agricultural**
1-5	Group 1 NEMA Design A and B Motors	8	17	20
6-20		8	19	20
21-50		15	22	20
51-100		14	29	20
101-200		21	28	19
201-500		21	29	20
1-5	Group 2 NEMA Design C Motors	8	17	19
6-20		8	19	19
21-50		16	27	18
51-100		16	33	17
101-200		23	29	16
1-5	Group 4 Brake Motors	8	19	19
6-20		9	20	19
21-30		17	27	18

For fire pump electric motors, DOE assumed an average lifetime of 29 years and developed a Weibull distribution around this value (both in the LCC and in the NIA).

DOE further developed Weibull distributions for each of these average lifetimes in years.

8.2.3.1 The Weibull Distribution

The Weibull distribution is a probability distribution commonly used to measure failure rates.[b] Its form is similar to an exponential distribution, which models a fixed failure rate, except that a Weibull distribution allows for a failure rate that changes over time in a particular fashion. The cumulative Weibull distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{, and}$$

$$P(x) = 1 \text{ for } x \leq \theta$$

Where:

$P(x)$ = probability that the equipment is still in use at age x,
x = equipment age,
α = scale parameter, which would be the decay length in an exponential distribution,
β = shape parameter, which determines the way in which the failure rate changes through time, and
θ = delay parameter, or location, which allows for a delay before any failures occur.

[b] For reference on the Weibull distribution, see sections 1.3.6.6.8 and 8.4.1.3 of the *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

When $\beta = 1$, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of mechanical equipment, β commonly is greater than 1, reflecting an increasing failure rate as equipment ages.

8.2.3.2 Mechanical Motor Lifetime and Application Lifetime

DOE's derived Weibull parameters for each representative unit's mechanical lifetimes are listed in Table 8.2.25. The Weibull parameters account for a three-year manufacturer warranty period. During this period DOE assumes that no motors fail.

Table 8.2.25 Weibull Parameters for Mechanical Motor Lifetimes by Sector

Representative Unit		Industrial Sector			Commercial Sector			Agricultural Sector		
		A	***β***	***θ***	***A***	***β***	***θ***	***A***	***β***	***θ***
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	19,712	2.65	26,280	34,339	2.65	6,540	27,331	2.65	4,287
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	68,993	2.65	26,280	61,796	2.65	8,672	25,396	2.65	3,983
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	68,993	2.65	26,280	89,450	2.65	9,173	24,741	2.65	3,880
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	19,712	2.65	26,280	34,339	2.65	6,540	27,331	2.65	4,287
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	68,993	2.65	26,280	61,796	2.65	8,672	25,396	2.65	3,983
9	Brake motor, 5 hp	19,712	2.65	26,280	34,339	2.65	6,540	27,331	2.65	4,287
10	Brake motor, 30 hp	68,993	2.65	26,280	61,796	2.65	8,672	25,396	2.65	3,983

DOE's derived Weibull parameters for motor applications are listed in Table 8.2.26.

Table 8.2.26 Weibull Parameters for Application Lifetime

	Application	Parameters		
		α	*Β*	*θ*
1	Fan	8.44	2.65	7.50
2	Air Compressor	8.44	2.65	7.50
3	Pump	6.19	2.65	5.50
4	Material Handling	11.25	2.65	10.00
5	Others	8.63	2.65	7.67
6	Fire Pump	26.14	110.09	3.00

In the scope of this life-cycle analysis, DOE combines these two distributions with the appropriately weighted duty factor distribution to select a lifetime for each motor.

Table 8.2.27 summarizes calculated motor lifetimes of sampled motors.

Table 8.2.27 Summary of Sampled Motor Lifetimes

Representative Unit		Median *yr*	Min *yr*	Max *yr*	Average *yr*
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	10.5	2.3	31.3	10.1
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	12.2	2.9	35.4	12.5
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	10.3	2.7	30.6	10.9
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	10.9	2.3	31.8	10.5
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	12.8	2.8	33.1	13.1
6	Fire pump, 5 hp, 4 poles, enclosed	28.8	14.8	51.4	29.1
7	Fire pump, 30 hp, 4 poles, enclosed	28.8	14.8	51.4	29.1
8	Fire pump, 75 hp, 4 poles, enclosed	28.8	14.8	51.4	29.1
9	Brake motor, 5 hp	28.8	14.8	51.4	29.1
10	Brake motor, 30 hp	28.8	14.8	51.4	29.1

8.2.4 Discount Rates

DOE derived the discount rates for the LCC and PBP analysis from estimates of the finance cost of purchasing the considered products. Following financial theory, the finance cost of raising funds to purchase equipment can be interpreted as: (1) the financial cost of any debt incurred to purchase equipment, or (2) the opportunity cost of any equity used to purchase equipment. DOE defines the discount rate as the weighted average cost of capital (WACC), calculated as the weighted average of the cost of equity financing and the cost of debt financing, as estimated from financial data for publicly traded firms in the sectors that purchase motors.

Damodaran Online is a widely used source of information about company debt and equity financing for most types of firms and was the primary source of data for this analysis.[23] Detailed sectors included in the Damondaran Online database were assigned to the aggregate categories of industrial or commercial. Due to limited data availability, DOE applies the discount rate estimated for the industrial sector to the agricultural sector.

DOE estimated the cost of equity using the capital asset pricing model (CAPM).[24] The CAPM assumes that the cost of equity (k_e) for a particular company is proportional to the systematic risk faced by that company, where high risk is associated with a high cost of equity and low risk is associated with a low cost of equity. The systematic risk facing a firm is determined by several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (*ERP*). The risk coefficient of the firm indicates the risk associated with that firm relative to the price variability in the stock market. The expected return on risk-free assets is defined by the yield on long-term government bonds. The *ERP* represents the difference between the expected stock market return and the risk-free rate. The cost of equity financing is estimated using the following equation, where the variables are defined as above:

$$k_e = R_f + (\beta \times ERP)$$

Where:

k_e = cost of equity,
R_f = expected return on risk-free assets,
β = risk coefficient of the firm, and
ERP = equity risk premium.

Several parameters of the cost of capital equations can vary substantially over time and, therefore, the estimates can vary with the time period over which data is selected and the technical details of the data-averaging method. For guidance on the time period for selecting and averaging data for key parameters and the averaging method, DOE used Federal Reserve methodologies for calculating these parameters. In its use of the CAPM, the Federal Reserve uses a forty-year period for calculating discount rate averages, utilizes the gross domestic product price deflator for estimating inflation, and considers the best method for determining the risk-free rate as one where "the time horizon of the investor is matched with the term of the risk-free security."[25]

By taking a forty-year geometric average of Federal Reserve data on annual nominal returns for 10-year Treasury bills, DOE estimated the following risk-free rates for 2010-2012 (Table 8.2.28).[26] DOE also estimated the ERP by calculating the difference between the risk-free rate and stock market return for the same time period, as estimated using Damodaran Online data on the historical return to stocks.[27]

Table 8.2.28 Risk-free rate and equity risk premium, 2010-2012

Year	Risk-free rate (%)	ERP (%)
2010	6.74	3.23
2011	6.61	2.94
2012	6.41	3.46

The cost of debt financing (k_d) is the interest rate paid on money borrowed by a company. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate. This risk adjustment factor depends on the variability of stock returns represented by standard deviations in stock prices. So for firm *i*, the cost of debt financing is:

$$k_{di} = R_f + R_{ai}$$

Where:

k_d = cost of debt financing for firm, *i*,
R_f = expected return on risk-free assets, and

R_{ai} = risk adjustment factor to risk-free rate for firm, *i*.

DOE estimates the WACC using the following equation:

$$WACC = k_e \times w_e + k_d \times w_d$$

Where:

$WACC$ = weighted average cost of capital,
w_e = proportion of equity financing, and
w_d = proportion of debt financing.

By adjusting for the influence of inflation, DOE estimates the real weighted average cost of capital, or discount rate, for each sector. DOE then aggregates the sectoral real weighted average costs of capital to estimate the discount rate for each of the three non-residential ownership types in the medium electric motors analysis, weighting each sector's discount rate by the number of companies in the sector.[c]

Table 8.2.29 shows the weighted average WACC values and distribution by ownership types in the medium electric motors analysis. While WACC values for any sector may trend higher or lower over substantial periods of time, these values represent a private sector cost of capital that is averaged over major business cycles. For the agricultural sector, DOE used the discount rates as calculated in the industrial sector.

Table 8.2.29 Distribution and Weighted Average Cost of Capital for Sectors that Purchase Medium Electric Motors

Cost of Capital (%)	Industrial Cost of Capital Distribution (%)	Cost of Capital (%)	Commercial Cost of Capital Distribution (%)
3.20	0.88	2.64	0.88
3.56	8.85	2.99	0.88
3.92	0.00	3.33	0.00
4.28	1.77	3.68	0.88
4.63	0.00	4.03	3.54
4.99	3.54	4.37	7.08
5.35	5.31	4.72	7.96
5.71	8.85	5.07	13.27
6.07	11.50	5.41	15.04

[c] Giving equal weight to each industry, rather than weighting by number of companies leads to a similar estimate of discount rates; the mean industrial / agricultural discount rate is estimated to be 6.06% and the mean commercial discount rate is estimated to be 5.92%.

6.43	15.93	5.76	9.73
6.79	13.27	6.11	12.39
7.15	10.62	6.45	11.50
7.51	4.42	6.80	7.08
7.87	5.31	7.15	4.42
8.23	6.19	7.49	3.54
8.59	1.77	7.84	0.88
8.95	1.77	8.19	0.88
Weighted average	6.34	**Weighted average**	5.66

8.2.5 Effective Date and Compliance Date of Standard

Any amended standard for electric motors shall apply to electric motors manufactured on or after a date which is five years after the effective date of the previous amendment. (42 U.S.C. 6313(b)(4)) In this case, the effective date of the previous amendment (established by EISA in 2007) is December 19, 2010, and the compliance date of any newly amended energy conservation standards for electric motors is December 19, 2015. Thus, for the LCC analysis, DOE assumed a compliance date of December 19, 2015. This was modeled using a date of January 1st 2016 in the LCC analysis.

8.2.6 Product Energy Efficiency in the Base Case

For purposes of conducting the LCC analysis, DOE analyzed efficiency levels relative to a base case (*i.e.*, the case without new energy efficiency standards). This requires an estimate of the distribution of product efficiencies in the base case (*i.e.*, what consumers would have purchased in the compliance year in the absence of new standards). DOE refers to this distribution of product energy efficiencies as the base-case efficiency distribution.

DOE used six major manufacturer and one distributor's catalog data to develop the base-case efficiency distributions using the number of models (in all representative units) meeting the requirements of each efficiency level in year 2012. The distribution is estimated separately for each representative unit.

Table 8.2.30 shows the energy efficiency distribution for in the base case for all representative units in 2012.

Table 8.2.30 Base Case Energy Efficiency Distribution in 2012

Unit #1: NEMA Design B, T-Frame, 5 hp, 4 poles, Enclosed		
Efficiency Level	**FL* Nominal Efficiency**	**Share**
0	82.5%	13.5%
1	87.5%	29.9%
2	89.5%	34.1%
3	90.2%	14.4%
4	91.0%	8.1%
Unit #2: NEMA Design B, T-Frame, 30 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	89.5%	7.4%
1	92.4%	34.5%
2	93.6%	41.5%
3	94.1%	9.1%
4	94.5%	7.5%
Unit #3: NEMA Design B, T-Frame, 75 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	93.0%	10.3%
1	94.1%	25.2%
2	95.4%	39.2%
3	95.8%	17.0%
4	96.2%	8.3%
Unit #4: NEMA Design C, T-Frame, 5 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	87.5%	91.7%
1	89.5%	8.3%
2	91.0%	0.0%
Unit #5: NEMA Design C, T-Frame, 50 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	93.0%	73.3%
1	94.5%	26.7%
2	95.0%	0.0%
Unit #6: Fire pump electric motor, 5 h, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	87.5%	82.1%
1	89.5%	12.8%
2	90.2%	5.1%
3	91.0%	0.0%
Unit #7: Fire pump electric motor, 30 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	92.4%	80.7%
1	93.6%	6.4%
2	94.1%	12.8%
3	94.5%	0.0%
Unit #8: Fire Pump, 75 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	94.1%	80.6%
1	95.4%	10.2%
2	95.8%	9.2%

3	96.2%	0.0%
Unit #9: Brake Motor 5 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	82.5%	36.5%
1	87.5%	34.8%
2	89.5%	27.5%
3	90.2%	0.9%
4	91.0%	0.4%
Unit #10: Brake Motor 30 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	89.5%	25.0%
1	92.4%	62.5%
2	93.6%	12.5%
3	94.1%	0.0%
4	94.5%	0.0%

*FL = Full Load

In order to establish the base case efficiency distribution in the compliance year, DOE assumed the efficiency distributions for equipment class group 1 and 4 vary over time based on historical data[28] for the market penetration of NEMA Premium motors within the market for integral AC induction motors. The assumed trend is detailed in chapter 10 of the NOPR TSD. For equipment class group 2 and 3, which represent a very minor share of the market (less than 0.2 percent), DOE believes the overall trend in efficiency improvement for the total integral AC induction motors may not be representative, so it kept the base case efficiency distributions in the compliance year equal to 2012 levels.

Using the base case efficiency distribution in the compliance year, DOE assigned an efficiency rating to each motor unit. If a unit is assigned an efficiency rating that is greater than or equal to the efficiency of the standard level under consideration, the LCC calculation shows that this unit would not be affected by that standard level.

Table 8.2.31   Base Case Energy Efficiency Distribution in the Compliance Year

Unit #1: NEMA Design B, T-Frame, 5 hp, 4 poles, Enclosed		
Efficiency Level	**FL* Nominal Efficiency**	**Share**
0	82.5%	11.0%
1	87.5%	29.9%
2	89.5%	36.6%
3	90.2%	14.4%
4	91.0%	8.1%
Unit #2: NEMA Design B, T-Frame, 30 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	89.5%	4.9%
1	92.4%	34.5%
2	93.6%	44.0%
3	94.1%	9.1%
4	94.5%	7.5%
Unit #3: NEMA Design B, T-Frame, 75 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	93.0%	7.8%
1	94.1%	25.2%
2	95.4%	41.7%
3	95.8%	17.0%
4	96.2%	8.3%
Unit #4: NEMA Design C, T-Frame, 5 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	87.5%	91.7%
1	89.5%	8.3%
2	91.0%	0.0%
Unit #5: NEMA Design C, T-Frame, 50 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	93.0%	73.3%
1	94.5%	26.7%
2	95.0%	0.0%
Unit #6: Fire pump electric motor, 5 h, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	87.5%	82.1%
1	89.5%	12.8%
2	90.2%	5.1%
3	91.0%	0.0%
Unit #7: Fire pump electric motor, 30 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	92.4%	80.7%
1	93.6%	6.4%
2	94.1%	12.8%
3	94.5%	0.0%
Unit #8: Fire Pump, 75 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	94.1%	80.6%
1	95.4%	10.2%

2	95.8%	9.2%
3	96.2%	0.0%
Unit #9: Brake Motor 5 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	82.5%	34.0%
1	87.5%	34.8%
2	89.5%	30.0%
3	90.2%	0.9%
4	91.0%	0.4%
Unit #10: Brake Motor 30 hp, 4 poles, Enclosed		
Efficiency Level	**FL Nominal Efficiency**	**Share**
0	89.5%	22.5%
1	92.4%	62.5%
2	93.6%	15.0%
3	94.1%	0.0%
4	94.5%	0.0%

*FL = Full Load

8.3 PAYBACK PERIOD INPUTS

The PBP is the amount of time it takes the consumer to recover the assumed higher purchase expense of more energy-efficient equipment as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase expense (*i.e.*, from a less efficient design to a more efficient design) to the decrease in annual operating expenditures. This type of calculation is known as a "simple" PBP, because it does not take into account changes in operating expense over time or the time value of money; the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Where:

ΔIC = change, generally an increase in the total installed cost between the more efficient standard level and the baseline design, and
ΔOC = change, generally decrease in annual operating expenses.

A PBP is expressed in years. A PBP that is greater than the life of the product indicates that the increased total installed cost is not recovered in reduced operating expenses.

The data inputs to PBP are the total installed cost of the equipment to the purchaser for each efficiency level and the annual (first-year) operating expenditures for each standard level. The inputs to the total installed cost are the equipment price and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost. The PBP uses the same inputs as the LCC analysis as described in section 8.2, except that lifetime, energy price trends, and discount rates are not required. Because the PBP is a "simple" payback, the required energy price is only for the year in which compliance with a new standard is required. The energy price DOE used in the PBP calculation was the price projected for that year.

8.4 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS FOR REPRESENTATIVE UNITS

This section presents the LCC and PBP results for the representative units analyzed. As discussed in section 8.1.1, DOE's approach for conducting the LCC analysis relied on developing samples of customers for each representative unit. DOE also characterized the uncertainty of many of the inputs to the analysis with probability distributions. DOE used a Monte Carlo simulation technique to perform the LCC calculations on the customers in the sample. For each set of sample customers using motors in each representative unit, DOE calculated the average LCC and LCC savings and the median and average PBP for each of the standard levels.

In the subsections below, DOE presents figures showing the distribution of LCCs in the base case for each representative unit. Also presented below for a specific standard level are figures showing the distribution of LCC impacts and the distribution of PBPs. The figures are presented as frequency charts that show the distribution of LCCs, LCC impacts, and PBPs with their corresponding probabilities of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples. The LCC and PBP calculations were performed 10,000 times by sampling from the probability distributions that DOE developed to characterize many of the inputs.

Based on the Monte Carlo simulations that DOE performed, for each efficiency level, DOE calculated the share of motor users with a net LCC benefit and with a net LCC cost. To illustrate the range of LCC and PBP impacts among motor end-users, the sections below present figures that provide such information for each representative unit.

8.4.1 Representative Unit 1, NEMA Design B, 5 Horsepower, 4 Poles, Enclosed Motor

Figure 8.4-1 is an example of a frequency chart showing the distribution of LCC savings for representative unit 1, at EL 2.

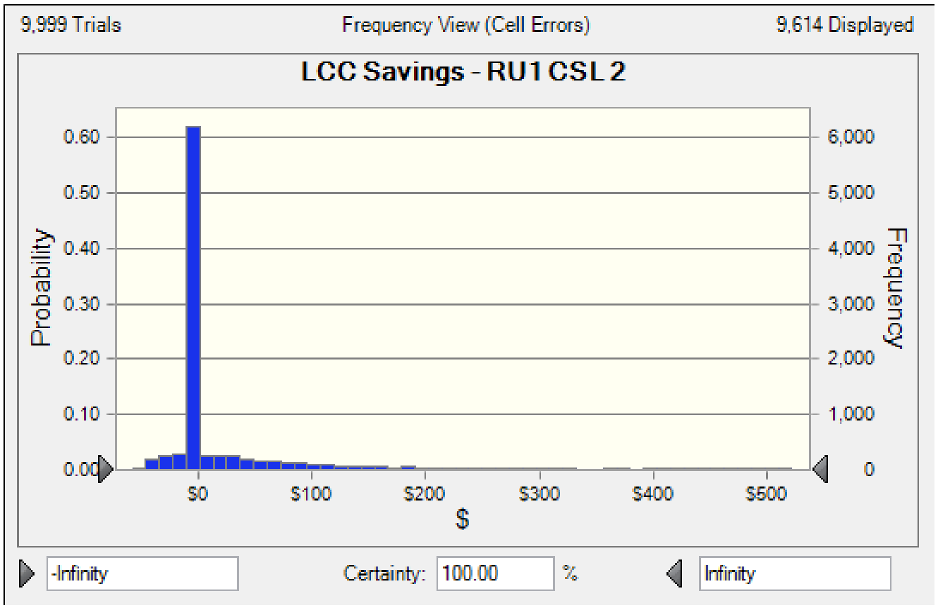

Figure 8.4-1 Representative Unit 1: Distribution of Life-Cycle Cost Savings for EL 2

Figure 8.4-2 is an example of a frequency chart showing the distribution of PBPs for the efficiency level corresponding to EL 3 for the representative unit 1. Because many motors operate for very few hours per year and because the operating cost savings is very small compared to the increase in first cost, there are a significant number of motors that may have extremely long PBPs. The distribution in the figure illustrates that most motors have a payback of less than 30 years, but the mean value of the distribution payback is larger (9.0 years) because of the small, but significant number of motors with PBPs longer than 30 years. Because of the skewed distribution in PBPs, DOE also considers the PBP of the typical customer, or the median of the distribution, which is 3.8 years for Figure 8.4-2.

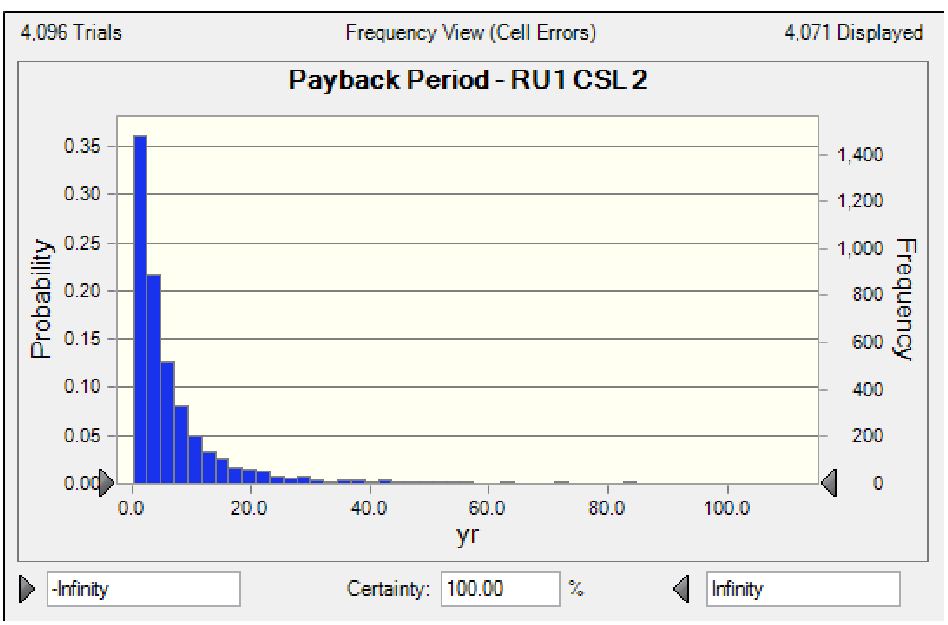

Figure 8.4-2 Representative Unit 1: Distribution of Payback Periods for EL 2

The distribution of PBPs for other representative units associated with other efficiency levels are illustrated in Appendix 8-B.

Table 8.4.1 summarizes the LCC and PBP results for representative unit 1 based on a run of 10,000 Monte Carlo samples. The most rigorous EL that provides positive average LCC savings is EL 3. DOE estimates that 42.0 percent of end-users would experience a net benefit (*i.e.*, LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $126, or 21.0 percent, while operating costs decrease by $78, or 10.1 percent.

Table 8.4.1 Life-Cycle Cost and Payback Period Results for Representative Unit 1: NEMA Design B, T-Frame, 5 horsepower, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	82.5	603	8,977	772	6,127	N/A	0.0	0.0	N/A	N/A
1	87.5	623	8,287	714	5,731	44	0.0	11.2	0.6	0.4
2	89.5	674	8,138	701	5,691	61	10.2	30.8	9.0	3.8
3	90.2	729	8,062	694	5,692	56	35.5	42.0	10.9	7.1
4	91.0	1,152	7,969	687	6,065	-283	85.4	6.8	63.3	31.4

8.4.2 Representative Unit 2, NEMA Design B, 30 Horsepower, 4 Poles, Enclosed Motor

Figure 8.4-3 is an example of a frequency chart showing the distribution of LCC savings for representative unit 2, at EL 2. The net benefit of LCC is $359 in this Monte Carlo run.

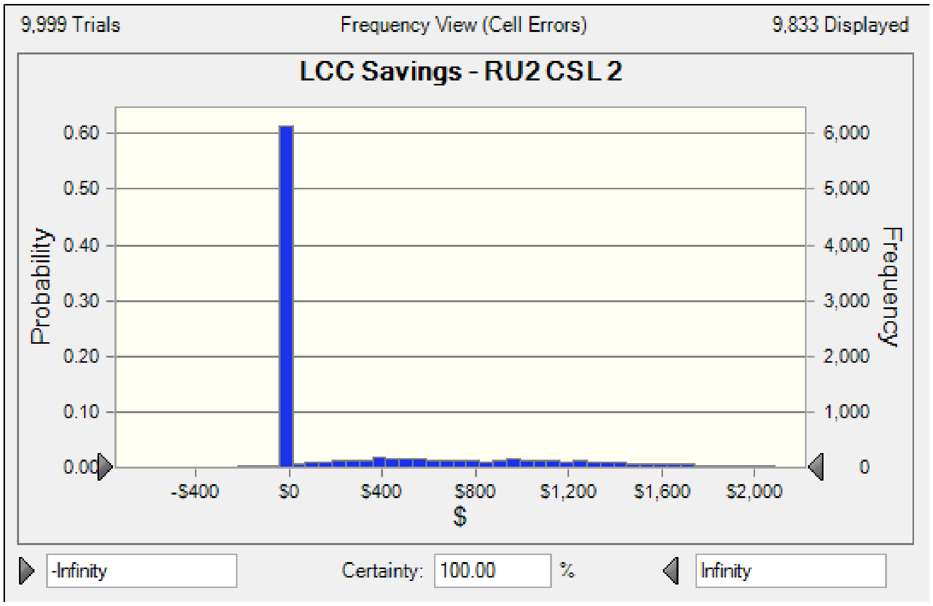

Figure 8.4-3 Representative Unit 2: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.2 summarizes the LCC and PBP results for representative unit 2 based on a run of 10,000 Monte Carlo samples. The most rigorous EL that provides positive average LCC savings is EL 3. DOE estimates that 36.1 percent of end-users would experience a net benefit (i.e., LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $768, or 47.7 percent, while operating costs decrease by $227, or 4.2 percent.

Table 8.4.2 Life-Cycle Cost and Payback Period Results for Representative Unit 2: NEMA Design B, T-Frame, 30 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	89.5	1,610	61,611	5,440	48,514	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	60,164	5,318	47,862	36	1.2	3.7	16.9	3.8
2	93.6	2,133	58,778	5,210	47,040	359	1.5	37.7	13.0	1.3
3	94.1	2,378	58,698	5,213	47,304	139	46.8	36.1	226	5.0
4	94.5	3,639	58,511	5,207	48,511	-978	83.9	8.6	196	25.6

8.4.3 Representative Unit 3, NEMA Design B, 75 Horsepower, 4 Poles, Enclosed Motor

Figure 8.4-4 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 2 for representative unit 3. The LCC net benefit is $618 in this Monte Carlo run.

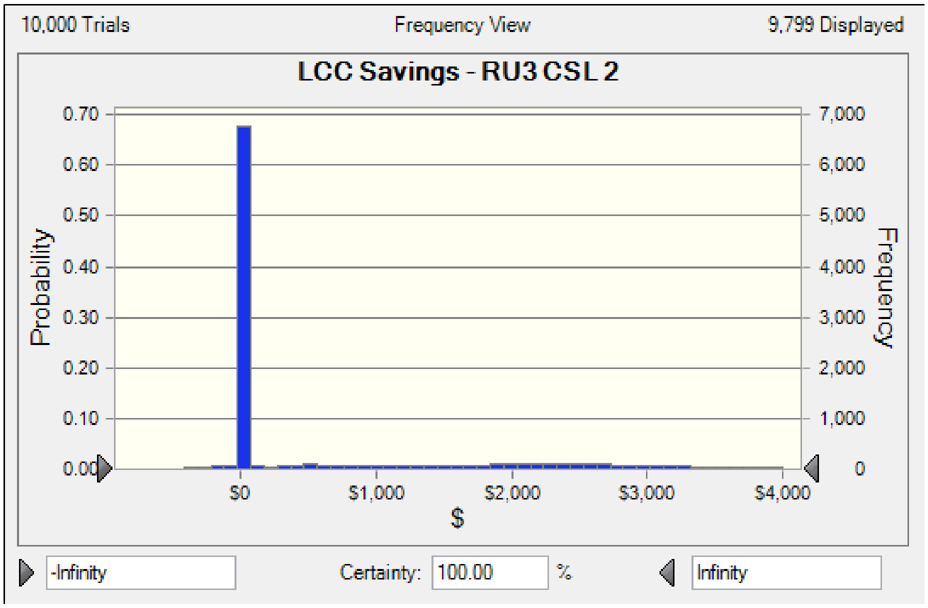

Figure 8.4-4 Representative Unit 3: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.3 summarizes the LCC and PBP results for representative unit 3 based on a run of 10,000 Monte Carlo samples. The most rigorous EL that provides positive average LCC savings is EL 2. DOE estimates that 30.1 percent of end-users would experience a net benefit (*i.e.*, LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $768, or 21.5 percent, while operating costs decrease by $354, or 2.3 percent.

Table 8.4.3 Life-Cycle Cost and Payback Period Results for Representative Unit 3: NEMA Design B, T-Frame, 75 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	3,576	195,566	15,283	131,207	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	194,167	15,194	130,778	48	2.9	5.2	20.8	3.5
2	95.4	4,344	190,458	14,929	129,034	626	2.7	30.1	5.2	1.9
3	95.8	5,082	190,392	14,944	129,898	-21	49.2	25.9	44.1	6.6
4	96.2	6,461	188,997	14,855	130,524	-594	70.3	21.2	65.4	16.1

8.4.4 Representative Unit 4, NEMA Design C, 5 Horsepower, 4 Poles, Enclosed Motor

Figure 8.4-5 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 1 for representative unit 4. The LCC net benefit is $52 in this Monte Carlo run.

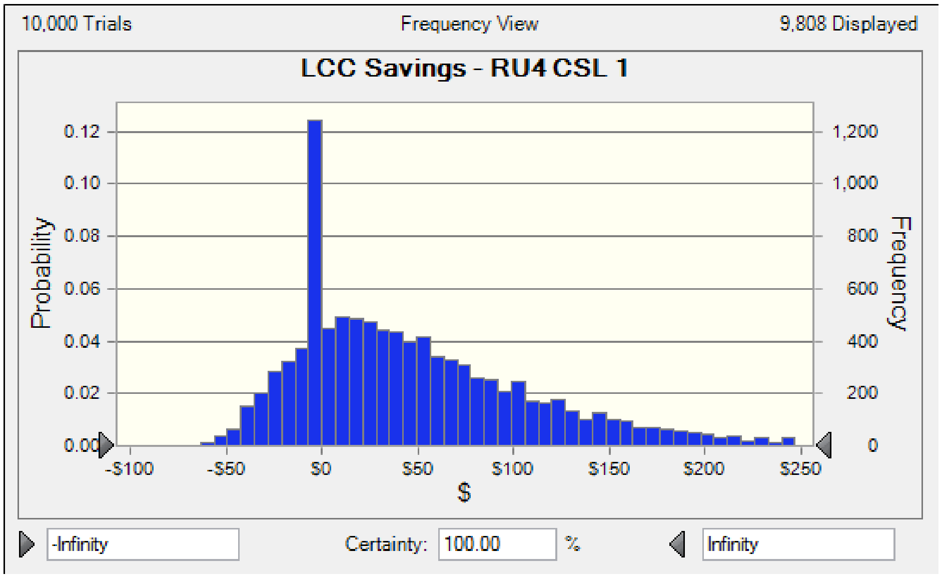

Figure 8.4-5 Representative Unit 4: Distribution of Life-Cycle Cost Savings for EL 1

Table 8.4.4 summarizes the LCC and PBP results for representative unit 4 based on a run of 10,000 Monte Carlo samples. The most rigorous EL that provides positive average LCC savings is EL 1. DOE estimates that 73.1 percent of end-users would experience a net benefit (*i.e.*, LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $45, or 7.5 percent, while operating costs decrease by $14, or 1.9 percent.

Table 8.4.4 Life-Cycle Cost and Payback Period Results for Representative Unit 4: NEMA Design C, T-Frame, 5 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	596	8,376	720	5,952	N/A	0.0	0.0	N/A	N/A
1	89.5	641	8,206	706	5,896	52	18.8	73.1	10.6	4.2
2	91.0	1,059	8,078	694	6,223	-275	96.7	3.3	34.8	23.7

8.4.5 Representative Unit 5, NEMA Design C, 50 Horsepower, 4 Poles, Enclosed Motor

Figure 8.4-6 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 1 for representative unit 5. The LCC net benefit is -$93 in this Monte Carlo run.

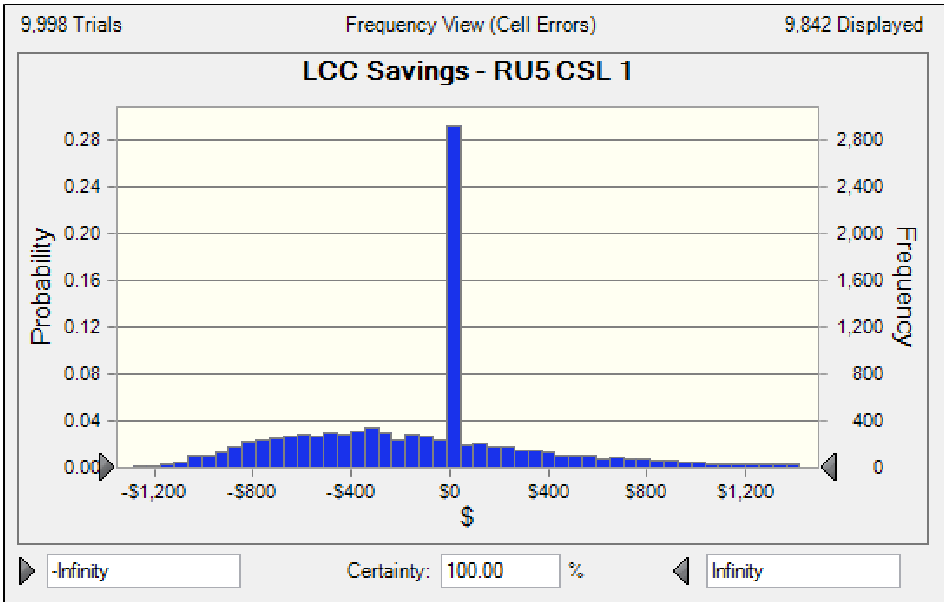

Figure 8.4-6 Representative Unit 5: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.5 summarizes the LCC and PBP results for representative unit 5 based on a run of 10,000 Monte Carlo samples. At EL 1, DOE estimates that 25.4 percent of end-users would experience a net benefit (*i.e.*, LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $969, or 33.0 percent, while operating costs decrease by $86, or 1.2 percent.

Table 8.4.5 Life-Cycle Cost and Payback Period results for Representative Unit 5: NEMA Design C, T-Frame, 50 hp, Four Pole, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,941	79,551	6,940	67,316	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	78,276	6,854	67,465	-93	47.7	25.4	41.7	12.5
2	95.0	4,610	77,653	6,810	67,752	-380	75.4	24.6	38.9	14.6

8.4.6 Representative Unit 6, Fire Pump, 5 Horsepower, 4 Poles, Enclosed Electric Motor

Figure 8.4-7 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 1 for representative unit 6. The LCC net benefit is -$43 in this Monte Carlo run.

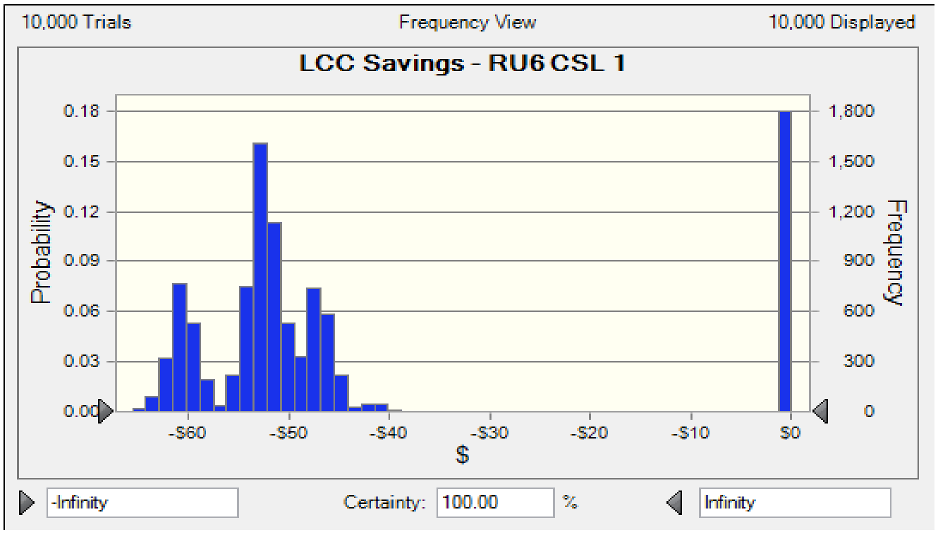

Figure 8.4-7 Representative Unit 6: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.6 summarizes the LCC and PBP results for Unit 6 motors based on a run of 10,000 Monte Carlo samples. All ELs lead to negative average LCC savings.

Table 8.4.6 Life-Cycle Cost and Payback Period Results for Representative Unit 6: Fire Pump, NEMA Design B, T-Frame, 5 hp, Four Poles, Enclosed Electric Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	625	9	2	656	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	709	-43	82.0	0.0	6,162	4,086
2	90.2	731	9	2	759	-91	94.9	0.0	1,310	513
3	91.0	1,153	9	2	1,186	-518	100.0	0.0	76,460	14,484

8.4.7 Representative Unit 7, Fire Pump, 30 Horsepower, 4 Poles, Enclosed Electric Motor

Figure 8.4-8 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 1 for representative unit 7. The LCC net benefit is -$88 in this Monte Carlo run.

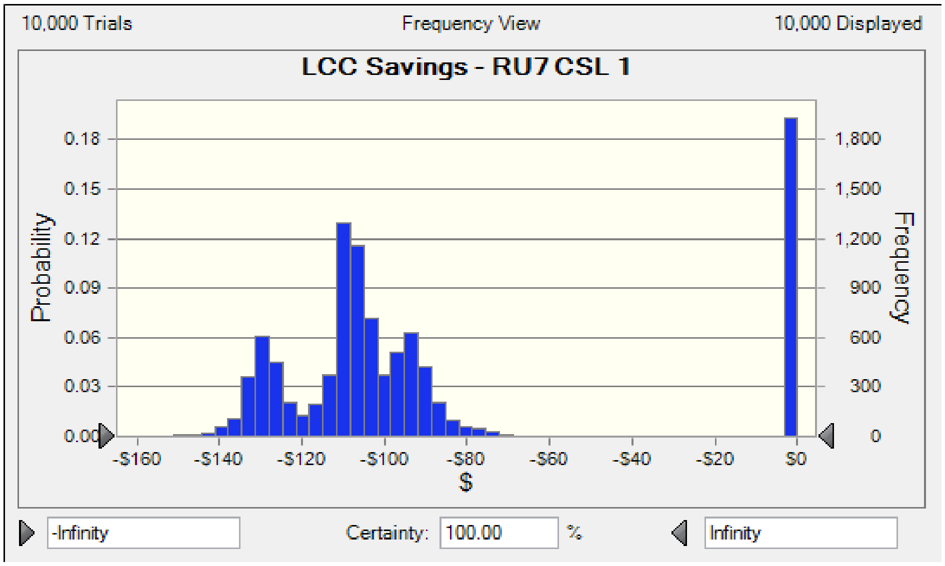

Figure 8.4-8 Representative Unit 7: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.7 summarizes the LCC and PBP results for representative unit 7 based on a run of 10,000 Monte Carlo samples. All ELs lead to negative average LCC savings.

Table 8.4.7 Life-Cycle Cost and Payback Period Results for Representative Unit 7: Fire Pump, NEMA Design B, T-Frame, 30 hp, Four Poles, Enclosed Electric Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	92.4	2,052	53	12	2,230	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	12	2,338	-88	80.7	0.0	928	375
2	94.1	2,410	52	12	2,583	-302	87.4	0.0	3,294	1,339
3	94.5	3,670	52	12	3,839	-1,558	100.0	0.0	11,435	2,768

8.4.8 Representative Unit 8, Fire Pump, 75 Horsepower, 4 Poles, Enclosed Electric Motor

Figure 8.4-9 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 1 for representative unit 8. The LCC net benefit is -$350 in this Monte Carlo run.

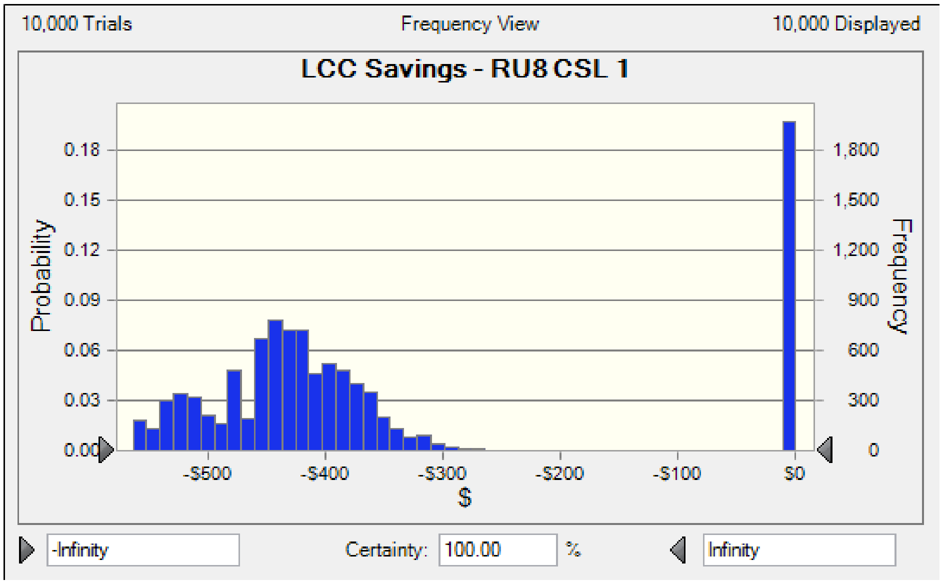

Figure 8.4-9 Representative Unit 8: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.8 summarizes the LCC and PBP results for representative unit 8 based on a run of 10,000 Monte Carlo samples. All ELs lead to negative average LCC savings.

Table 8.4.8 Life-Cycle Cost and Payback Period Results for Representative Unit 8: Fire Pump, NEMA Design B, T-Frame, 75 hp, Four Poles, Enclosed Electric Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with		Average	Median
							Net Cost *%*	Net Benefit *%*		
0	94.1	3,881	130	28	4,280	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	24	4,716	-350	80.3	0.0	503	151
2	95.8	5,102	128	26	5,483	-1,044	90.5	0.0	4,057	945
3	96.2	6,482	127	24	6,825	-2,386	100.0	0.0	3,258	728

8.4.9 Representative Unit 9, Brake Motor, NEMA Design B, T-Frame, 5 Horsepower, Four Poles, Enclosed Motor

Figure 8.4-10 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 2 for representative unit 9. The LCC net benefit is $169 in this Monte Carlo run.

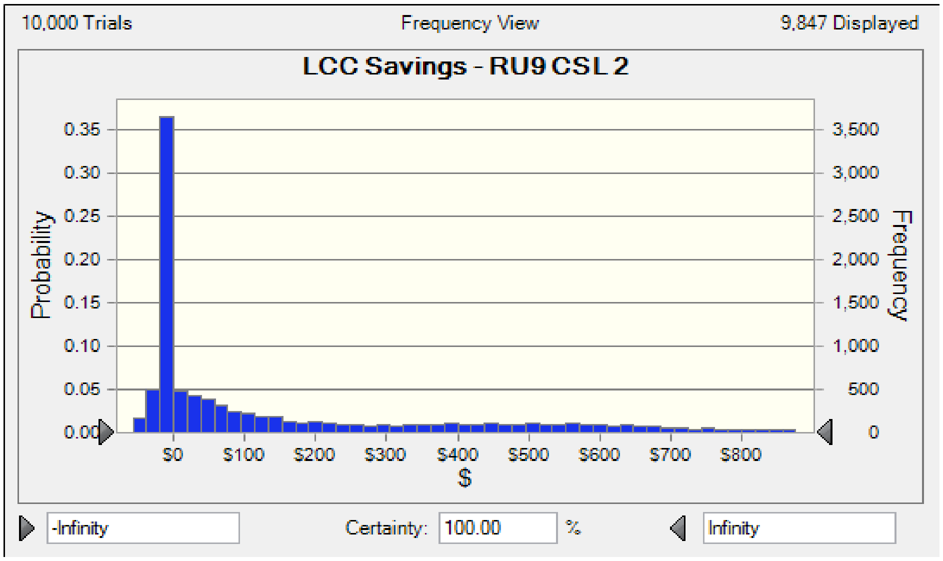

Figure 8.4-10 Representative Unit 9: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.9 summarizes the LCC and PBP results for representative unit 9 based on a run of 10,000 Monte Carlo samples. The most rigorous EL that provides positive average LCC savings is EL 3. DOE estimates that 65.3 percent of end-users would experience a net benefit (i.e., LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $126, or 20.9 percent, while operating costs decrease by $44, or 5.5 percent.

Table 8.4.9 Life-Cycle Cost and Payback Period Results for Representative Unit 9: NEMA Design B, T-Frame, 5 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	82.5	603	8,079	801	5,878	N/A	0.0	0.0	N/A	N/A
1	87.5	623	7,430	746	5,477	141	0.0	34.8	0.6	0.4
2	89.5	674	7,290	751	5,438	169	12.0	57.1	117.5	1.9
3	90.2	729	7,219	757	5,442	163	33.4	65.3	19.4	3.5
4	91.0	1,152	7,132	765	5,812	-203	78.6	20.9	809	15.6

8.4.10 Representative Unit 10, Brake Motor, NEMA Design B, T-Frame, 30 Horsepower, Four Poles, Enclosed Motor

Figure 8.4-11 is an example of a frequency chart showing the distribution of LCC savings for the case of EL 2 for representative unit 10. The LCC net benefit is $741 in this Monte Carlo run.

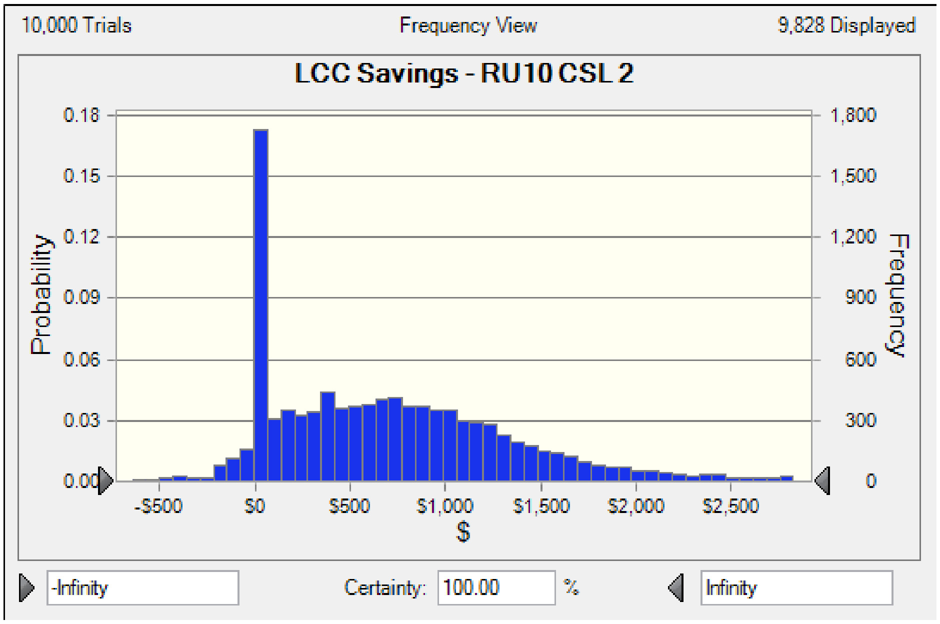

Figure 8.4-11 Representative Unit 10: Distribution of Life-Cycle Cost Savings for EL 2

Table 8.4.10 summarizes the LCC and PBP results for representative unit 10 based on a run of 10,000 Monte Carlo samples. The most rigorous EL that provides positive average LCC savings is EL 3. DOE estimates that 68.3 percent of end-users would experience a net benefit (*i.e.*, LCC decrease) at this EL. At this EL the increase in average total installed cost (relative to the base case) is $768, or 47.7 percent, while operating costs decrease by $186, or 4.4 percent.

Table 8.4.10 Life-Cycle Cost and Payback Period Results for Representative Unit 10: Brake Motor, NEMA Design B, T-Frame, 30 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	89.5	1,610	48,394	4,257	41,567	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	47,178	4,156	41,011	116	6.6	15.5	19.0	5.2
2	93.6	2,133	45,999	4,067	40,281	741	4.6	80.7	3.9	1.7
3	94.1	2,378	45,934	4,071	40,560	462	31.7	68.3	14.6	4.6
4	94.5	3,639	45,777	4,067	41,786	-764	85.2	14.8	63	18.1

8.5 LIFE-CYCLE COST SENSITIVITY CALCULATIONS

DOE developed a number of sensitivity analyses in order to analyze the particular impacts of many inputs to its LCC analysis. These sensitivity analyses include lower and higher retail price discounts and two alternative energy price trend scenarios. Table 8.5.1 displays the user choices and associated values for each sensitivity parameter analyzed.

Table 8.5.1 Life-Cycle Cost Sensitivity Case Parameters and Values

Parameter	Choices	Typical Value
Energy Price Trend	Default	AEO 2013 Reference Case
	High Value	AEO 2013 High Case
	Low Value	AEO 2013 Low Case
Retail Price Discount	Default	1
	High Discount	0.7
	Medium Discount	0.5
	Low Discount	0.3

Table 8.5.2 compares the average LCC savings using the default value for energy price trends with the LCC savings using high and low sensitivity values for representative units 2, 5, and 7. As expected, DOE observed larger savings with higher energy prices and smaller savings with lower energy prices.

Table 8.5.2 Life-Cycle Cost Results for Energy Price Trend Sensitivity Cases

Representative Unit 2				
Energy Efficiency Level	Efficiency %	Average LCC Savings $		
		Default	High	Low
0	82.5	N/A	N/A	N/A
1	87.5	36	38	36
2	89.5	359	372	358
3	90.2	139	154	138
4	91.0	-978	-959	-980
Representative Unit 5				
Energy Efficiency Level	**Efficiency %**	**Average LCC Savings $**		
		Default	**High**	**Low**
0	93.0	N/A	N/A	N/A
1	94.5	-93	-72	-97
2	95.0	-380	-343	-386
Representative Unit 7				
Energy Efficiency Level	**Efficiency %**	**Average LCC Savings $**		
		Default	**High**	**Low**
0	92.4	N/A	N/A	N/A
1	93.6	-88	-88	-88
2	94.1	-302	-301	-302
3	94.5	-1558	-1558	-1558

Table 8.5.3 shows an example of retail price discount sensitivity analyses for representative units 2, 5, and 7. The default case does not include any discounts, whereas the other cases incorporate

different discounts. The sensitivity results reflect that the higher the discount used, the greater the savings that are achieved.

Table 8.5.3 Life-Cycle Cost Results for Retail Price Discount Sensitivity Cases

Representative Unit 2					
Energy Efficiency Level	**Efficiency %**	**Average LCC Savings $**			
		Default	**Low**	**Medium**	**High**
0	82.5	N/A	N/A	N/A	N/A
1	87.5	36	48	45	41
2	89.5	359	401	389	377
3	90.2	139	302	255	209
4	91.0	-978	-75	-333	-591
Representative Unit 5					
Energy Efficiency Level	**Efficiency %**	**Average LCC Savings $**			
		Default	**Low**	**Medium**	**High**
0	93.0	N/A	N/A	N/A	N/A
1	94.5	-93	362	232	102
2	95.0	-380	555	288	21
Representative Unit 7					
Energy Efficiency Level	**Efficiency %**	**Average LCC Savings $**			
		Default	**Low**	**Medium**	**High**
0	92.4	N/A	N/A	N/A	N/A
1	93.6	-88	-27	-44	-62
2	94.1	-302	-114	-167	-221
3	94.5	-1558	-570	-852	-1134

DOE collected the results of each sensitivity analysis, applied individually, in appendix 8-C. The Department's LCC analysis and PBP spreadsheet tool is available for download via the Internet[d] and allows the user to examine the results for the sensitivity scenario of their choice.

8.6 REBUTTABLE PAYBACK PERIOD

A more energy-efficient motor will usually cost more to buy than a motor of standard energy efficiency. However, the more efficient motor will usually cost less to operate due to reductions in operating costs (*i.e.*, lower energy bills). The PBP is the time (usually expressed in years) it takes to recover the additional installed cost of the more efficient motor through energy cost savings. The Energy Policy and Conservation Act (EPCA) provides a rebuttable presumption that, in essence, an energy conservation standard is economically justified if the increased purchase cost for a product that meets the standard is less than three times the value of the first-year energy savings resulting from the standard. However, DOE routinely conducts a

[d] See links from this web site: http://www1.eere.energy.gov/buildings/appliance_standards/

full economic analysis that considers the full range of impacts, including those to the customer, manufacturer, nation, and environment, as required under 42 U.S.C. 6295(o)(2)(B)(i) and 42 U.S.C. 6316(e)(1). The results of this analysis serve as the basis for DOE to evaluate definitively the economic justification for a potential standard level (thereby supporting or rebutting the results of any preliminary determination of economic justification).

The results of DOE's rebuttable PBP calculations are shown in Table 8.6.1 below.

Table 8.6.1 Rebuttable Presumption Payback for All Representative Units

Representative Unit		Payback Period *years*			
		EL 1	**EL 2**	**EL 3**	**EL 4**
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	0.3	0.6	1.0	4.1
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	1.9	1.7	2.2	5.4
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	0.9	1.1	1.9	3.2
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	1.4	8.1	-	-
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	5.7	7.4	-	-
6	Fire pump, 5 hp, 4 poles, enclosed	1,102	1,709	6,628	-
7	Fire pump, 30 hp, 4 poles, enclosed	148	334	1,228	-
8	Fire pump, 75 hp, 4 poles, enclosed	90.1	175	303	-
9	Integral Brake, T-frame, 5 hp, 4 poles, enclosed	0.3	0.7	1.1	4.2
10	Integral Brake, T-frame, 30 hp, 4 poles, enclosed	2.1	1.9	2.5	6.2

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to project annual product shipments and presents results for electric motors considered in this analysis under base- and standards-case efficiency levels.

DOE developed a shipments model to predict shipments of electric motors covered in this analysis. The core of the shipments analysis is a model that DOE developed to simulate how future purchases are incorporated into an in-service stock of aging motors that are gradually replaced. DOE's motors shipments projections are based on forecasts of economic growth and do not incorporate a distinction within shipments between replacements and purchases for new applications.

To formulate its total shipments estimates, DOE began with shipments data from a market research report[1], input from interested parties, and responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)). Based on two databases of motor field data[2,3], U.S. Census Bureau's Current Industrial Reports[4,5], and stakeholder input, DOE then developed a distribution of shipments across each of the four equipment class groups (NEMA Design A and B, NEMA Design C, fire pump, and brake motors). Within each category, motor shipments were split into subcategories by horsepower ratings, rotational speeds (corresponding to 2-pole, 4-pole, 6-pole, and 8-pole motors), and two enclosure types (open or enclosed); projections within each of these subcategories were summed to arrive at shipments at the equipment class level.

The shipments model is prepared as a Microsoft Excel spreadsheet that is accessible on the Internet (http://www.eere.energy.gov/buildings/appliance_standards/). Appendix 10-A discusses how to access the shipments model and other related spreadsheets and provides basic instructions for using them. The rest of this chapter explains the shipments model in more detail. Section 9.2 provides a summary of the data DOE used to develop estimates of the shipments of covered electric motors by equipment class and for each sector and applications. Section 9.3 describes the methodology that underlies development of the model and presents the shipments projection.

9.2 TOTAL SHIPMENTS

In the preliminary analysis, DOE estimated total shipments of electric motors to 4.56 million units in 2011 based on a market research report[1] and data provided by the Motor

Coalition[a]. This amount did not include NEMA 56-frame size electric motors (one million units) and 150,000 integral brake motors, as these electric motors were not covered in the preliminary analysis scope.

In this notice of proposed rulemaking (NOPR), DOE included enclosed NEMA 56-frame size electric motors as well as integral brake motors. Based on data provided by the Motor Coalition and responses to the RFI, annual shipments of covered motors were estimated to total 5.43 million units in 2011. This corresponds to the addition of 0.73 million enclosed NEMA 56-frame size electric motors[b] and 0.14 million integral brake motors with 3-digit NEMA frame sizes or enclosed 56-frames[c].

After estimating the total shipments for 2011, DOE drew upon three data sources to develop a distribution of the total shipments across the 580 equipment classes: input from interested parties, data from extensive field measurements collected by the Washington State University Extension Energy Program (WSU), Applied Proactive Technologies and the New York State Energy Research and Development Authority (NYSERDA) 2 ("WSU/NYSERDA database"), and field data compiled by the Industrial Assessment Center (IAC) at Oregon State University (OSU) ("Northwest Industrial Database")[3]. The different distributions across equipment class groups and motor configurations are presented in sections 9.2.1 to 9.2.4.

9.2.1 Distribution Across Equipment Class Groups

DOE derived the distribution by equipment class group (ECG) from the WSU/NYSERDA database from the National Electrical Manufacturers Association's (NEMA's) estimate of the share of brake motors provided in response to the RFI. Results are presented in Table 9.2.1.

Table 9.2.1 Total Unit Shipped in 2011 by Equipment Class Group (thousand units)

ECG 1: NEMA Design A and B	ECG 2: NEMA Design C	ECG 3: Fire Pump Electric Motors	ECG 4: Brake Motors
5,121	9.7	1.3	299

9.2.2 Distribution Across Horsepower

Shipments were first distributed by horsepower range, based on the U.S. Census Bureau's Current Industrial Reports and input from the Motor Coalition (Table 9.2.2). [4,5]

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[a] The Motor Coalition members include the following: American Council for an Energy-Efficient Economy, Alliance to Save Energy, Appliance Standard Awareness Project, Earthjustice, Natural Resources Defense Council, Northeast Energy Efficiency Partnerships, Northwest Energy Efficiency Alliance, National Electrical Manufacturers Association, and Pacific Gas and Electric.

[b] DOE derived market shares of enclosed versus open enclosures in the 1 to 5 horsepower range from two databases of motor field usage data[2,3] and used it to estimate the number of enclosed NEMA 56-frame size electric motors based on the one million estimated annual units of NEMA 56-frame size electric motors shipped.

[c] DOE derived market shares of enclosed versus open enclosures and NEMA 56-frames versus NEMA 3-digit frames in the 1 to 5 horsepower range from two databases of motor field usage data[2,3] to estimate the number of integral brake motors with enclosed 56-frames and NEMA 3-digit frames shipped in the year 2011.

Table 9.2.2 Share of Motors by Horsepower Range

Range *hp*	**2011 Shipments (*1,000 units*)**	**Percentage of Total (*%*)**
1 – 5	3,491	64.3
6 – 20	1,408	25.9
21 – 50	356	6.5
51 – 100	117	2.2
101 – 200	39	0.7
201 – 500	20	0.4
Total	5,431	100.0

DOE then split shipments by individual horsepower rating, based on the distribution observed in the WSU/NYSERDA and the Northwest Industrial databases (Table 9.2.3). For some ECG, motors are not available in horsepower ratings, and DOE adjusted the shipments distribution to account for this.

Table 9.2.3 Share of Motors by Horsepower Rating

Horsepower rating *hp*	**Percentage of Total (*%*)**
1	5.95
1.5	3.48
2	6.59
3	8.26
5	13.17
7.5	8.14
10	8.33
15	7.59
20	4.97
25	4.67
30	4.27
40	4.12
50	3.71
60	2.46
75	3.14
100	3.09
125	1.70
150	2.14
200	1.87
250	0.87
300	0.62
350	0.28
400	0.24
450	0.09
500	0.25

9.2.3 Distribution Across Pole Configurations and Enclosures

DOE derived the distribution by pole configuration and enclosure from the WSU/NYSERDA and the Northwest Industrial databases (Table 9.2.4).

Table 9.2.4 Share of Motors by Pole Configuration and Enclosure (All Equipment Class Groups)

Enclosure	**Open**				**Enclosed**			
Range *hp*	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1 – 5	1.4%	8.8%	1.3%	0.1%	5.7%	20.9%	2.9%	1.3%
6 – 20	0.9%	5.6%	0.5%	0.1%	6.0%	15.8%	1.4%	0.2%
21 – 50	0.3%	2.1%	0.2%	0.1%	2.5%	7.6%	1.4%	0.1%
51 – 100	0.1%	0.8%	0.3%	0.1%	0.6%	3.8%	1.0%	0.1%
101 – 200	0.0%	0.3%	0.1%	0.1%	0.2%	2.3%	1.0%	0.2%
201 – 500	0.1%	0.2%	0.2%	0.1%	0.2%	0.6%	0.3%	0.1%

DOE then combined the distribution by horsepower and the share of motors by pole and enclosure configuration to estimate the shipment distribution per equipment class. For some ECG, motors are not available in all pole configurations, and DOE adjusted the shipments distribution to account for this.

9.2.4 Distribution Across Equipment Classes, Sectors and Applications

DOE used the data presented in Table 9.2.1, Table 9.2.2, Table 9.2.3, and Table 9.2.4 to produce market shares for each of the 580 equipment classes. Further, DOE developed a model of the applications and sectors for which motors covered in this analysis are used. These distributions are presented in chapter 7, Energy Use Characterization.

9.3 SHIPMENTS PROJECTION

9.3.1 Shipments Model

DOE projected shipments of covered motors throughout the 30-year analysis period, which starts at the compliance date of the standard (December 19, 2015[a]). DOE projects total shipments using a model driven by forecasted economic growth. Based on a previous publication[6], DOE assumed that motors sales are driven by economic growth and machinery production growth for equipment including motors.

Based on historical data for the period 1993-2011 on U.S. shipments provided by the U.S. Census Bureau[4,7]and NEMA[8,9] and private fixed investment data from the Bureau of Economic Analysis's (BEA)[10,11], DOE assumes that annual shipments growth rates correlate to the annual

[a] The compliance date of December 19, 2015 was modeled using January 1st 2016 in the analysis.

growth rate of private fixed investment in selected equipment and structures[12,a] including motors (Figure 9.3.1).

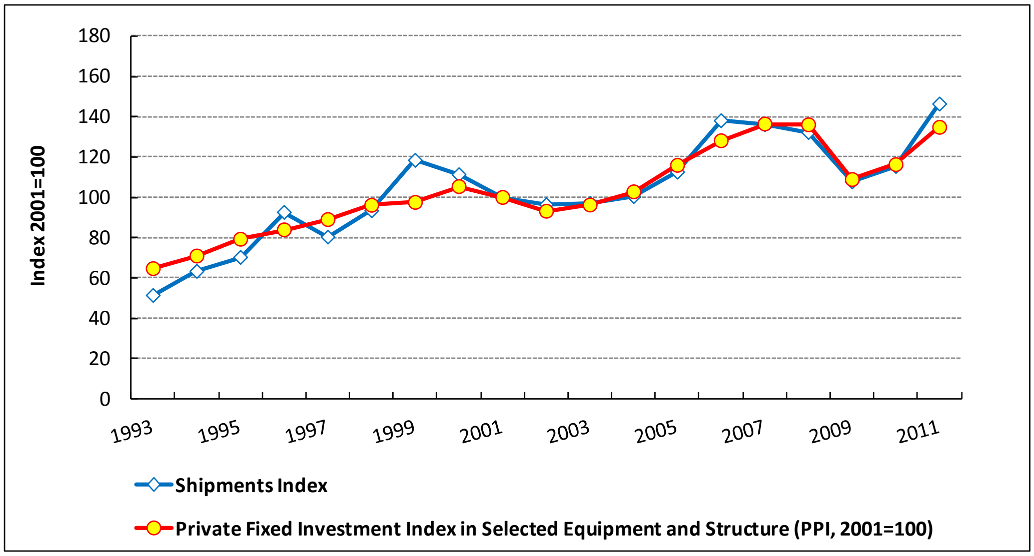

Figure 9.3.1 Shipments Index vs. Private Fixed Investment Index in Selected Equipment and Structure

DOE developed a relationship between shipments and private fixed investment in equipment and structures including motors (indexed to 2001). The relation, derived from a linear regression (R^2>0.91), is expressed by the following equation:

$$Shipments_{index}(y) = 1.15126 \cdot FixInvest_{index}(y) - 15.17265$$ [Equation 1, Step 0]

Where:

$Shipments_{index}$ (y) is the shipments index based in 2001 in year *y*, and
$FixInvest_{index}$ (y) is the private fixed investment index based in 2001 for selected equipment and structure including motors in year *y*.

DOE projects private fixed investment in selected equipment and structure from 2015 through 2040 based on the real "gross domestic product" (GDP) growth from the Energy Information Administration's *Annual Energy Outlook*[13] for 2013 (*AEO2013*) for the period 2015–2040. DOE then extrapolated the GDP growth trend from 2040 to 2044. The steps for the calculation are:

[a] Heating, ventilating, and air conditioning (HVAC) equipment that incorporates motors is typically included in "structures" and not in equipment. Based on RSMeans, DOE estimates that 9 percent of investments in structures are related to HVAC equipment.

1) Based on historical data from the BEA, DOE projected private fixed investment in equipment and structure including motors as a share of total private fixed investment in equipment and structure for 2015 to 2044.
2) For 2015 to 2040, DOE used total private fixed investment in equipment and structures data (private domestic investment data) from *AEO2013* to project private fixed investment in equipment and structure including motors.
3) From 2040 to 2044, DOE used *AEO2013* data to estimate a trend for private domestic investment as a share of GDP using a linear regression (R^2>0.96). DOE then projected the GDP for 2040 to 2044 using a quadratic regression based on *AEO2013* data (R^2>0.99). Using the GDP projection, DOE projected *private domestic investment* and estimated private fixed investment in equipment and structure including motors.
4) DOE used the data on projected private fixed investment in equipment and structure including motors and Equation 1 to estimate shipments growth over the analysis period (2015–2044).

Following the same methodology, DOE estimated shipments projections for the Reference Economic Growth Case, the High Economic Growth Case, and Low Economic Growth Case available in *AEO2013*.

9.3.2 Shipments in Standards Cases

Sales of electric motors may be sensitive to increases in the installed cost that may result from efficiency standards. Increased motor prices could affect the repair versus replace decision that the user makes and could lead to increases in the longevity of less efficient motors and decreased shipments. However, DOE did not find sufficient data to quantitatively estimate the impact of increased efficiency levels on shipments and, therefore, used a price elasticity equal to zero as a default.

9.3.3 Shipments Data

Figure 9.3.2 shows annual shipments for each scenario case over the 30-years analysis period starting at the compliance year. The analysis uses January 1st, 2016 to represent the compliance date of December 19, 2015.

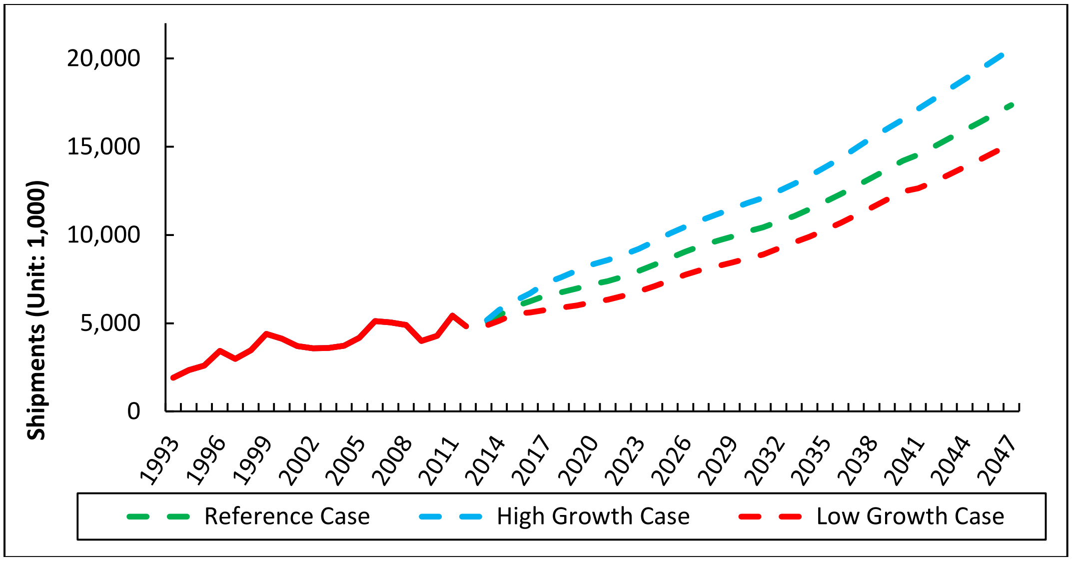

Figure 9.3.2 Shipments Projection by Scenario Case

Table 9.3.1 shows the annual and cumulative shipments for each equipment class grouping for Reference Case

Table 9.3.1 Annual and Cumulative Shipments Projection

Equipment Class Grouping	Annual Shipments *thousand units*				
	2016**	**2025**	**2035**	**2045****	**Cumulative over 30-years**
NEMA Designs A & B	5,897	8,197	11,206	15,473	302,880
NEMA Design C	11	16	21	29	575
Fire Pump	2	2	3	4	77
Brake	344	478	654	902	17,666
Total*	6,254	8,693	11,883	16,409	321,198

*Total may not sum up because of rounding.
** The shipments analysis uses January 1st, 2016 to represent the compliance date of December 19, 2015.

There are two major assumptions inherent in the shipments model:

1) The relative market shares of the different equipment classes are constant over time.
2) U.S. production, imports, exports, and, therefore, shipments (*i.e.*, apparent consumption) have the same growth rate as described by the shipments index provided by NEMA (see section 9.3.1).[8,9]

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

This chapter examines selected national impacts attributable to each trial standard level (TSL) considered for electric motors. Electric motors considered in this analysis have been categorized into four distinct equipment class groups: (1) National Electrical Manufacturers Association (NEMA) Design A and B motors, (2) NEMA Design C motors, (3) fire pump electric motors, and (4) brake motors. For each of these equipment class groups, and for each equipment class, DOE evaluated the following impacts: national energy savings (NES) attributable to each potential standard level, monetary value of the lifetime energy savings to consumers of the considered equipment, increased total lifetime cost of the equipment because of standards, and net-present value (NPV) resulting from increased energy efficiency (the difference between the energy cost savings and the increased total lifetime cost of the equipment).

To conduct its national impacts analysis (NIA), DOE determined both the NES and NPV for each TSL being considered as the new standard for electric motors. DOE performed all calculations for each considered equipment class group and equipment class using Microsoft Excel spreadsheet models, which are accessible on the Internet.[a] Details and instructions for using the NIA model are provided in Appendix 10-A of the Technical Support Document (TSD). The spreadsheets combine the calculations for determining the NES and NPV for each considered equipment class group and equipment class with input from the appropriate shipments model that DOE used to project future purchases of the considered equipment. Chapter 9 provides a detailed description of the shipments models.

To calculate the national impacts of new and amended standards for all equipment class groups considered in this rulemaking DOE used (a) scaling factors (described in Chapter 5 and Section 10.3.2 below) to estimate equipment related costs, and (b) operational profiles to estimate annual energy consumption for all equipment classes. DOE derived the scaling factors from the engineering outputs for the ten representative units, data from manufacturer internet catalogs and the usage profiles from the LCC analysis (described in Chapter 8 and Section 10.3.2.1 below).

Figure 10.2.1 presents a graphical flow diagram of the electric motor NIA spreadsheet model. In the diagram, the arrows show the direction of information flow for the calculation. The information begins with inputs (shown as parallelograms). As information flows from these inputs, it is integrated into intermediate results (shown as rectangles) into major outputs (shown as boxes with curved bottom edges).

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[a] See www.eere.energy.gov/buildings/appliance_standards/

The NIA calculation started with the shipments model. This model produces a projection of annual shipments of motors. DOE used the annual projection of such shipments to produce an accounting of annual national energy savings, annual national energy cost savings, and annual national incremental non-energy costs resulting from purchasing, installing and operating the units projected to be shipped in each year of the analysis period during their estimated lifetime. The annual values, therefore, refer to the lifetime, cumulative energy related savings and non-energy related additional costs associated to the units marketed in each year of the analysis period.

To calculate the annual national energy savings, DOE first estimated the lifetime primary and fuel-fuel-cycle[b] (FFC) energy consumption at the unit level and for each year in the analysis period, for motors of each equipment class used in industry, commercial buildings and agriculture. The unit's lifetime primary and FFC energy consumptions were then scaled up to the national level based on the annual shipments projection and according to two scenarios: the *base case* scenario, with no changes in the existing energy efficiency standards; and (b) the *standards case* scenario, where energy efficiency standards are set at the energy efficiency level corresponding to one of the TSLs. This produced, for each equipment class and sector, two sets of two streams of annual national energy consumption, from which DOE derived two streams of annual NES from motors shipped in each year of the analysis period: one that accounts for primary energy savings, and one that accounts for the FFC energy savings. The annual national primary and FFC energy savings of all equipment classes within an equipment class group and sectors were, each one, aggregated over the full analysis period into national energy primary and FFC savings by equipment class group. DOE then summed the aggregated national primary and FFC energy savings to produce, respectively, the primary and FFC NES of all equipment class groups.

DOE followed a similar procedure to calculate the annual national energy cost savings and the annual national incremental non-energy costs. DOE first estimated the lifetime energy cost and the lifetime non-energy costs at unit level and for each year in the analysis period, for motors of each equipment class, within each equipment class group, used in industry, commercial buildings and agriculture. The unit lifetime energy and non-energy costs, estimated for units shipped in each year in the analysis period, were then scaled up to the national level based on the annual shipments projection and for the same—*base case* and *standards case*—scenarios described above. This produced, for each equipment class and sector: (a) two streams of annual national energy costs, from which DOE derived a stream of annual national energy cost savings associated with each year in the analysis period, and its corresponding present-value, and (b) two streams of annual national non-energy costs, from which DOE derived a stream of annual national incremental equipment non-energy costs associated with each year in the analysis period, and its corresponding present-value. The present-values of the annual national energy cost savings and the annual national incremental non-energy costs of all equipment classes within an equipment class group and sectors were aggregated, respectively, into the total national energy cost savings and national incremental non-energy costs by equipment class group. DOE then calculated the difference between the aggregated national

[b] The full-fuel-cycle energy consumption adds to the primary energy consumption the energy consumed by the energy supply chain upstream to power plants.

energy cost savings and national incremental non-energy costs to obtain the NPV of each equipment class group, and summed these values across equipment class groups to produce the total NPV. Two models included in the NIA are provided below—the NES model in Section 10.2, and the NPV model in Section 10.3. Each technical description begins with a summary of the model. It then provides a descriptive overview of how DOE performed each model's calculations and follows with a summary of the inputs. The final subsections of each technical description describe each of the major inputs and computation steps in detail and with equations, when appropriate. After the technical model descriptions, this chapter presents the results of the NIA calculations.

10.2 NATIONAL ENERGY SAVINGS

DOE developed the NES model to estimate the total national primary and FFC energy savings using information from the life-cycle cost (LCC) relative to energy consumption, combined with the results from the shipments model. The savings shown in the NES reflect decreased energy losses resulting from the installation of more efficient electric motors nationwide (as a consequence of new or amended standards), in comparison to a base case with no changes in the current national standards. Positive values of NES correspond to net energy savings, that is, a decrease in energy consumption after implementation of a standard in comparison to the energy consumption in the base case scenario.

10.2.1 National Energy Savings Overview

DOE calculated the cumulative primary and FFC energy savings from an electric motor efficiency standard, relative to a base case scenario of no standard, over the analysis period. It calculated NES for each TSL in units of quadrillion British thermal units (Btus) (quads), for standards with a compliance date of December 19, 2015.[c] The NES calculation started with estimates of shipments, which are outputs of the shipments model (Chapter 9).[d] DOE then obtained values of electric motor parameters from the LCC analysis (Chapter 8), projections of site-to-primary conversion factors[e] from the *Annual Energy Outlook*[1] (AEO) and projections of site-to-upstream conversion factors[f] from a NEMS-based methodology, and calculated the market average of the total primary and FFC energy used over the lifetime of units shipped in each year of the analysis period for both a base case and a standards case. Since in the standards case part of the units shipped is more efficient than its corresponding in the base case, the market average energy consumed per unit decreases in the standards case relative to the base case. For each year analyzed, the lifetime primary and FFC energy savings from all motors of a given capacity and configuration (combination of enclosure and number of poles), shipped in that year

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[c] The analysis uses January 1st, 2016 to represent the compliance date of December 19, 2015. Therefore, the 30-year analysis period 2015-2044 is referred to as 2016-2045 in this chapter.
[d] Shipments provided by the shipment model do not account for the price-elasticity of demand. Therefore, NES results reported in this chapter were estimated under the assumption of zero price-elasticity. Appendix 10-C presents NES results for a scenario where shipments were adjusted based on a non-zero price-elasticity of demand.
[e] The site-to-primary factors account for electricity generation, transmission and distribution losses.
[f] The site-to-upstream factors translate site energy consumption into the energy consumed in the supply chain of the fuels used for electricity generation.

to each sector, are the differences in their primary and FFC energy use between the corresponding base case and the standards case scenarios.

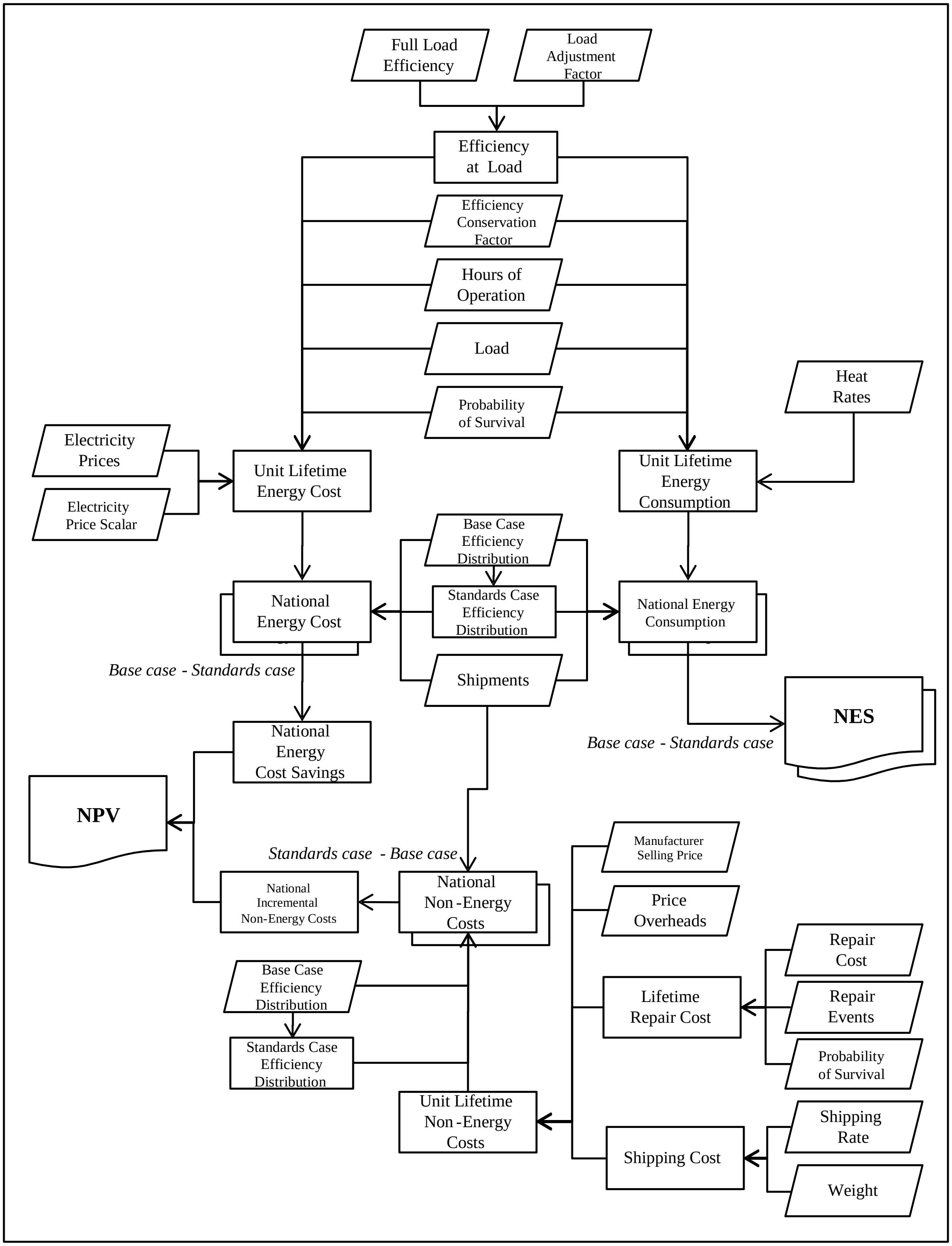

Figure 10.2.1 National Impact Analysis Model Flowchart

This calculation is expressed by the following formulas:

Lifetime Primary Energy Savings

$$nSES_{hp,g}(y) = \sum_s \sum_a \left(nSECbc_{hp,g}(s,a,y) - nSECstd_{hp,g}(s,a,y) \right) \quad \text{i.}$$

$$nSECbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uSEC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y) \right) \quad \text{ii.}$$

$$nSECstd_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uSEC_{hp,g,c}(s,a,y) \cdot Mstd_{hp,c}(y) \right) \quad \text{iii.}$$

$$uSEC_{hp,g,c}(s,a,y) = \sum_{i=1..LT} aSEC_{hp,g,c}(s,a,y,i) \quad \text{iv.}$$

where:

$nSES_{hp,g}(y)$	=	the lifetime primary energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*,
$nSECbc_{hp,g}(s,a,y)$	=	the base case, lifetime primary energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,
$nSECstd_{hp,g}(s,a,y)$	=	the standards case, lifetime primary energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,
$Shp_{hp,g}(s,y)$	=	the number of motors with capacity *hp* and configuration *g* shipped in year *y* to sector *s*,
$A(a)$	=	the probability of a motor to be used in application *a* ($\sum A(a) = 1$),
$uSEC_{hp,g,c}(s,a,y)$	=	the lifetime primary energy consumption of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y* to be used in application *a* in sector *s*,
$aSEC_{hp,g,c}(s,a,y,i)$	=	the annual primary energy consumption in the i-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*, shipped in year *y* to be used in application *a* in sector *s*,
$Mbc_{hp,c}(y)$	=	the base case market share of units with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y*, and
$Mstd_{hp,c}(y)$	=	the standards case market share of units with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y*.

Lifetime Full-Fuel-Cycle Energy Savings

$$nFES_{hp,g}(y) = \sum_s \sum_a \left(nFECbc_{hp,g}(s,a,y) - nFECstd_{hp,g}(s,a,y) \right) \quad \text{v.}$$

$$nFECbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uFEC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y) \right) \quad \text{vi.}$$

$$nFECstd_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uFEC_{hp,g,c}(s,a,y) \cdot Mstd_{hp,c}(y) \right) \qquad \text{vii.}$$

$$uFEC_{hp,g,c}(s,a,y) = \sum_{i=1..LT} \left(aSEC_{hp,g,c}(s,a,y,i) \cdot ffc(y+i-1) \right) \qquad \text{viii.}$$

where:

$nFES_{hp,g}(y)$	= the lifetime FFC energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*,
$nFECbc_{hp,g}(s,a,y)$	= the base case, lifetime FFC energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,
$nFECstd_{hp,g}(s,a,y)$	= the standards case, lifetime FFC energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,
$Shp_{hp,g}(s,y)$	= the number of motors with capacity *hp* and configuration *g* shipped in year *y* to sector *s*,
$A(a)$	= the probability of a motor to be used in application *a* ($\sum A(a) = 1$),
$uFEC_{hp,g,c}(s,a,y)$	= the lifetime FFC energy consumption of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y* to be used in application *a* in sector *s*,
$aSEC_{hp,g,c}(s,a,y,i)$	= the annual primary energy consumption in the i-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*, shipped in year *y* to be used in application *a* in sector *s*,
$ffc(y)$	= the primary-to-FFC conversion factor in year *y*,
$Mbc_{hp,c}(y)$	= the base case market share of units with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y*, and
$Mstd_{hp,c}(y)$	= the standards case market share of units with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y*.

DOE used the lifetime primary and FFC energy savings estimated for all motors shipped from 2016 through 2045 to calculate the total primary NES (NES_{src}) and the total FFC NES (NES_{FFC}) for the analysis period.[c] The calculation used the following formulas:

$$NES_{src} = \sum_{hp} \sum_{g} \sum_{y=2016}^{2045} nSES_{hp,g}(y) \qquad \text{ix.}$$

$$NES_{FFC} = \sum_{hp} \sum_{g} \sum_{y=2016}^{2045} nFES_{hp,g}(y) \qquad \text{x.}$$

where:

$nSES_{hp,g}(y)$	= the lifetime primary energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*, and

$nFES_{hp,g}(y)$ = the lifetime FFC energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*.

Once the shipments model provides the estimate of shipments, and the site-to-primary and site-to-upstream factors convert site energy consumption respectively into primary and upstream energy consumption, the key to the NES calculation is in calculating the unit annual site energy consumption and market share distributions using inputs from the LCC analysis. The next section summarizes the inputs necessary for the NES calculation and then presents them individually; the following sections detail, respectively, how the unit lifetime site energy consumption and the standards case efficiency distribution were calculated.

10.2.2 National Energy Savings Inputs

The NES model inputs include: (a) the parameters necessary to calculate the unit site energy consumption, (b) the site-to-primary conversion factors, which enable the calculation of primary energy consumption from site energy use, (c) the site-to-upstream conversion factors which – in addition to the site-to-primary factors – enable the calculation of FFC energy consumption from site energy use, and (d) shipment efficiency distributions in the base case. The list of NES model inputs is as follows:

1. motor capacity;
2. annual hours of operation;
3. operating load;
4. energy efficiency (at the operating load, and including efficiency adjustment due to repairs);
5. lifetime (probability) distribution;
6. electricity site-to-primary conversion factors;
7. electricity site-to-upstream conversion factors, and
8. base case shipments efficiency distribution.

10.2.2.1 Motor Capacity

The motor capacity refers to the unit horsepower (hp) rating converted to kilowatts (kW) using the following conversion factor: 1 hp = 0.746 kW.

10.2.2.2 Annual Hours of Operation

For the NIA, DOE considered the average annual hours of operation by sector, application and horsepower ranges described in Chapter 7, Section 7.2.6.

10.2.2.3 Operating Load

For the NIA, DOE considered the average operating load by application described in Chapter 7, Section 7.2.5.

10.2.2.4 Energy Efficiency

For the NIA, DOE considered the energy efficiencies by EL presented in Chapter 5. Those efficiencies, however, refer to motors performance when operating at full load. Since motors usually do not operate at full load, DOE adjusted the full load efficiencies to the part-load levels corresponding to the motors' weighted average operating load across applications, based on part load efficiency data from the engineering analysis (Chapter 5). Additionally, DOE assumed that ten percent of repaired motors have a slight decrease in their energy efficiency after undergoing a repair, and that the repair frequency varies by horsepower size and sector (see Chapter 8, Section 8.2.2.1 for more details). To account for the effects of repair on the energy efficiency of motors, DOE used a time-varying adjusting factor that reduces the initial motor efficiency over its lifetime (see Table 10.2.1).[g]

Table 10.2.1 Factors to Adjust Motor Initial Efficiency to its Efficiency after Repair

Year of Operation	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
Industry						
Motors < 40 hp						
1-7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
8-14	1.00000	1.00000	0.99900	0.99900	0.99900	0.99900
15-21	1.00000	1.00000	0.99800	0.99800	0.99800	0.99800
22-28	1.00000	1.00000	0.99700	0.99700	0.99700	0.99700
29-30	1.00000	1.00000	0.99601	0.99601	0.99601	0.99601
Motors ≥ 40 hp						
1-7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
8-14	1.00000	1.00000	0.99950	0.99950	0.99950	0.99950
15-21	1.00000	1.00000	0.99900	0.99900	0.99900	0.99900
22-28	1.00000	1.00000	0.99850	0.99850	0.99850	0.99850
29-30	1.00000	1.00000	0.99800	0.99800	0.99800	0.99800
Commercial Buildings						
Motors < 40 hp						
1-9	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
10	1.00000	1.00000	1.00000	1.00000	0.99900	1.00000
11	1.00000	1.00000	1.00000	1.00000	0.99900	0.99900
12-14	1.00000	1.00000	0.99900	1.00000	0.99900	0.99900
15-18	1.00000	1.00000	0.99900	0.99900	0.99900	0.99900
19-20	1.00000	1.00000	0.99900	0.99900	0.99800	0.99900
21-22	1.00000	1.00000	0.99900	0.99900	0.99800	0.99800
23-27	1.00000	1.00000	0.99800	0.99900	0.99800	0.99800
28	1.00000	1.00000	0.99800	0.99900	0.99700	0.99800

[g] The Electrical Apparatus Service Association (EASA) commented that a comprehensive study has been done by EASA and the Association of Electrical and Mechanical Trades to investigate the effect of repair and rewind on electric motor efficiency. EASA commented that the study showed that electric motor efficiency could be maintained by following the good practices identified in the study. (EASA, No.7 at pp. 1-2) Both EASA Standard AR100-2010 and the EASA/AEMT Rewind Study are available at http://www.easa.com/.

Year of Operation	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
29-30	1.00000	1.00000	0.99800	0.99800	0.99700	0.99800
Motors ≥ 40 hp						
1-9	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
10	1.00000	1.00000	1.00000	1.00000	0.99950	1.00000
11	1.00000	1.00000	1.00000	1.00000	0.99950	0.99950
12-14	1.00000	1.00000	0.99950	1.00000	0.99950	0.99950
15-18	1.00000	1.00000	0.99950	0.99950	0.99950	0.99950
19-20	1.00000	1.00000	0.99950	0.99950	0.99900	0.99950
21-22	1.00000	1.00000	0.99950	0.99950	0.99900	0.99900
23-27	1.00000	1.00000	0.99900	0.99950	0.99900	0.99900
28	1.00000	1.00000	0.99900	0.99950	0.99850	0.99900
29-30	1.00000	1.00000	0.99900	0.99900	0.99850	0.99900
Agriculture						
Motors < 40 hp						
1-10	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
11-20	0.99900	0.99900	0.99900	0.99900	0.99900	0.99900
21-30	0.99800	0.99800	0.99800	0.99800	0.99800	0.99800
Motors ≥ 40 hp						
1-10	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
11-20	0.99950	0.99950	0.99950	0.99950	0.99950	0.99950
21-30	0.99900	0.99900	0.99900	0.99900	0.99900	0.99900

10.2.2.5 Lifetime Distribution

For the NIA, DOE uses motor average lifetime in years derived from motor mechanical lifetime in hours (see Chapter 8, Section 8.2.3) and from annual operating hours (see Section 10.2.2.2).

10.2.2.6 Electricity Site-to-Primary Conversion Factors

DOE calculates primary energy savings (power plant energy consumption) from site energy savings by applying a factor to account for losses associated with the generation, transmission, and distribution of electricity. DOE derived annual marginal site-to-primary factors based on the version of the National Energy Modeling System (NEMS) that corresponds to Energy Information Administration (EIA's) *Annual Energy Outlook 2013* (*AEO 2013*).[1] The factors change over time in response to projected changes in the types of power plants projected to provide electricity to the country. Figure 10.2.2 shows the site-to-primary factors for the projection period. The value reported in AEO for year 2040 (the last year available in *AEO*) was extrapolated through the end of the projection period.

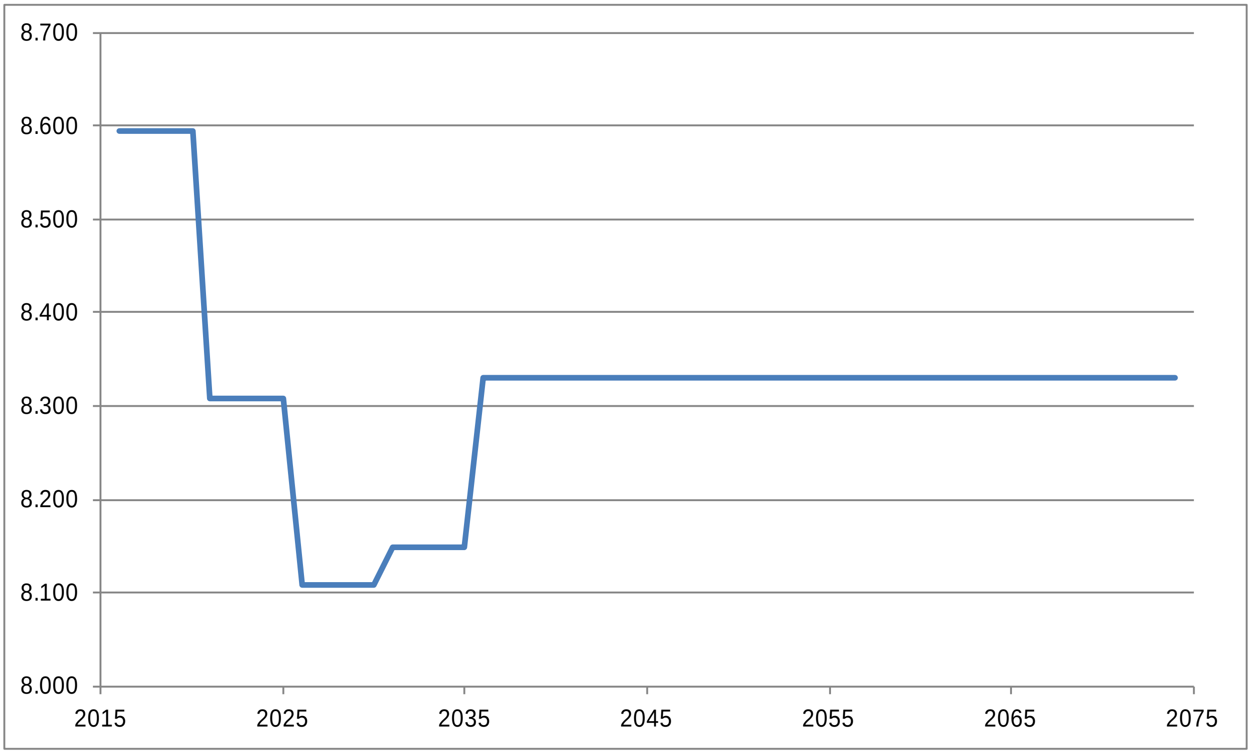

Figure 10.2.2 Site-to-Power Plant Energy Use Factor for Electric Motors

10.2.2.7 Electricity Site-to-Upstream Conversion Factors

The full-fuel-cycle (FFC) measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. To complete the full-fuel-cycle by encompassing the energy consumed in extracting, processing, and transporting or distributing primary fuels, which DOE refers to as "upstream" activities, DOE developed site-to-upstream multipliers[h] using the data and projections generated by the National Energy Modeling System (NEMS) used for *AEO 2013*.[1] The AEO provides extensive information about the energy system, including projections of future oil, natural gas and coal supply, energy use for oil and gas field and refinery operations, and fuel consumption and emissions related to electric power production. This information can be used to define a set of parameters representing the energy intensity of energy production.

Table 10.2.2 shows the energy multipliers used to estimate the energy saved upstream to power plants resulting from motors site energy savings for selected years. The method used to calculate the site-to-upstream energy multipliers is described in appendix 10-D.

[h] FFC multipliers discussed in this chapter relate to the upstream part of the FFC process.

Table 10.2.2 Site-to-Upstream Energy Multipliers (Based on AEO 2013)

	2015	2020	2025	2030	2035	2040
Electricity	0.043	0.041	0.040	0.040	0.041	0.040

10.2.2.8 Efficiency Distribution

To estimate market averages for unit energy consumption DOE used statistical distributions of shipments across ELs. For the base case in 2012, DOE developed such distributions from a database which DOE built upon data collected from internet catalogs from six major manufacturers and one large distributor (see Table 10.2.3).

Table 10.2.3 Base Case Energy Efficiency Distributions in 2012

	Market Share in 2012				
	EL 0	EL 1	EL 2	EL 3	EL 4
Equipment Class 1 (NEMA Design A and B)					
1-5 hp	13.5%	29.9%	34.1%	14.4%	8.1%
6-20 hp	12.1%	31.4%	28.5%	18.1%	9.8%
21-50 hp	7.4%	34.5%	41.5%	9.1%	7.5%
51-100 hp	10.3%	25.2%	39.2%	17.0%	8.3%
101-200 hp	8.1%	24.4%	26.1%	27.0%	14.3%
201-500 hp	20.6%	36.6%	21.3%	15.8%	5.7%
Equipment Class 2(NEMA Design C)					
1-5 hp	91.7%	8.3%	0.0%	-	-
6-20 hp	100.0%	0.0%	0.0%	-	-
21-50 hp	73.3%	26.7%	0.0%	-	-
51-100 hp	75.0%	25.0%	0.0%	-	-
101-200 hp	52.2%	34.8%	13.0%	-	-
Equipment Class 3 (Fire Pump Electric Motors)					
1-5 hp	82.1%	12.8%	5.1%	0.0%	-
6-20 hp	79.2%	20.8%	0.0%	0.0%	-
21-50 hp	80.7%	6.4%	12.8%	0.0%	-
51-100 hp	80.6%	10.2%	9.2%	0.0%	-
101-200 hp	97.1%	0.0%	2.9%	0.0%	-
201-500 hp	100.0%	0.0%	0.0%	0.0%	-
Equipment Class 4 (Brake Motors)					
1-5 hp	36.5%	34.8%	27.5%	0.9%	0.4%
6-20 hp	35.4%	40.0%	13.8%	10.8%	0.0%
21-30 hp	25.0%	62.5%	12.5%	0.0%	0.0%

In order to establish the base case efficiency distribution in the compliance year and over the analysis period (2016-2045)[c] DOE made different assumptions regarding the four equipment class groups. For equipment class groups 1 and 4 DOE assumed the efficiency distributions vary over time and are influenced by the existing NEMA Premium labeling program and the energy conservation standard established by the Energy Independence and Security Act of 2007 (EISA). (Pub. L. No. 110–140, Section 313(b)(1)). As for equipment class groups 2 and 3, which represent a very minor share of the market (less than 0.2 percent), DOE believes the overall trend in efficiency improvement for the total integral AC induction motors may not be relevant and therefore kept the base case efficiency distributions constant and equal to 2012 levels.

To estimate the market response to the NEMA Premium program and EISA regulation, DOE relied on (a) historical data[2] for the market penetration of NEMA Premium motors within the market for integral AC induction motors, and (b) the market penetration of NEMA Premium motors in 2012 that DOE derived from manufacturer catalogs. Based on these data DOE developed the following model to project the market penetration of NEMA Premium motors ($M(t)$) in the absence of any new regulations:

$$M(t) = 0.08604 \cdot \ln(1.01031 \cdot t - 0.19634) + 0.11774 \qquad \text{xi.}$$

where:

t	= the year of existence of the NEMA Premium program (t=1,2,3…), and
$M(t)$	= the market penetration of NEMA Premium motors.

Figure 10.2.3 presents the estimated market penetration of NEMA Premium motors since the NEMA Premium program was launched through the end of the analysis period of this rulemaking. DOE adjusted the base case market share of the EL corresponding to NEMA Premium efficiency (EL 2) for equipment class groups 1 and 4 using the market penetration of NEMA Premium motors estimated from the model above (xi) to calculate the increase in market penetration of these motors for each year in the analysis period relative to 2012. For each year in the analysis period, the increase in market share of EL 2 relative to 2012 was compensated with a decrease in market share in lower ELs. The resulting base case efficiency distribution in the compliance year is presented in Table 10.2.4. The dynamics of the base case efficiency distribution for equipment class group 1 is showed in Figure 10.2.4 for each horsepower range.

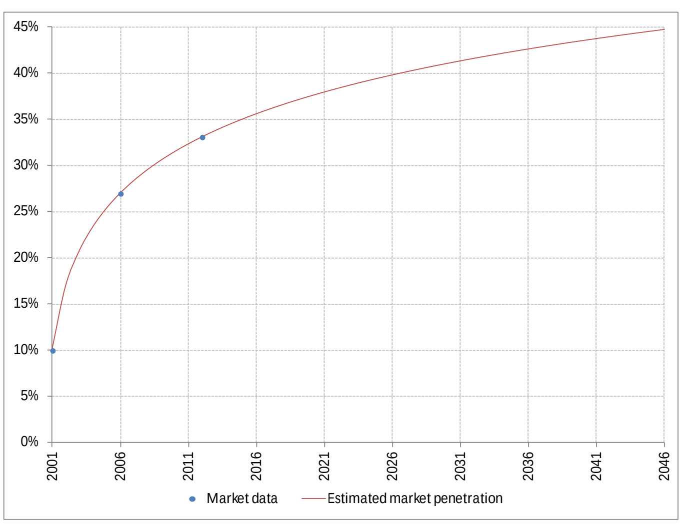

Figure 10.2.3 Estimate of NEMA Premium Motors Market Penetration

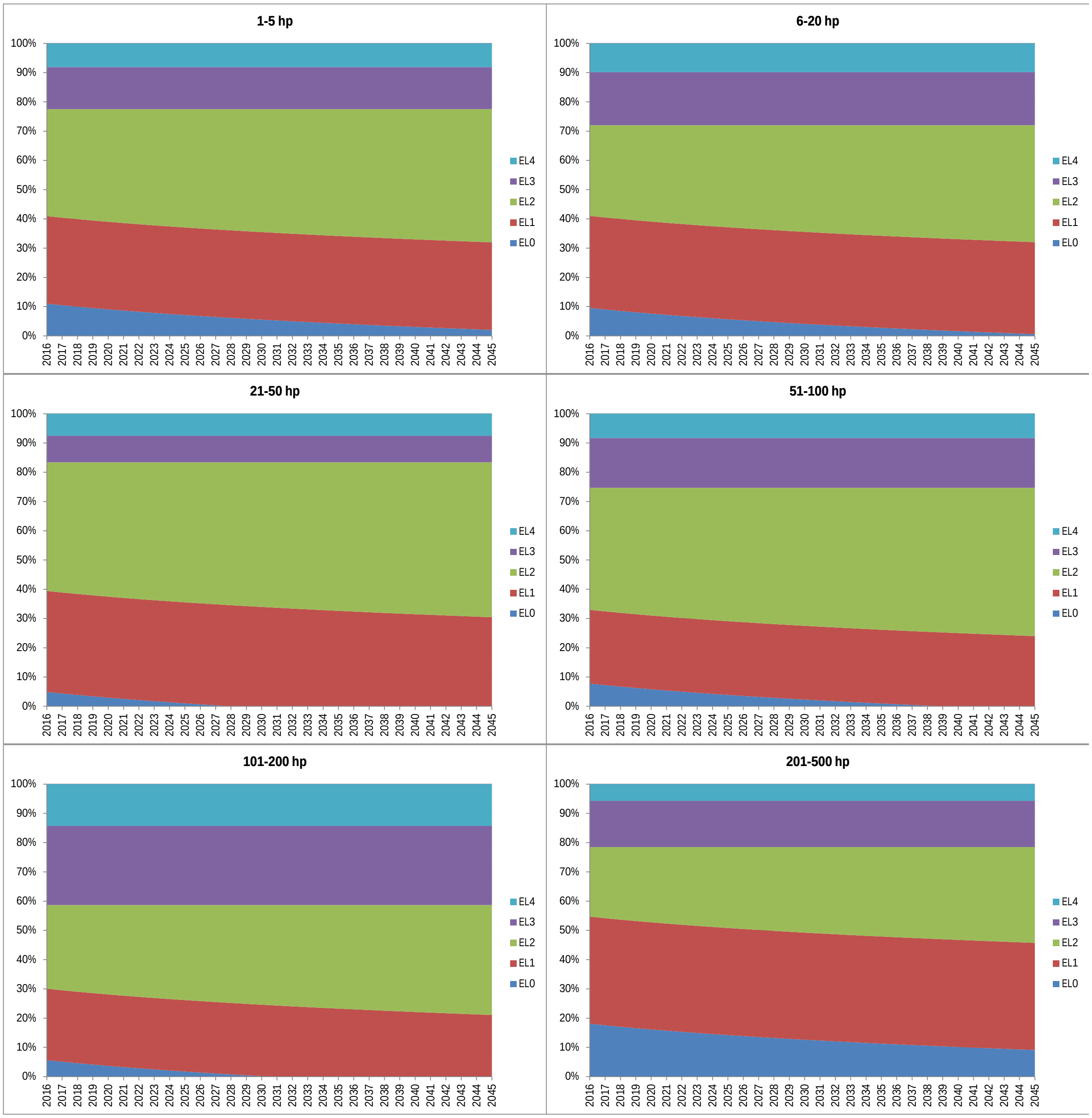

Figure 10.2.4 Base Case Efficiency Distributions for Equipment Class Group 1

Table 10.2.4 Base Case Energy Efficiency Distributions in 2016

	Market Share in 2016				
	EL 0	EL 1	EL 2	EL 3	EL 4
Equipment Class 1 (NEMA Design A and B)					
1-5 hp	10.5%	29.9%	37.1%	14.4%	8.1%
6-20 hp	9.0%	31.4%	31.5%	18.1%	9.8%
21-50 hp	4.4%	34.5%	44.5%	9.1%	7.5%
51-100 hp	7.2%	25.2%	42.3%	17.0%	8.3%
101-200 hp	5.1%	24.4%	29.2%	27.0%	14.3%
201-500 hp	17.6%	36.6%	24.3%	15.8%	5.7%
Equipment Class 2(NEMA Design C)					
1-5 hp	91.7%	8.3%	0.0%	-	-
6-20 hp	100.0%	0.0%	0.0%	-	-
21-50 hp	73.3%	26.7%	0.0%	-	-
51-100 hp	75.0%	25.0%	0.0%	-	-
101-200 hp	52.2%	34.8%	13.0%	-	-
Equipment Class 3 (Fire Pump Electric Motors)					
1-5 hp	82.1%	12.8%	5.1%	0.0%	-
6-20 hp	79.2%	20.8%	0.0%	0.0%	-
21-50 hp	80.7%	6.4%	12.8%	0.0%	-
51-100 hp	80.6%	10.2%	9.2%	0.0%	-
101-200 hp	97.1%	0.0%	2.9%	0.0%	-
201-500 hp	100.0%	0.0%	0.0%	0.0%	-
Equipment Class 4 (Brake Motors)					
1-5 hp	33.4%	34.8%	30.5%	0.9%	0.4%
6-20 hp	32.3%	40.0%	16.9%	10.8%	0.0%
21-30 hp	22.0%	62.5%	15.5%	0.0%	0.0%

10.2.3 Unit Annual Primary Energy Consumption

The unit annual primary energy consumption expresses an estimate of the amount of primary energy that a motor of a given equipment class, meeting the efficiency level of a given EL, and shipped in a given year to a given sector to be used in a given application will consume in each year of its lifetime. It refers to the variable $aSEC_{hp,g,c}$ in iv and viii, and is evaluated from the following formulas:

$$aSEC_{hp,g,c}(s,a,y,i) = UEC_{hp,g,c}(s,a,i) \cdot P_{hp}(s,i) \cdot StoS(y+i-1) \qquad \text{xii.}$$

$$UEC_{hp,g,c}(s,a,i) = \frac{(hp \times 0.757) \cdot Load(a) \cdot Hours_{hp}(s,a)}{fEff_c \cdot aEff_{hp,c}(a) \cdot Conserv(i)} \qquad \text{xiii.}$$

where:

$aSEC_{hp,g,c}(s,a,y,i)$ = the annual primary energy consumption in the i-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y* to be used in application *a* in sector *s*,
$UEC_{hp,g,c}(s,a,i)$ = the annual site energy consumption in the *i*-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c* used for application *a* in sector *s*,
$StoS(t)$ = the site-to-primary conversion factor projected to year *t*,
$P_{hp}(s,i)$ = the probability that a unit with capacity *hp*, used in sector *s* will be in operation in the *i*-th year of its lifetime,
hp = the unit capacity (in horse-power),
$Load(a)$ = the typical load of a motor used in application *a*,
$Hours_{hp}(s,a)$ = annual hours of operation of a unit with capacity *hp*, used for application *a* in sector *s*,
$fEff_c$ = the full-load efficiency of a unit with efficiency level at EL *c*,
$aEff_{hp,c}(a)$ = the factor used to adjust the full-load efficiency of a unit with capacity *hp* and efficiency level at EL *c* used in application *a* to the efficiency corresponding to its typical load, and
$Conserv(i)$ = the energy efficiency conservation factor used to reduce the unit initial efficiency to the efficiency it is estimated to present in its *i*-th year of operation due to repairs.

10.2.4 Standards Case Shipment Efficiency Distribution

Section 10.2.2.8 described the market efficiency distribution across ELs that DOE used for the base case scenario. For the standards case DOE relied on those base case distributions and calculated the efficiency distributions following the "roll-up" approach where all shipments to the ELs lower than the EL corresponding to the chosen standards level are offset from the former to the latter. The market shares in the standards case are calculated from:

$$Mstd_{hp,c}(y) = \begin{cases} 0, & c < c^* \\ \sum_{j=1}^{c^*} Mbc_{hp,j}(y), & c = c^* \\ Mbc_{hp,c}(y), & c > c^* \end{cases} \qquad \text{xiv.}$$

where:

$Mstd_{hp,c}(y)$ = the standards case market share of units with capacity *hp* and efficiency level at EL *c* shipped in year *y*,
$Mbc_{hp,c}(y)$ = the base case market share of units with capacity *hp* and efficiency level at EL *c* shipped in year *y*, and
c^* = the selected EL.

For equipment class groups 1 and 4, DOE further assumed in the standards case scenario for TSLs 2 and 3 that the EL immediately above the EL corresponding to the standards level would behave similarly to the NEMA Premium level, i.e. the share of motors at this EL would follow the same (historical and projected) dynamics of the NEMA Premium market penetration. As a consequence, for those equipment class groups, market shares in the standards case for TSLs 2 and 3 are calculated from:

$$Mstd'_{hp,c}(y) = \begin{cases} 0, & c < c^* \\ Mstd_{hp,c}(y) - Prm(t), & c = c^* \\ Mstd_{hp,c}(y) + Prm(t), & c = c^* + 1 \\ Mstd_{hp,c}(y), & c > c^* + 1 \end{cases} \quad \text{xv.}$$

where:

$Mstd'_{hp,c}(y)$ = the standards case market share of units with capacity *hp* and efficiency level at EL *c* shipped in year *y*,
$Mstd_{hp,c}(y)$ = the "rolled-up" standards case market share (as calculated from xiv) of units with capacity *hp* and efficiency level at EL *c* shipped in year *y*,
$Prm(t)$ = the increase in market share penetration of NEMA Premium motors in the t^{th} year of the NEMA Premium program ($t = y - 2015$), and
c^* = the selected EL (c^*=2, 3).

Figure 10.2.5 to Figure 10.2.7 show the standards case efficiency distributions by horsepower range for equipment class group 1 for standard case efficiency levels EL 1, EL 2, and EL 3 (which correspond to TSL 1, 2, and 3, respectively). For the standard case efficiency level EL 4 (which corresponds to TSL 4), 100 percent of the shipments would be at EL 4.

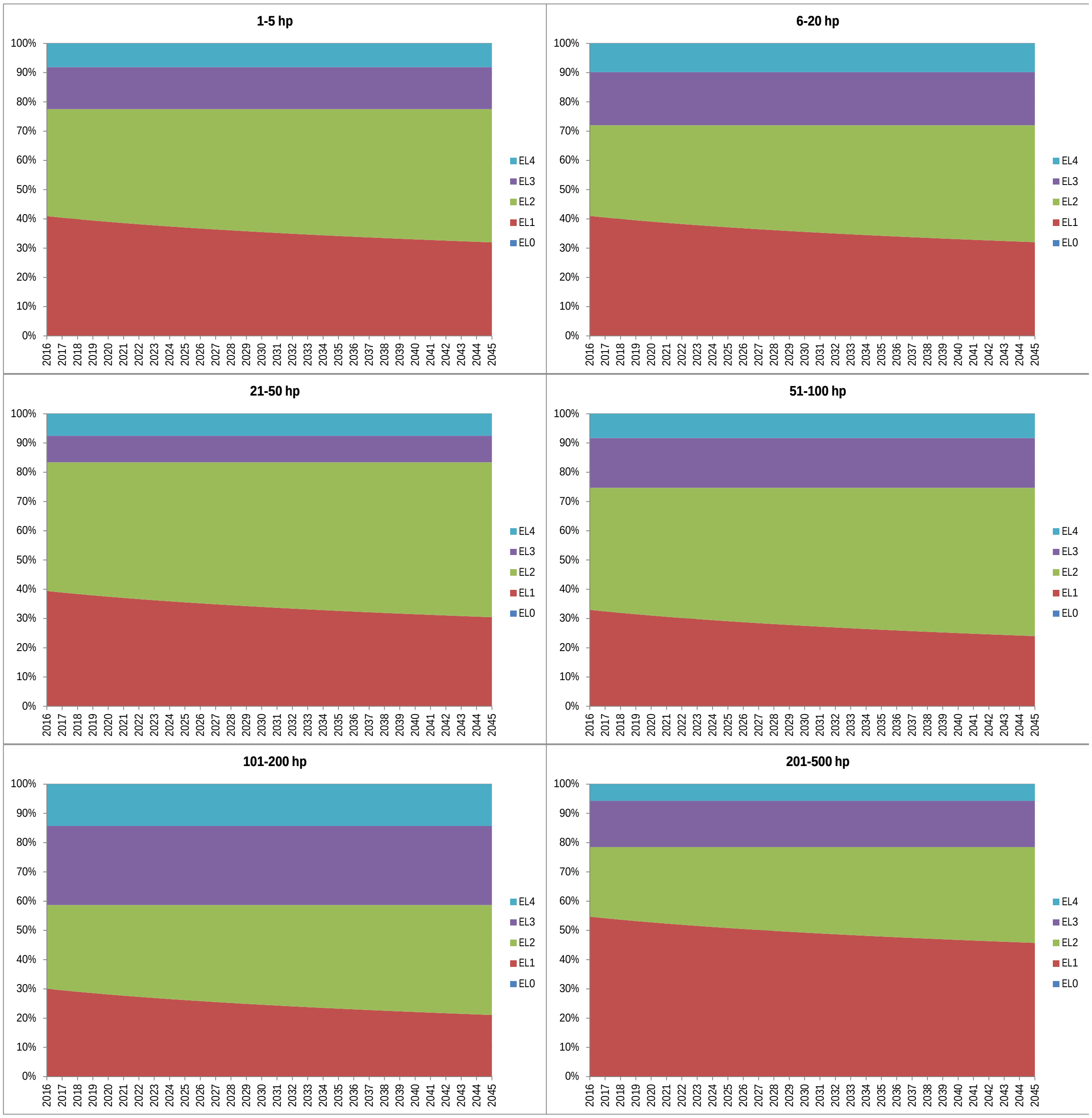

Figure 10.2.5 Standards Case Efficiency Distributions for Equipment Class Group 1 (EL 1, corresponds to TSL 1)

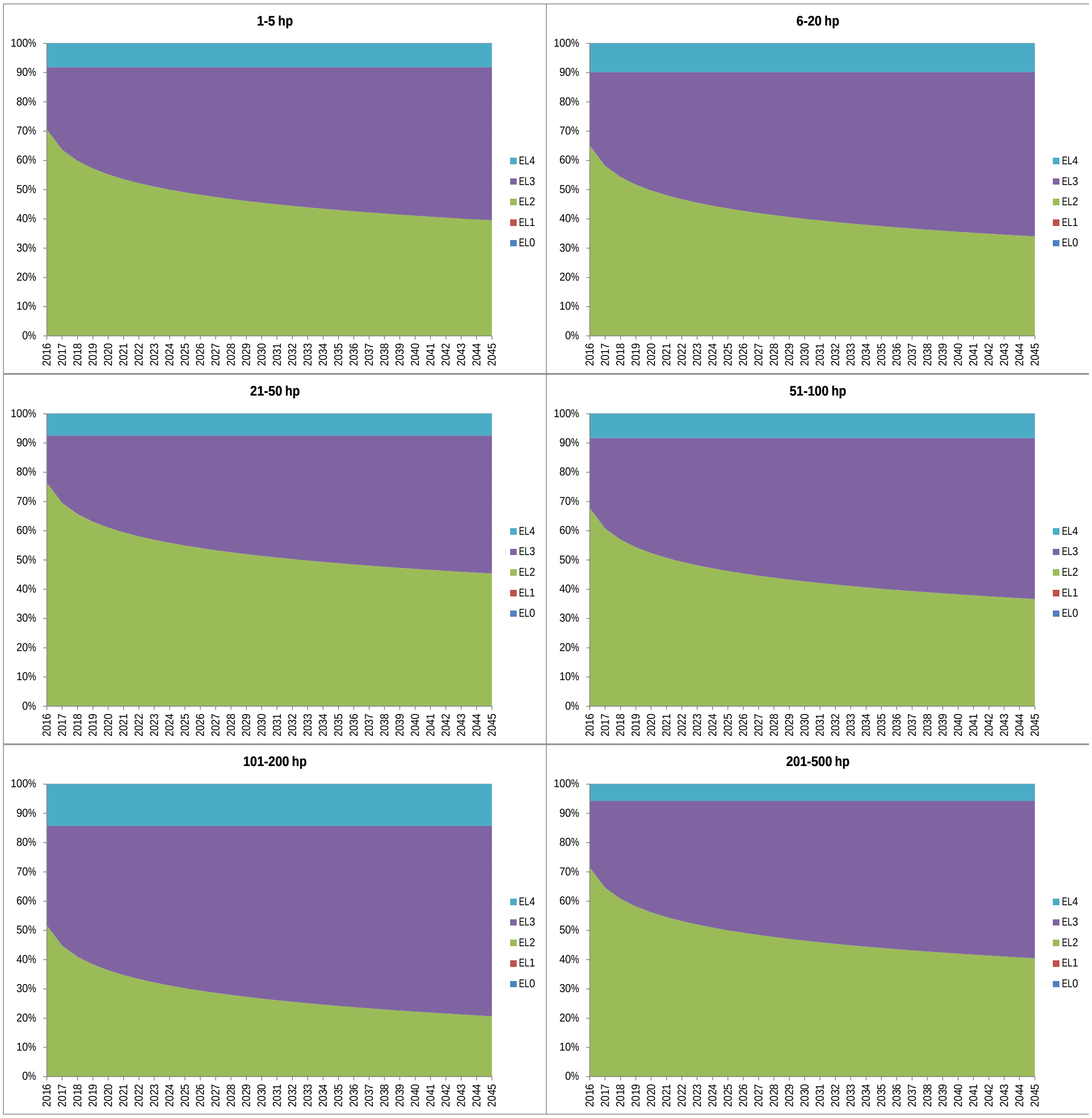

Figure 10.2.6 Standards Case Efficiency Distributions for Equipment Class Group 1 (EL 2, corresponds to TSL 2)

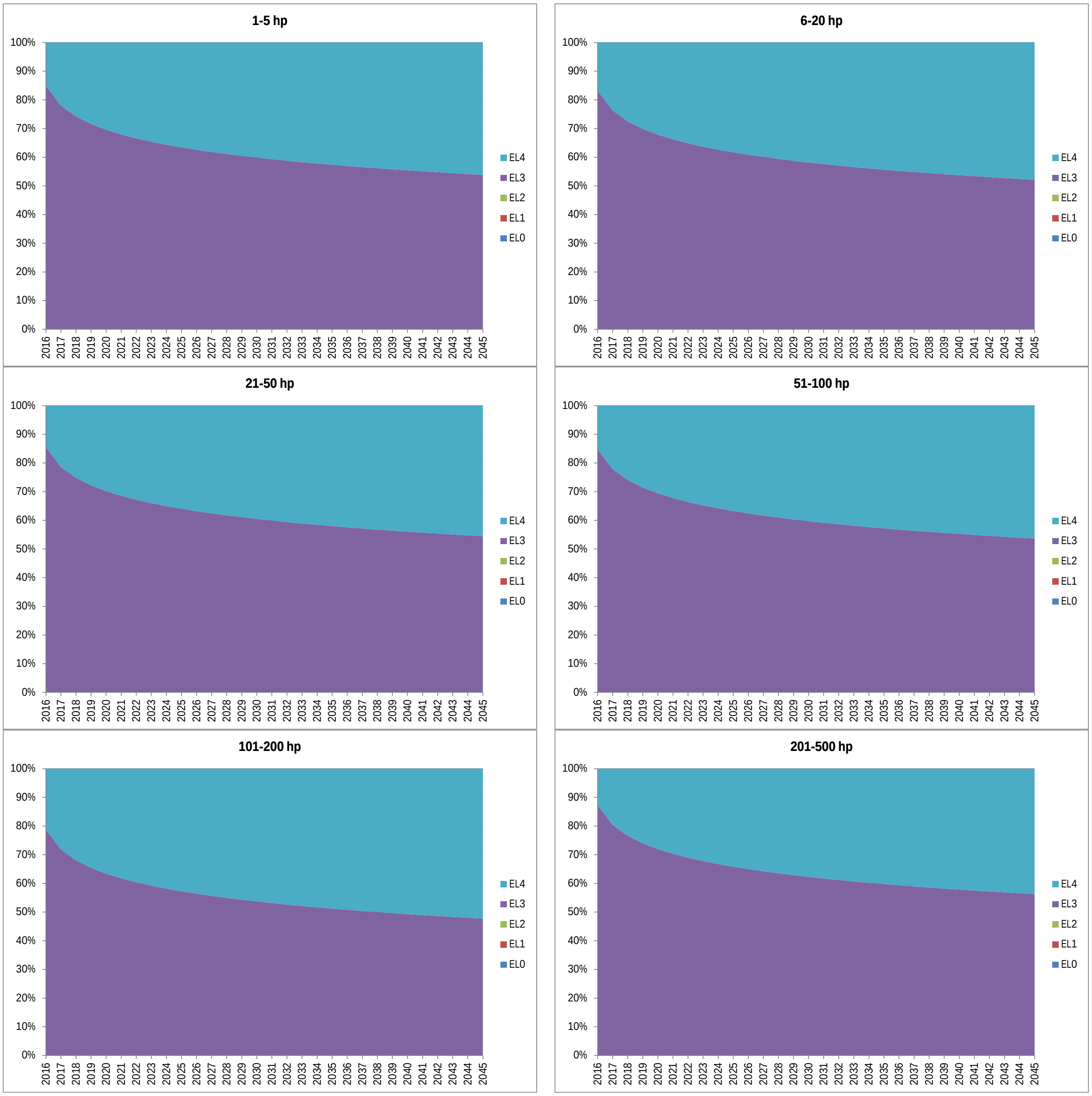

Figure 10.2.7 Standards Case Efficiency Distributions for Equipment Class Group 1 (EL3, corresponds to TSL 3)

10.3 NET PRESENT VALUE

DOE estimated the national financial impact on consumers from the imposition of new and amended energy efficiency standards using a national NPV accounting component in the national impact spreadsheet. DOE combined the output of the shipments model with energy and financial data from the LCC analysis to calculate an annual stream of costs and benefits resulting from candidate electric motors energy efficiency standards. It discounted this time series to the year 2013 and summed the result, yielding the national NPV.

10.3.1 Net Present Value Overview

The NPV is the present value of the incremental economic impact of an efficiency level. Like the NES, the NPV calculation started with the motor shipments estimated by the shipments model.[i] DOE then obtained motor input data and average electricity costs from the LCC analysis, and estimated motor non-energy and energy lifetime costs. For both a base case and a standards case, DOE first calculated the amount spent on motor purchases and lifetime repairs,[j] and then calculated the lifetime energy cost by applying the average electricity prices to the electricity used by motors shipped at each year of the analysis period over their lifetime. In the standards case, more expensive yet more efficient units replace the less efficient ones. Thus, in the standards case, whereas the market average lifetime equipment non-energy costs per unit are greater relative to the base case, the lifetime energy costs are lower. When the energy cost decrease outweighs the non-energy costs increase, the standards have a positive impact on consumers; otherwise, the standards impact is negative.

DOE discounted the non-energy and energy expenses with motors using a national average discount factor. The discount factor converts a future expense to a present value. The difference in present value of the non-energy and energy expenses between the base case and the standards case scenarios leads to the national NPV impact. DOE calculated the NPV impact in 2013 from motors that were purchased between the compliance date of the standards and 2045[c], inclusive, to calculate the total NPV impact from purchases during the analysis period. Mathematically, the NPV is the value in the present time of a time series of costs and savings, described by the equation:

$$NPV = PVS - PVC \qquad \text{xvi.}$$

where:

PVS = the present value of electricity cost savings, and
PVC = the present value of incremental non-energy costs.

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[i] Shipments provided by the shipment model do not account for the price-elasticity of demand. Therefore, NPV results reported in this chapter were estimated under the assumption of zero price-elasticity. Appendix 10-C presents NPV results for a scenario where shipments were adjusted based on a non-zero price-elasticity of demand.

[j] DOE did not account for installation costs and maintenance costs. Although these costs might have significant impacts on a user's budget, they do not vary with the efficiency level of the motor and therefore would have no impact in the difference of non-energy costs between the base case and the standards case scenarios.

PVS and *PVC* are determined according to the following expressions:

$$PVS = \sum_{hp} \sum_{g} \sum_{y=2016}^{2045} nECS_{hp,g}(y) \cdot (1 + r)^{2013-y} \qquad \text{xvii.}$$

$$nECS_{hp,g}(y) = \sum_s \sum_a \left(nNCbc_{hp,g}(s,a,y) - nNCstd_{hp,g}(s,a,y) \right) \qquad \text{xviii.}$$

$$nNCbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uNC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y) \right) \qquad \text{xix.}$$

$$nNCstd_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uNC_{hp,g,c}(s,a,y) \cdot Mstd_{hp,c}(y) \right) \qquad \text{xx.}$$

and:

$$PVS = \sum_{hp} \sum_{g} \sum_{y=2016}^{2045} nIEC_{hp,g}(y) \times (1 + r)^{2013-y} \qquad \text{xxi.}$$

$$nIEC_{hp,g}(y) = \sum_s \sum_a \left(nQCbc_{hp,g}(s,a,y) - nQCstd_{hp,g}(s,a,y) \right) \qquad \text{xxii.}$$

$$nQCbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uQC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y) \right) \qquad \text{xxiii.}$$

$$nQCstd_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uQC_{hp,g,c}(s,a,y) \cdot Mstd_{hp,c}(y) \right) \qquad \text{xxiv.}$$

where:

$nECS_{hp,g}(y)$ = the lifetime energy cost savings of all motors shipped in year *y*,
$nNCbc_{hp,g}(s,a,y)$ = the base case, lifetime energy cost of all motors shipped in year *y*,
$nNCstd_{hp,g}(s,a,y)$ = the standards case, lifetime energy cost of all motors shipped in year *y*,
$uNC_{hp,g,c}(s,a,y)$ = the lifetime energy cost of a unit with efficiency level at EL *c* shipped in year *y*,
$nIEC_{hp,g}(y)$ = the lifetime incremental equipment non-energy costs of all motors shipped in year *y*,
$nQCbc_{hp,g}(s,a,y)$ = the base case, lifetime equipment non-energy costs of all motors shipped in year *y*,
$nQCstd_{hp,g}(s,a,y)$ = the standards case, lifetime equipment non-energy costs of all motors shipped in year *y*,
$uQC_{hp,g,c}(s,a,y)$ = the lifetime equipment non-energy costs of a unit with efficiency level at EL *c* shipped in year *y*,
$Shp_{hp,g}(s,y)$ = the number of motors with capacity *hp* and configuration *g* shipped in year *y* to sector *s*,

$Mbc_{hp,c}(y)$	=	the base case market share of units with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y*, and
$Mstd_{hp,c}(y)$	=	the standards case market share of units with capacity *hp*, configuration *g* and efficiency level at EL *c* shipped in year *y*, and
r	=	the discount rate.

Once the shipments model provides the estimate of shipments, the following sections describe the inputs necessary for the NPV calculation and detail how unit lifetime energy and non-energy costs are calculated.

10.3.2 Net Present Value Inputs

The NPV model inputs include: (a) the parameters that help calculate the unit energy consumption, (b) the electricity prices that enable the calculation of energy costs, (c) equipment first- and non-energy operating costs, and (d) shipment efficiency distributions for the base case. The list of NPV model inputs is as follows:

1. motor capacity;
2. annual hours of operation;
3. operating load;
4. energy efficiency (at the operating load, and including efficiency degradation due to repairs);
5. manufacturer selling price (MSP) and price overheads;
6. motor weight and shipment costs;
7. repair costs;
8. lifetime (probability) distribution;
9. electricity price;
10. discount rate;
11. base case shipments efficiency distribution.

Inputs 1-4, 8 and 11 have already been introduced in Section 10.2.2 and therefore are not described in this section.

10.3.2.1 Manufacturer Selling Price and Price Overheads

The Engineering Analysis, Chapter 5 provides MSP data for ten representative units. DOE developed scaling relationships to estimate MSPs for all covered equipment classes following a two-step procedure.

First DOE developed a model to estimate the MSPs of 4-pole enclosed motors for all motor horsepowers. The model follows a general power law regression, and is expressed by the following equation:

$$MSP_{4,e}(hp) = a \cdot hp^b \qquad \text{xxv.}$$

where:

$MSP_{4,e}(hp)$	= the MSP of a 4-pole enclosed unit with capacity *hp*, and
a and b	= parameters calibrated for each equipment class group and EL.

DOE calibrated the model in equation xxv to each equipment class group and EL level using the corresponding MSPs of the representative units provided by the engineering analysis. Table 10.3.1 presents the values of parameters a and b that DOE estimated for each equipment class group and EL level. As mentioned in Chapter 5, the MSPs for equipment class groups 3 and 4 were derived from the MSPs of equipment class group 1.

Table 10.3.1 Parameters used to Estimate Manufacturer Selling Price of 4-Pole Enclosed Motors across Horsepower

Equipment Class Group I (NEMA Design A and B)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
a	1.15E+02	1.17E+02	1.22E+02	1.26E+02	2.46E+02
b	6.23E-01	6.60E-01	6.75E-01	7.04E-01	6.23E-01
Equipment Class Group 2 (NEMA Design C)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
a	1.13E+02	1.13E+02	2.29E+02	-	-
b	6.67E-01	7.44E-01	6.19E-01	-	-
Equipment Class Group 3 (Fire Pump Electric Motors)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
a	1.17E+02	1.22E+02	1.26E+02	2.46E+02	-
b	6.60E-01	6.75E-01	7.04E-01	6.23E-01	-
Equipment Class Group 4 (Brake Motors)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
a	1.15E+02	1.17E+02	1.22E+02	1.26E+02	2.46E+02
b	6.23E-01	6.60E-01	6.75E-01	7.04E-01	6.23E-01

Figure 10.3.1 shows how the MSPs estimated for 4-pole enclosed motors in equipment class group 1 vary with horsepower for each EL level. In the figure, the markers in red represent the MSPs of the representative units provided by the engineering analysis.

In a second step DOE established an index to describe how MSPs vary with pole and enclosure across horsepower ratings (at a fixed EL). DOE established these indices using statistical estimates derived from a database of motor prices which DOE built upon data collected from internet catalogs from six major manufacturers and one large distributor (see Table 10.3.2 for an example of these indices estimated for Designs A and B motors). DOE used the indices in Table 10.3.2 and the MSPs estimated from model in equation xxv for 4-pole enclosed motors to estimate the MSPs of all other equipment classes. The final MSP estimates are available in the NIA spreadsheet.

After estimating MSPs for all equipment classes, DOE used average baseline and incremental markups to calculate equipment prices. Chapter 6 provides more details on the markups calculation.

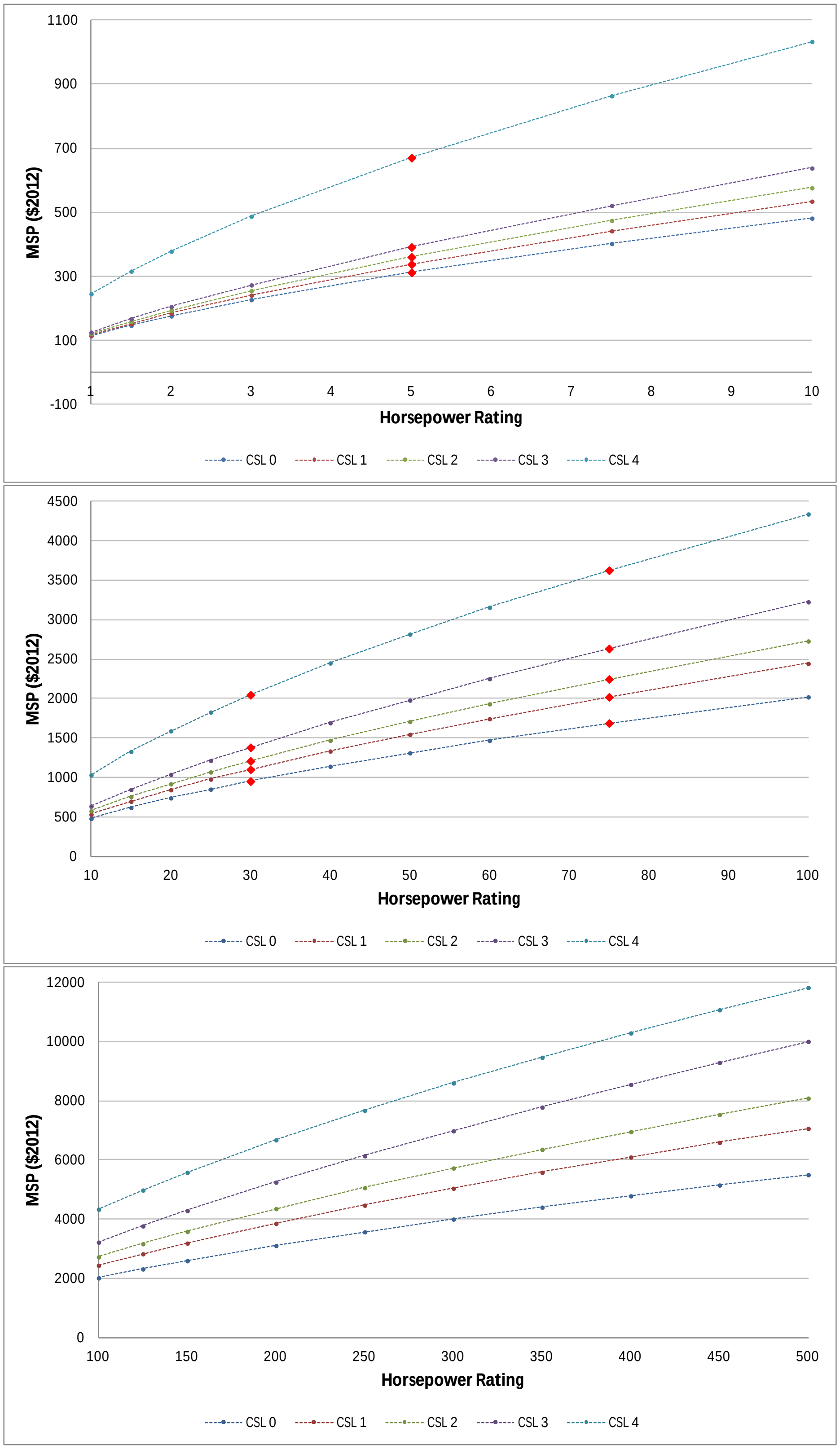

Figure 10.3.1 Estimated Manufacturer Selling Price by EL for 4-Pole Enclosed Equipment Class Group 1 Motors

Table 10.3.2 Indices used to Scale Manufacturer Selling Price across Poles and Enclosures (Equipment Class Group 1)

	Open				Enclosed			
hp	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1	0.962	0.974	0.993	1.026	1.013	1.000	1.024	1.074
1.5	0.945	0.963	0.990	1.037	1.018	1.000	1.034	1.105
2	0.930	0.952	0.987	1.047	1.023	1.000	1.044	1.135
3	0.904	0.934	0.982	1.065	1.032	1.000	1.061	1.186
5	0.861	0.905	0.974	1.094	1.047	1.000	1.087	1.268
7.5	0.822	0.879	0.967	1.120	1.060	1.000	1.112	1.343
10	0.793	0.859	0.961	1.140	1.070	1.000	1.130	1.400
15	0.752	0.831	0.953	1.167	1.083	1.000	1.156	1.478
20	0.725	0.813	0.948	1.185	1.092	1.000	1.173	1.530
25	0.706	0.800	0.945	1.198	1.099	1.000	1.185	1.567
30	0.691	0.790	0.942	1.208	1.104	1.000	1.194	1.595
40	0.671	0.776	0.938	1.221	1.110	1.000	1.207	1.634
50	0.658	0.767	0.936	1.230	1.115	1.000	1.215	1.660
60	0.648	0.761	0.934	1.237	1.118	1.000	1.221	1.678
75	0.638	0.754	0.932	1.244	1.122	1.000	1.227	1.697
100	0.628	0.746	0.930	1.251	1.125	1.000	1.234	1.718
125	0.621	0.742	0.929	1.255	1.127	1.000	1.238	1.731
150	0.616	0.739	0.928	1.258	1.129	1.000	1.241	1.740
200	0.610	0.735	0.927	1.262	1.131	1.000	1.245	1.751
250	0.607	0.732	0.926	1.265	1.132	1.000	1.247	1.758
300	0.604	0.731	0.926	1.266	1.133	1.000	1.249	1.763
350	0.602	0.729	0.925	1.268	1.134	1.000	1.250	1.766
400	0.601	0.728	0.925	1.269	1.134	1.000	1.251	1.769
450	0.600	0.728	0.925	1.269	1.134	1.000	1.251	1.771
500	0.599	0.727	0.925	1.270	1.135	1.000	1.252	1.773

10.3.2.2 Projection of Future Equipment Prices

For reasons discussed in Chapter 8 of the TSD (Section 8.2.1.1), DOE used a constant price assumption for the default projection in the NIA. To investigate the impact of different equipment price projections on consumers' net present value (NPV) for the considered TSLs, DOE also considered two alternative price trends. One of these used an exponential fit on the deflated price index for electric motors, and the other is based on *AEO2012*'s projected price index for industrial equipment[3]. Details on how these alternative price trends were developed are in Appendix 10-B, which also presents results from the sensitivity analysis DOE developed based on these two equipment price scenarios.

10.3.2.3 Motor Weight and Shipment Costs

DOE used the same approach described in Section 10.3.2.1 to derive weight data for all covered equipment classes based on outputs from the engineering analysis, Chapter 5. First DOE developed a model to estimate the weight of 4-pole enclosed motors for all motor horsepowers. The model follows a general power law regression, and is expressed by the following equation:

$$Weight_{4,e}(hp) = c \cdot hp^d \qquad \text{xxvi.}$$

where:

$Weight_{4,e}(hp)$	= the weight of a 4-pole enclosed unit with capacity *hp*, and
c and *d*	= parameters calibrated for each equipment class group and EL.

DOE calibrated the model in equation xxvi to each equipment class group and EL level using the corresponding weight of the representative units provided by the engineering analysis. Table 10.3.3 presents the values of parameters *c* and *d* that DOE estimated for each equipment class group and EL level. As mentioned in Chapter 5, the weight for equipment class groups 3 and 4 were derived from the weight of equipment class group 1.

Table 10.3.3 Parameters used to Estimate the Weight of 4-Pole Enclosed Motors across Horsepower

Equipment Class 1 (NEMA Design A and B)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
c	2.66E+01	2.83E+01	3.32E+01	3.32E+01	4.32E+01
d	7.43E-01	7.65E-01	7.43E-01	7.71E-01	7.58E-01
Equipment Class 2 (NEMA Design C)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
c	1.87E+01	2.16E+01	2.98E+01	-	-
d	8.89E-01	8.94E-01	8.33E-01	-	-
Equipment Class 3 (Fire Pump Motors)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
c	2.83E+01	3.32E+01	3.32E+01	4.32E+01	-
d	7.65E-01	7.43E-01	7.71E-01	7.58E-01	-
Equipment Class 4 (Brake Motors)					
	EL 0	**EL 1**	**EL 2**	**EL 3**	**EL 4**
c	2.66E+01	2.83E+01	3.32E+01	3.32E+01	4.32E+01
d	7.43E-01	7.65E-01	7.43E-01	7.71E-01	7.58E-01

In a second step DOE established an index to describe how weights vary with pole and enclosure across horsepower ratings (at a fixed EL). DOE established these indices using statistical estimates derived from a database of motor prices which DOE built upon data collected from internet catalogs from six major manufacturers and one large distributor (see Table 10.3.4 for an example of these indices estimated for Designs A and B motors). DOE used the indices in Table 10.3.4 and the weights estimated from model equation xxvi for 4-pole enclosed motors to estimate the weight of all other equipment classes. The final weight estimates are available in the NIA spreadsheet.

Table 10.3.4 Indices used to Scale Weight across Poles and Enclosures (Equipment Class Group 1)

	Open				Enclosed			
hp	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1	0.970	0.978	1.003	1.011	1.000	1.000	1.016	1.034
1.5	0.956	0.968	1.005	1.016	1.000	1.000	1.024	1.050
2	0.943	0.959	1.006	1.021	1.001	1.000	1.031	1.064
3	0.920	0.942	1.008	1.030	1.001	1.000	1.044	1.091
5	0.881	0.913	1.013	1.044	1.001	1.000	1.065	1.135
7.5	0.842	0.885	1.017	1.059	1.002	1.000	1.086	1.180
10	0.811	0.862	1.020	1.071	1.002	1.000	1.103	1.215
15	0.765	0.829	1.025	1.088	1.003	1.000	1.128	1.267
20	0.733	0.805	1.028	1.100	1.003	1.000	1.146	1.303
25	0.708	0.788	1.031	1.109	1.003	1.000	1.159	1.331
30	0.690	0.774	1.033	1.116	1.003	1.000	1.169	1.352
40	0.663	0.755	1.035	1.126	1.004	1.000	1.184	1.383
50	0.644	0.741	1.037	1.133	1.004	1.000	1.194	1.404
60	0.631	0.731	1.039	1.138	1.004	1.000	1.201	1.419
75	0.616	0.721	1.040	1.143	1.004	1.000	1.209	1.436
100	0.600	0.709	1.042	1.149	1.004	1.000	1.218	1.454
125	0.590	0.702	1.043	1.153	1.004	1.000	1.223	1.465
150	0.583	0.697	1.044	1.155	1.005	1.000	1.227	1.473
200	0.574	0.690	1.045	1.159	1.005	1.000	1.232	1.484
250	0.568	0.686	1.045	1.161	1.005	1.000	1.235	1.490
300	0.564	0.683	1.046	1.162	1.005	1.000	1.237	1.494
350	0.561	0.681	1.046	1.164	1.005	1.000	1.239	1.498
400	0.559	0.679	1.046	1.164	1.005	1.000	1.240	1.500
450	0.558	0.678	1.046	1.165	1.005	1.000	1.241	1.502
500	0.556	0.677	1.047	1.165	1.005	1.000	1.242	1.504

10.3.2.4 Repair Costs

DOE calculated the repair costs in two steps. First DOE considered the cost of one repair event by motor horsepower, configuration and efficiency level described in Chapter 8, Section 8.2.2.4. Then DOE calculated the lifetime repair cost of a motor with a given horsepower, configuration and efficiency level, operating in a certain sector, as the present-value of a stream of repair events occurring within a fixed frequency – depending on the sector and horsepower range – until the end of the life of the equipment. For the calculation of the present-value DOE used the two discount rates discussed in Section 10.3.2.6. However, DOE understands that not all motors will operate for 30 years. Consequently, in the calculation of present value, DOE multiplied the cost of each repair event by the probability that the motor will be in operation by that time, according to its horsepower rating and the sector where the motor is used. (See Section 10.2.2.5 above for more about lifetime distributions.)

10.3.2.5 Electricity Prices

For the NIA, DOE considered the electricity prices by sector as national weighted averages of the regional weighted average electricity prices described in Chapter 8, Section 8.2.2.2.

10.3.2.6 Discount Rate

The discount rate expresses the time value of money. DOE used real discount rates of 3 percent and 7 percent, as established by the U.S. Office of Management and Budget (OMB) guidelines on regulatory analysis. [4] The discount rates DOE used in the LCC are distinct from those it used in the NPV calculations, in that the NPV discount rates represent the societal rate of return on capital investment, whereas LCC discount rates reflect the owner cost of capital and the financial environment of electric utilities and commercial and industrial entities.

10.3.3 Unit Lifetime Energy Cost

The unit lifetime energy cost expresses an estimate of the market average expense with electricity that owners of all motors of a given equipment class, shipped in a given year, will have to operate these motors over their lifetime. It refers to the variable $uNC_{hp,g,c}$ in xix and xx, and is evaluated as the sum of the annual energy cost over the motor lifetime:

$$uNC_{hp,g,c}(s,a,y) = \sum_{i=1}^{30}\left(UEC_{hp,g,c}(s,a,i)\cdot nP(y+i-1)\cdot(1+r)^{1-i}\cdot O_{hp}(s,i)\right) \quad \text{xxvii.}$$

$$UEC_{hp,g,c}(s,a,i) = \frac{(hp \times 0.757)\cdot Load(a)\cdot Hours_{hp}(s,a)}{fEff_c \cdot aEff_{hp,c}(a)\cdot Conserv(i)} \quad \text{xxviii.}$$

where:

$uNC_{hp,g,c}(s,a,y)$	= the lifetime energy cost of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*, shipped in year *y* and used for application *a* in sector *s*,
$UEC_{hp,g,c}(s,a,i)$	= the site energy consumption in the *i*-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c* used for application *a* in sector *s*,
$nP(\text{t})$	= the national average electricity price in year *t*,
r	= the discount rate,
$O_{hp}(s,i)$	= the probability that a unit with capacity *hp*, used in sector *s* will be in operation in the *i*-th year of its lifetime,
hp	= the unit capacity (in horse-power),
$Load(a)$	= the typical load of a motor used in application *a*,

$Hours_{hp}(s,a)$	=	annual hours of operation of a unit with capacity *hp*, used for application *a* in sector *s*,
$fEff_c$	=	the full-load efficiency of a unit with efficiency level at EL *c*,
$aEff_{hp,c}(a)$	=	the factor used to adjust the full-load efficiency of a unit with capacity *hp* and efficiency level at EL *c* used in application *a* to the efficiency corresponding to its typical load, and
$Conserv(i)$	=	the energy efficiency conservation factor used to reduce the unit initial efficiency to the efficiency it is estimated to present in its *i*-th year of operation due to repairs.

10.3.4 Unit Lifetime Non-Energy Costs

The unit lifetime non-energy costs expresses an estimate of the market average expenses that owners of all motors of a given equipment class, shipped in a given year, will have with purchasing and repairing these motors over their lifetime. It refers to the variable $uQC_{hp,g,c}$ in xxiii and xxiv, and is evaluated as the sum of the motor initial costs with the present-value of all repair costs over the motor lifetime:

$$uQC_{hp,g,c}(s,y) = uIC_{hp,g,c}(y) + \sum_{i=1}^{30}\left(uRC_{hp,g,c}(i)\cdot(1+r)^{1-i}\cdot O_{hp}(s,i)\right) \qquad \text{xxix.}$$

$$uIC_{hp,g,c}(y) = kP(y)\cdot uQC_{hp,g,c} + uSC_{hp,g,c} \qquad \text{xxx.}$$

$$uQC_{hp,g,c} = MSP_{hp,g,0}\cdot(OVHbase - OVHinc) + MSP_{hp,g,c}\cdot OVHinc \qquad \text{xxxi.}$$

$$uSC_{hp,g,c} = uWeight_{hp,g,c}\cdot sP \qquad \text{xxxii.}$$

$$uRC_{hp,g,c}(i) = \begin{cases} uRCepact_{hp,g}\cdot kR_c, i = 6, 11, 16, 21, 26 \\ 0, i \neq 6, 11, 16, 21, 26 \end{cases} \qquad \text{xxxiii.}$$

where:

$uQC_{hp,g,c}(s,a,y)$	=	the lifetime non-energy costs of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*, shipped in year *y* to sector *s*,
$uIC_{hp,g,c}(y)$	=	the total installed cost of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*, shipped in year *y*,
$kP(y)$	=	the price-trend multiplier for a unit shipped in year *y*,
$uQC_{hp,g,c}$	=	the retail price of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*,
$uSC_{hp,g,c}$	=	the shipment cost of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*,
$MSP_{hp,g,c}$	=	the manufacturer price of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*,
$OVHbase$	=	the baseline price overhead,
$OVHinc$	=	the incremental price overhead,

$uWeight_{hp,g,c}$	=	the weight of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c*,
sP	=	the per pound shipment cost,
$uRC_{hp,g,c}(i)$	=	the repair cost of a unit with capacity *hp*, configuration *g* and efficiency level at EL *c* in its *i*-th year of operation,
$uRCepact_{hp,g}$	=	the repair cost of a unit with capacity *hp*, configuration *g* and efficiency level below the applicable under the Energy Policy Act of 1992 (EPACT 1992),
kR_c	=	the repair cost adder of a unit with efficiency level at EL *c* relative to the repair cost of a unit with efficiency level below EPACT 1992,
$O_{hp}(s,i)$	=	the probability that a unit with capacity *hp*, used in sector *s* will be in operation in the *i*-th year of its lifetime, and
r	=	the discount rate.

10.4 TRIAL STANDARD LEVELS

DOE developed TSLs that combine efficiency levels for each equipment class group. Table 10.4.1 presents the efficiency levels for each equipment class group in each TSL. TSL 4 consists of the max-tech efficiency levels. TSL 3 consists of those efficiency levels that are one level above the levels at TSL 2. TSL 2 refers to the efficiency levels closest to the ones recommended by the Motor Coalition[k] in their comments to the preliminary analysis.[5] TSL 1 consists of EL 1 efficiency levels for equipment class groups 1, 2, and 4, and of EL 0 for equipment class group 3.

Table 10.4.1 Trial Standard Levels for Electric Motors

Equipment Class Group	Trial Standard Level (Efficiency Level)			
	1	**2**	**3**	**4**
1: NEMA Design A and B	EL 1	EL 2	EL 3	EL 4
2: NEMA Design C	EL 1	EL 1	EL 2	EL 2
3I: NEMA Fire Pump Electric Motors	EL 0	EL 0	EL 1	EL 3
4: NEMA Brake Motors	EL 1	EL 2	EL 3	EL 4

[k] The members of the Motor Coalition include: National Electrical Manufacturers Association (NEMA), American Council for an Energy-Efficient Economy (ACEEE), Appliance Standards Awareness Project (ASAP), Alliance to Save Energy (ASE), Earthjustice, Natural Resources Defense Council (NRDC), Northwest Energy Efficiency Alliance (NEEA), Northeast Energy Efficiency Partnerships (NEEP), and Northwest Power and Conservation Council (NPCC).

10.5 RESULTS

10.5.1 National Energy Savings and Net Present Value for Trial Standard Levels

DOE evaluated NES and NPV for each equipment class group and TSL using the inputs and methodologies described in Sections 10.2 and 10.3. Table 10.5.1 and Table 10.5.2 present respectively NES and NPV results.

Table 10.5.1 Cumulative National Energy Savings for Electric Motors Trial Standard Levels from Units Sold over the 30-year Analysis Period

Equipment Class Group	**Energy**	**Trial Standard Level**			
		1	2	3	4
		(*billion 2012$*)			
1: NEMA Design A and B	Primary	0.821	6.273	9.860	12.642
2: NEMA Design C		0.019	0.019	0.030	0.030
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.256	0.578	0.714	0.814
Total All Classes		1.096	6.869	10.604	13.486
1: NEMA Design A and B	FFC	0.834	6.377	10.023	12.852
2: NEMA Design C		0.019	0.019	0.030	0.030
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.261	0.587	0.726	0.827
Total All Classes		1.114	6.983	10.780	13.709

Table 10.5.2 Net Present Value for Electric Motors for Electric Motors Trial Standard Levels from Units Sold over the 30-year Analysis Period

Equipment Class Group	Discount Rate	Trial Standard Level			
		1	2	3	4
		(*billion 2012$*)			
1: NEMA Design A and B	3%	4.473	20.704	1.538	-41.183
2: NEMA Design C		0.049	0.049	-0.028	-0.028
3: Fire Pump Electric Motors		0.000	0.000	-0.003	-0.031
4: Brake Motors		1.311	2.514	1.462	-1.152
Total All Classes		5.832	23.267	2.969	-42.394
1: NEMA Design A and B	7%	2.159	7.681	-3.697	-29.086
2: NEMA Design C		0.014	0.014	-0.034	-0.034
3: Fire Pump Electric Motors		0.000	0.000	-0.002	-0.016
4: Brake Motors		0.531	0.957	0.349	-1.170
Total All Classes		2.704	8.652	-3.384	-30.306

10.5.2 Scenario Analysis

DOE also performed a scenario analysis to assess how changes in economic growth would affect the former NES and NPV results reported in Tables Table 10.5.1 and Table 10.5.2. Table 10.5.3 through Table 10.5.6 present NES and NPV results for both the low- and high economic growth scenarios.

Table 10.5.3 Cumulative National Energy Savings for the Low Economic Growth Scenario

Equipment Class Group	Energy	Trial Standard Level			
		1	2	3	4
		(billion 2012$)			
1: NEMA Design A and B	Primary	0.709	5.423	8.525	10.931
2: NEMA Design C		0.016	0.016	0.026	0.026
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.222	0.500	0.617	0.703
Total All Classes		0.947	5.938	9.168	11.660
1: NEMA Design A and B	FFC	0.721	5.513	8.666	11.112
2: NEMA Design C		0.016	0.016	0.026	0.026
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.225	0.508	0.628	0.715
Total All Classes		0.962	6.037	9.320	11.853

Table 10.5.4 Net Present Value for the Low Economic Growth Scenario

Equipment Class Group	Discount Rate	Trial Standard Level			
		1	2	3	4
		(billion 2012$)			
1: NEMA Design A and B	3%	3.713	16.543	-0.792	-38.309
2: NEMA Design C		0.038	0.038	-0.031	-0.031
3: Fire Pump Electric Motors		0.000	0.000	-0.003	-0.026
4: Brake Motors		1.079	2.049	1.112	-1.168
Total All Classes		4.830	18.630	0.287	-39.534
1: NEMA Design A and B	7%	1.807	6.173	-3.906	-26.057
2: NEMA Design C		0.011	0.011	-0.032	-0.032
3: Fire Pump Electric Motors		0.000	0.000	-0.001	-0.014
4: Brake Motors		0.441	0.786	0.251	-1.069
Total All Classes		2.258	6.969	-3.688	-27.172

Table 10.5.5 Cumulative National Energy Savings for the High Economic Growth Scenario

Equipment Class Group	Energy	Trial Standard Level			
		1	2	3	4
		(*billion 2012$*)			
1: NEMA Design A and B	Primary	0.946	7.285	11.456	14.685
2: NEMA Design C		0.022	0.022	0.035	0.035
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.298	0.671	0.830	0.945
Total All Classes		1.265	7.978	12.320	15.665
1: NEMA Design A and B	FFC	0.961	7.406	11.646	14.929
2: NEMA Design C		0.022	0.022	0.035	0.035
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.303	0.683	0.843	0.961
Total All Classes		1.286	8.111	12.525	15.925

Table 10.5.6 Net Present Value for the High Economic Growth Scenario

Equipment Class Group	Discount Rate	Trial Standard Level			
		1	2	3	4
		(*billion 2012$*)			
1: NEMA Design A and B	3%	5.439	26.366	5.454	-42.865
2: NEMA Design C		0.064	0.064	-0.021	-0.021
3: Fire Pump Electric Motors		0.000	0.000	-0.003	-0.035
4: Brake Motors		1.614	3.131	1.960	-1.026
Total All Classes		7.117	29.561	7.389	-43.947
1: NEMA Design A and B	7%	2.603	9.737	-2.944	-31.739
2: NEMA Design C		0.019	0.019	-0.035	-0.035
3: Fire Pump Electric Motors		0.000	0.000	-0.002	-0.019
4: Brake Motors		0.648	1.184	0.498	-1.235
Total All Classes		3.270	10.940	-2.482	-33.029

10.5.3 Sensitivity Analysis

Besides calculating NES and NPV values for the inputs described in Sections 10.2.2 and 10.3.2 above, DOE performed a sensitivity analysis for some of those inputs, namely the annual hours of operation, MSP and repair cost. While changes in the annual hours of operation affect both the NES and NPV, a variation in the MSP and repair cost impacts only the NPV. Table 10.5.7 through Table 10.5.10 summarize the impacts that a change of ±10 percent in these variables has on the former NES and NPV values, as reported in Table 10.5.1 and Table 10.5.2.

Table 10.5.7 Cumulative National Energy Savings Variation in Response to ±10 Percent Changes in Hours of Operation*

Equipment Class Group	Energy	Trial Standard Level			
		1	2	3	4
		(*billion 2012$*)			
1: NEMA Design A and B	Primary	±0.082	±0.627	±0.986	±1.264
2: NEMA Design C		±0.002	±0.002	±0.003	±0.003
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		±0.026	±0.058	±0.071	±0.081
Total All Classes		±0.110	±0.687	±1.060	±1.349
1: NEMA Design A and B	FFC	±0.083	±0.638	±1.002	±1.285
2: NEMA Design C		±0.002	±0.002	±0.003	±0.003
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		±0.026	±0.059	±0.073	±0.083
Total All Classes		±0.111	±0.698	±1.078	±1.371

* NES and hours of operation are positively correlated, which means that an increase in NES results from an increase in hours of operation.

Table 10.5.8 Net Present Value Variation in Response to ±10 Percent Changes in Hours of Operation*

Equipment Class Group	Discount Rate	Trial Standard Level			
		1	2	3	4
		(billion 2012$)			
1: NEMA Design A and B	3%	±0.503	±3.425	±5.352	±6.873
2: NEMA Design C		±0.010	±0.010	±0.016	±0.016
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		±0.145	±0.324	±0.400	±0.457
Total All Classes		±0.659	±3.760	±5.768	±7.346
1: NEMA Design A and B	7%	±0.251	±1.438	±2.224	±2.867
2: NEMA Design C		±0.004	±0.004	±0.007	±0.007
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		±0.061	±0.134	±0.165	±0.188
Total All Classes		±0.317	±1.576	±2.395	±3.062

* NPV and hours of operation are positively correlated, which means that an increase in NPV results from an increase in hours of operation.

Table 10.5.9 Net Present Value Variation in Response to ±10 Percent Changes in Manufacturer Selling Price*

Equipment Class Group	Discount Rate	Trial Standard Level			
		1	2	3	4
		(billion 2012$)			
1: NEMA Design A and B	3%	±0.049	±0.966	±4.300	±9.530
2: NEMA Design C		±0.004	±0.004	±0.017	±0.017
3: Fire Pump Electric Motors		0.000	0.000	0.000	±0.003
4: Brake Motors		±0.013	±0.059	±0.226	±0.525
Total All Classes		±0.065	±1.029	±4.544	±10.075
1: NEMA Design A and B	7%	±0.031	±0.508	±2.210	±5.120
2: NEMA Design C		±0.002	±0.002	±0.009	±0.009
3: Fire Pump Electric Motors		0.000	0.000	0.000	±0.002
4: Brake Motors		±0.007	±0.031	±0.116	±0.282
Total All Classes		±0.040	±0.541	±2.335	±5.413

* NPV and MSP are negatively correlated, which means that an increase in NPV results from a decrease in MSP.

Table 10.5.10 Net Present Value Variation in Response to ±10 Percent Changes in Repair Cost*

Equipment Class Group	Discount Rate	Trial Standard Level			
		1	2	3	4
		(*billion 2012$*)			
1: NEMA Design A and B	3%	0.000	±0.263	±0.536	±0.772
2: NEMA Design C		±0.001	±0.001	±0.001	±0.001
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.000	±0.005	±0.008	±0.011
Total All Classes		±0.001	±0.268	±0.545	±0.785
1: NEMA Design A and B	7%	0.000	±0.095	±0.195	±0.285
2: NEMA Design C		0.000	0.000	0.000	0.000
3: Fire Pump Electric Motors		0.000	0.000	0.000	0.000
4: Brake Motors		0.000	±0.002	±0.003	±0.004
Total All Classes		0.000	±0.097	±0.198	±0.290

* NPV and repair cost are negatively correlated, which means that an increase in NPV results from a decrease in repair cost.

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CHAPTER 11. CUSTOMER SUBGROUP ANALYSIS

11.1 INTRODUCTION

The customer subgroup analysis evaluates impacts on any identifiable groups or customers who may be disproportionately affected by any national energy conservation standard. The U.S. Department of Energy (DOE) evaluates impacts on particular subgroups of customers primarily by analyzing the life-cycle cost (LCC) impacts and payback period (PBP) for those customers from the considered energy efficiency levels. DOE determines the impact on customer subgroups using the LCC spreadsheet models for electric motors. Chapter 8 explains in detail the inputs to the models used in determining LCC impacts and PBPs.

For the notice of proposed rulemaking (NOPR), DOE evaluated impacts on customers located in regions with lower electricity prices, customers which are small businesses, and customers which are part of the industrial, agricultural and commercial sector.

This chapter describes the subgroup identification in further detail and gives the results of the LCC and PBP analyses for the considered subgroups.

11.2 SUBGROUPS DEFINITION

11.2.1 Low Electricity Price Regions

Customers in the low electricity price regions represent the users of electric motors which are located in the regions with lower electricity prices for each sector (industrial, agricultural, and commercial). DOE analyzed impacts on those customers by using the lowest electricity rate among the four Census regions considered for each sector. DOE used electricity rate in the South Census region ($0.076/kWh) for the agricultural and industrial customer subgroups, and the electricity rate in the Midwest Census region ($0.089/kWh) for the commercial customer subgroups analysis.

11.2.2 Small Businesses

The Small Business Administration (SBA) defines a small business by its annual receipts or its number of employees. Electric motors are used throughout the U.S. economy, so DOE did not assign a different distribution of motor applications or sectors of the economy to this subgroup.

To calculate discount rates for small companies that purchase electric motors, DOE used the same methodology as for the general population of electric motor customers as presented in chapter 8.[a] Although the methodology is appropriate, the capital asset pricing model (CAPM)[b] described in chapter 8 for the general population underestimates the cost of capital for small companies. In CAPM, the risk premium β is used to account for the higher returns associated with greater risk. However, for small companies, particularly very small companies, historic returns have been significantly higher than the CAPM equation predicts. This additional return can be accounted for by adding a size premium to the cost of equity for small firms:

$$k_e = R_f + (\beta \times ERP) + S$$

k_e = Cost of equity,
R_f = Expected return on risk-free assets,
β = Risk coefficient of the firm,
ERP = Equity risk premium, and
S = Size Premium.

DOE obtained size premium data from Ibbotson Associates' Stocks, Bonds, Bills, and Inflation 2009 Yearbook.[1] For the period of 1926–2008, the average size premium for the smallest companies in all industries is 5.81 percent, implying that on average, historic performance of small companies has been 5.81 percent higher than the CAPM estimate of the small company cost of equity.[c]

DOE calculated the real weighted average cost of capital (as described in chapter 8) using the cost of equity including a size premium for small companies instead of the CAPM cost of equity. DOE estimates that small companies have average discount rates 2.53% higher than the sector average in the industrial sector and 2.71% higher than the sector average in the commercial sector, based on data from Damodaran[2] (see Table 11.2.1).

Table 11.2.1 Discount Rate Difference Between Small Company and Sector Average

Sector		**Discount Rate**		
		Average	**Std Dev**	**Small Company Discount Rate Premium**
Industrial	Entire Sector	6.34%	1.21%	2.53%
	Small Companies	8.87%	2.17%	
Commercial	Entire Sector	5.66%	1.08%	2.71%
	Small Companies	8.37%	2.33%	

In chapter 8, DOE estimated the average discount rate to be 6.34% for industrial customers and 5.66% for commercial customers. Applying the additional small capitalization

[a] DOE assumed that small businesses as a whole are a reasonable approximation for small businesses which use small electric motors.
[b] See 8.2.4.3 for more extensive description of CAPM and its parameters.
[c] In this calculation, small companies are defined as companies with market capitalization of less than or equal to $84.5 million, the Ibbotson Associates' definition of Decile 10 companies.

discount rate premiums, as presented in Table 11.2.1, the average small business discount rate is 8.87% for the industrial sector and 8.37% for the commercial sector. Due to limited data availability, DOE applies the small business discount rate estimated for the industrial sector to the agricultural sector.

11.2.3 Customers by Sector of the Economy

Customers may operate their motors differently depending on the sector: industrial, agricultural, or commercial. Typically, customers of the industrial sectors show higher operating hours than customers in the agricultural sectors.

DOE conducted analysis by using the sector specific average operating hours for each sectors in chapter 7 to evaluate the impact of standards by sector.

11.3 RESULTS FOR ELECTRIC MOTOR SUBGROUPS

11.3.1 Representative Unit 1, NEMA Design B, 5 Horsepower, 4 Poles, Enclosed Motor

11.3.1.1 Low Electricity Price Regions

Table 11.3.1 Representative Unit 1 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,977	695	5,540	N/A	0.0	0.0	N/A	N/A
1	87.5	623	8,287	642	5,187	40	0.0	11.2	0.7	0.5
2	89.5	674	8,138	631	5,157	52	11.7	29.3	10.3	4.3
3	90.2	729	8,062	624	5,164	43	40.7	36.9	12.2	8.0
4	91.0	1,152	7,969	618	5,542	-302	86.6	5.6	85.5	35.4

11.3.1.2 Small Businesses

Table 11.3.2 Representative Unit 1 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,977	772	5,494	N/A	0.0	0.0	N/A	N/A
1	87.5	623	8,287	714	5,146	39	0.0	11.2	0.6	0.4
2	89.5	674	8,138	701	5,117	51	12.0	29.0	9.0	3.8
3	90.2	729	8,062	694	5,124	42	41.8	35.7	10.9	7.1
4	91.0	1,152	7,969	687	5,502	-303	86.7	5.6	63.3	31.4

11.3.1.3 Agricultural Sector

Table 11.3.3 Representative Unit 1 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	4,371	362	3,745	N/A	0.0	0.0	N/A	N/A
1	87.5	623	4,037	337	3,550	22	0.1	11.2	1.2	0.8
2	89.5	674	3,964	338	3,604	0	28.7	12.3	2,492	7.3
3	90.2	729	3,927	339	3,670	-51	69.3	8.3	175	22.3
4	91.0	1,152	3,882	341	4,107	-455	92.1	0.2	1,147	130

11.3.1.4 Industrial Sector

Table 11.3.4 Representative Unit 1 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	15,629	1,137	7,201	N/A	0.0	0.0	N/A	N/A
1	87.5	623	14,400	1,048	6,702	55	0.0	11.2	0.4	0.2
2	89.5	674	14,144	1,029	6,647	78	6.7	34.3	4.9	2.4
3	90.2	729	14,009	1,019	6,641	81	22.2	55.4	6.5	4.4
4	91.0	1,152	13,844	1,007	6,997	-246	82.7	9.6	30.3	19.3

11.3.1.5 Commercial Sector

Table 11.3.5 Representative Unit 1 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	6,724	651	5,800	N/A	0.0	0.0	N/A	N/A
1	87.5	623	6,218	603	5,432	42	0.0	11.2	0.7	0.5
2	89.5	674	6,104	592	5,397	56	11.4	29.6	10.3	4.5
3	90.2	729	6,049	586	5,403	49	39.9	37.7	12.4	8.4
4	91.0	1,152	5,980	580	5,778	-294	86.3	6.0	76.9	36.9

11.3.2 Representative Unit 2, NEMA Design B, 30 Horsepower, 4 Poles, Enclosed Motor

11.3.2.1 Low Electricity Price Regions

Table 11.3.6 Representative Unit 2 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	61,611	4,887	43,656	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	60,164	4,777	43,118	30	1.3	3.6	19.9	4.3
2	93.6	2,133	58,778	4,682	42,405	310	1.9	37.3	4.4	1.5
3	94.1	2,378	58,698	4,686	42,676	85	49.3	33.7	68.1	5.8
4	94.5	3,639	58,511	4,681	43,897	-1,046	86.6	5.9	832	28.9

11.3.2.2 Small Businesses

Table 11.3.7 Representative Unit 2 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	61,611	5,440	42,416	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	60,164	5,318	41,902	28	1.3	3.6	16.9	3.8
2	93.6	2,133	58,778	5,210	41,201	303	1.8	37.3	13.0	1.3
3	94.1	2,378	58,698	5,213	41,462	86	48.8	34.1	226	5.0
4	94.5	3,639	58,511	5,207	42,675	-1,037	87.0	5.6	196	25.6

11.3.2.3 Agricultural Sector

Table 11.3.8 Representative Unit 2 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	21,097	1,637	15,479	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	20,621	1,604	15,608	-6	3.7	1.2	38.5	13.8
2	93.6	2,133	20,117	1,580	15,506	33	12.4	26.8	15.1	5.2
3	94.1	2,378	20,099	1,589	15,818	-226	77.8	5.1	94.8	21.8
4	94.5	3,639	20,037	1,595	17,124	-1,434	92.6	0.0	561	100

11.3.2.4 Industrial Sector

Table 11.3.9 Representative Unit 2 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	95,482	7,030	58,554	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	93,287	6,874	57,694	45	0.9	4.1	9.8	3.1
2	93.6	2,133	91,064	6,725	56,594	474	0.8	38.4	1.6	0.8
3	94.1	2,378	90,965	6,728	56,860	253	42.1	40.9	212	3.3
4	94.5	3,639	90,680	6,718	58,037	-837	79.4	13.1	195	17.7

11.3.2.5 Commercial Sector

Table 11.3.10 Representative Unit 2 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	49,614	4,888	45,096	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	48,435	4,778	44,525	31	1.3	3.7	20.2	4.5
2	93.6	2,133	47,339	4,685	43,797	317	1.8	37.3	13.3	1.5
3	94.1	2,378	47,267	4,687	44,060	98	48.2	34.7	41.1	5.5
4	94.5	3,639	47,115	4,683	45,277	-1,028	85.7	6.8	210	27.4

11.3.3 Representative Unit 3, NEMA Design B, 75 Horsepower, 4 Poles, Enclosed Motor

11.3.3.1 Low Electricity Price Regions

Table 11.3.11 Representative Unit 3 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	3,576	195,566	14,322	122,862	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	194,167	14,238	122,474	43	3.0	5.1	36.8	3.6
2	95.4	4,344	190,458	13,991	120,887	569	3.0	29.9	6.8	2.0
3	95.8	5,082	190,392	14,007	121,755	-82	50.4	24.6	45.0	7.0
4	96.2	6,461	188,997	13,925	122,439	-709	72.3	19.2	75.8	17.4

11.3.3.2 Small Businesses

Table 11.3.12 Representative Unit 3 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	3,576	195,566	15,283	115,332	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	194,167	15,194	114,994	39	3.1	5.0	20.8	3.5
2	95.4	4,344	190,458	14,929	113,526	526	3.1	29.7	5.2	1.9
3	95.8	5,082	190,392	14,944	114,373	-109	51.2	23.8	44.1	6.6
4	96.2	6,461	188,997	14,855	115,092	-767	74.2	17.4	65.4	16.1

11.3.3.3 Agricultural Sector

Table 11.3.13 Representative Unit 3 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	3,576	50,951	3,912	36,273	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	50,602	3,894	36,409	-10	6.4	1.6	64.3	13.4
2	95.4	4,344	49,621	3,844	36,458	-27	21.6	11.3	17.7	10.2
3	95.8	5,082	49,616	3,865	37,361	-704	74.3	0.8	270	37.4
4	96.2	6,461	49,243	3,857	38,657	-1,890	91.5	0.0	541	87.8

11.3.3.4 Industrial Sector

Table 11.3.14 Representative Unit 3 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	3,576	242,271	17,761	146,644	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	240,549	17,666	146,192	54	2.4	5.6	19.4	2.8
2	95.4	4,344	235,934	17,353	144,135	727	0.9	31.9	4.0	1.5
3	95.8	5,082	235,863	17,369	145,003	76	45.0	30.1	39.8	5.3
4	96.2	6,461	234,124	17,262	145,508	-386	66.2	25.3	58.9	13.5

11.3.3.5 Commercial Sector

Table 11.3.15 Representative Unit 3 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	3,576	128,827	12,622	120,533	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	127,872	12,545	120,133	42	2.9	5.2	27.0	4.2
2	95.4	4,344	125,484	12,334	118,644	529	2.3	30.5	9.6	2.6
3	95.8	5,082	125,410	12,346	119,483	-102	52.5	22.6	65.5	8.7
4	96.2	6,461	124,520	12,277	120,213	-770	74.7	16.8	84.3	20.4

11.3.4 Representative Unit 4, NEMA Design C, 5 Horsepower, 4 Poles, Enclosed Motor

11.3.4.1 Low Electricity Price Regions

Table 11.3.16 Representative Unit 4 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	596	8,376	649	5,377	N/A	0.0	0.0	N/A	N/A
1	89.5	641	8,206	637	5,332	41	23.0	68.9	11.0	4.8
2	91.0	1,059	8,078	626	5,668	-294	98.1	1.9	38.9	26.7

11.3.4.2 Small Businesses

Table 11.3.17 Representative Unit 4 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	596	8,376	720	5,309	N/A	0.0	0.0	N/A	N/A
1	89.5	641	8,206	706	5,265	41	23.8	68.2	10.6	4.2
2	91.0	1,059	8,078	694	5,602	-297	97.9	2.1	34.8	23.7

11.3.4.3 Agricultural Sector

Table 11.3.18 Representative Unit 4 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	87.5	596	4,109	342	3,577	N/A	0.0	0.0	N/A	N/A
1	89.5	641	4,026	342	3,624	-43	83.1	8.9	340	18.3
2	91.0	1,059	3,963	341	4,028	-447	100.0	0.0	597	112

11.3.4.4 Industrial Sector

Table 11.3.19 Representative Unit 4 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	87.5	596	14,756	1,074	6,778	N/A	0.0	0.0	N/A	N/A
1	89.5	641	14,455	1,053	6,703	69	7.7	84.3	4.9	2.5
2	91.0	1,059	14,231	1,035	7,020	-248	96.2	3.8	21.8	14.6

11.3.4.5 Commercial Sector

Table 11.3.20 Representative Unit 4 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	87.5	596	6,185	600	5,689	N/A	0.0	0.0	N/A	N/A
1	89.5	641	6,059	588	5,638	46	22.2	69.7	12.9	4.8
2	91.0	1,059	5,965	578	5,968	-284	96.8	3.3	39.5	27.0

11.3.5 Representative Unit 5, NEMA Design C, 50 Horsepower, 4 Poles, Enclosed Motor

11.3.5.1 Low Electricity Price Regions

Table 11.3.21 Representative Unit 5 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	79,551	6,260	60,797	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	78,276	6,184	61,049	-169	52.8	20.3	49.4	14.3
2	95.0	4,610	77,653	6,146	61,387	-507	81.9	18.1	49.4	16.7

11.3.5.2 Small Businesses

Table 11.3.22 Representative Unit 5 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	79,551	6,940	58,310	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	78,276	6,854	58,573	-178	53.5	19.7	41.7	12.5
2	95.0	4,610	77,653	6,810	58,916	-521	83.1	16.9	38.9	14.6

11.3.5.3 Agricultural Sector

Table 11.3.23 Representative Unit 5 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	37,613	2,880	27,795	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	37,009	2,857	28,559	-552	72.6	0.6	144	40.1
2	95.0	4,610	36,714	2,846	29,157	-1,150	100.0	0.0	272	48.8

11.3.5.4 Industrial Sector

Table 11.3.24 Representative Unit 5 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	134,548	9,895	87,075	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	132,390	9,764	86,902	142	32.5	40.7	17.1	7.8
2	95.0	4,610	131,336	9,698	87,036	8	55.7	44.3	22.0	9.3

11.3.5.5 Commercial Sector

Table 11.3.25 Representative Unit 5 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	59,646	5,869	60,474	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	58,688	5,799	60,749	-173	53.1	20.1	46.7	14.1
2	95.0	4,610	58,221	5,763	61,088	-512	82.5	17.4	41.4	16.7

11.3.6 Representative Unit 6, Fire Pump, 5 Horsepower, 4 Poles, Enclosed Electric Motor

11.3.6.1 Low Electricity Price Regions

Table 11.3.26 Representative Unit 6 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	655	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	708	-44	82.0	0.0	6,809	4,548
2	90.2	731	9	2	758	-91	94.9	0.0	1,409	520
3	91.0	1,153	9	2	1,184	-518	100.0	0.0	25,158	15,409

11.3.6.2 Small Businesses

Table 11.3.27 Representative Unit 6 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	649	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	702	-43	82.0	0.0	6,162	4,086
2	90.2	731	9	2	753	-92	94.9	0.0	1,310	513
3	91.0	1,153	9	2	1,179	-517	100.0	0.0	76,460	14,484

11.3.6.3 Agricultural Sector

Table 11.3.28 Representative Unit 6 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	653	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	706	-43	82.0	0.0	7,427	4,971
2	90.2	731	9	2	756	-91	94.9	0.0	1,483	534
3	91.0	1,153	9	2	1,182	-518	100.0	0.0	27,897	16,409

11.3.6.4 Industrial Sector

Table 11.3.29 Representative Unit 6 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	653	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	706	-43	82.0	0.0	7,611	5,089
2	90.2	731	9	2	756	-91	94.9	0.0	1,512	535
3	91.0	1,153	9	2	1,182	-518	100.0	0.0	27,052	16,454

11.3.6.5 Commercial Sector

Table 11.3.30 Representative Unit 6 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	657	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	710	-44	82.0	0.0	5,753	3,745
2	90.2	731	9	2	760	-91	94.9	0.0	1,227	507
3	91.0	1,153	9	2	1,187	-518	100.0	0.0	79,600	13,996

11.3.7 Representative Unit 7, Fire Pump, 30 Horsepower, 4 Poles, Enclosed Electric Motor

11.3.7.1 Low Electricity Price Regions

Table 11.3.31 Representative Unit 7 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	2,052	53	12	2,222	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	11	2,330	-88	80.7	0.0	1,110	389
2	94.1	2,410	52	11	2,575	-302	87.4	0.0	3,399	1,406
3	94.5	3,670	52	11	3,831	-1,558	100.0	0.0	11,964	2,842

11.3.7.2 Small Businesses

Table 11.3.32 Representative Unit 7 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	2,052	53	12	2,192	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	12	2,301	-88	80.7	0.0	928	375
2	94.1	2,410	52	12	2,546	-302	87.4	0.0	3,294	1,339
3	94.5	3,670	52	12	3,803	-1,559	100.0	0.0	11,435	2,768

11.3.7.3 Agricultural Sector

Table 11.3.33 Representative Unit 7 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	92.4	2,052	53	11	2,211	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	11	2,320	-88	80.7	0.0	1,170	402
2	94.1	2,410	52	11	2,565	-302	87.4	0.0	3,850	1,480
3	94.5	3,670	52	11	3,821	-1,558	100.0	0.0	19,856	2,947

11.3.7.4 Industrial Sector

Table 11.3.34 Representative Unit 7 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	92.4	2,052	54	11	2,211	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	11	2,320	-88	80.7	0.0	2,774	402
2	94.1	2,410	52	11	2,565	-302	87.4	0.0	4,616	1,472
3	94.5	3,670	52	11	3,821	-1,558	100.0	0.0	11,045	2,928

11.3.7.5 Commercial Sector

Table 11.3.35 Representative Unit 7 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	92.4	2,052	53	13	2,236	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	12	2,345	-88	80.7	0.0	994	366
2	94.1	2,410	52	12	2,590	-301	87.4	0.0	4,569	1,305
3	94.5	3,670	52	12	3,846	-1,558	100.0	0.0	11,311	2,738

11.3.8 Representative Unit 8, Fire Pump, 75 Horsepower, 4 Poles, Enclosed Electric Motor

11.3.8.1 Low Electricity Price Regions

Table 11.3.36 Representative Unit 8 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	130	27	4,269	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	24	4,705	-350	80.3	0.0	528	152
2	95.8	5,102	128	26	5,472	-1,044	90.5	0.0	4,312	955
3	96.2	6,482	127	23	6,814	-2,386	100.0	0.0	3,226	733

11.3.8.2 Small Businesses

Table 11.3.37 Representative Unit 8 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	130	28	4,196	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	24	4,642	-358	80.3	0.0	503	151
2	95.8	5,102	128	26	5,403	-1,047	90.5	0.0	4,057	945
3	96.2	6,482	127	24	6,753	-2,397	100.0	0.0	3,258	728

11.3.8.3 Agricultural Sector

Table 11.3.38 Representative Unit 8 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	131	27	4,264	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	24	4,700	-350	80.3	0.0	503	154
2	95.8	5,102	128	25	5,466	-1,044	90.5	0.0	5,685	967
3	96.2	6,482	127	23	6,809	-2,387	100.0	0.0	3,266	736

11.3.8.4 Industrial Sector

Table 11.3.39 Representative Unit 8 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	131	27	4,263	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	23	4,699	-350	80.3	0.0	524	154
2	95.8	5,102	128	25	5,466	-1,044	90.5	0.0	5,727	961
3	96.2	6,482	127	23	6,809	-2,387	100.0	0.0	3,302	737

11.3.8.5 Commercial Sector

Table 11.3.40 Representative Unit 8 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	130	30	4,324	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	27	4,757	-348	80.3	0.0	429	147
2	95.8	5,102	127	29	5,525	-1,043	90.5	0.0	3,352	903
3	96.2	6,482	127	26	6,866	-2,384	100.0	0.0	2,612	709

11.3.9 Representative Unit 9, Brake Motor, NEMA Design B, T-Frame, 5 Horsepower, Four Poles, Enclosed Motor

11.3.9.1 Low Electricity Price Regions

Table 11.3.41 Representative Unit 9 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	82.5	603	8,079	735	5,320	N/A	0.0	0.0	N/A	N/A
1	87.5	623	7,430	685	4,963	125	0.0	34.8	0.7	0.5
2	89.5	674	7,290	691	4,934	146	13.7	55.5	132	2.1
3	90.2	729	7,219	698	4,943	135	38.9	59.8	24.0	3.9
4	91.0	1,152	7,132	706	5,319	-237	81.8	17.8	994	17.6

11.3.9.2 Small Businesses

Table 11.3.42 Representative Unit 9 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	82.5	603	8,079	801	5,231	N/A	0.0	0.0	N/A	N/A
1	87.5	623	7,430	746	4,882	123	0.0	34.8	0.6	0.4
2	89.5	674	7,290	751	4,854	143	14.1	55.1	117	1.9
3	90.2	729	7,219	757	4,864	131	40.5	58.2	19.4	3.5
4	91.0	1,152	7,132	765	5,240	-242	82.5	17.1	809	15.6

11.3.9.3 Agricultural Sector

Table 11.3.43 Representative Unit 9 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	4,291	428	3,824	N/A	0.0	0.0	N/A	N/A
1	87.5	623	3,940	402	3,611	74	0.1	34.7	1.2	0.8
2	89.5	674	3,864	414	3,667	35	35.9	33.2	11.1	3.9
3	90.2	729	3,826	423	3,735	-32	73.8	24.9	41.7	8.2
4	91.0	1,152	3,779	434	4,174	-469	98.6	1.0	138	45.4

11.3.9.4 Industrial Sector

Table 11.3.44 Representative Unit 9 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	14,971	1,201	6,995	N/A	0.0	0.0	N/A	N/A
1	87.5	623	13,770	1,114	6,504	171	0.0	34.8	0.4	0.2
2	89.5	674	13,521	1,113	6,450	208	8.1	61.0	8.3	1.3
3	90.2	729	13,390	1,115	6,445	212	21.5	77.2	35.0	3.6
4	91.0	1,152	13,228	1,118	6,802	-142	71.6	27.9	582	16.1

11.3.9.5 Commercial Sector

Table 11.3.45 Representative Unit 9 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	5,715	666	5,529	N/A	0.0	0.0	N/A	N/A
1	87.5	623	5,257	622	5,156	131	0.0	34.8	0.7	0.5
2	89.5	674	5,156	629	5,121	155	13.3	55.8	128	2.1
3	90.2	729	5,106	637	5,130	146	37.3	61.4	78.8	3.4
4	91.0	1,152	5,044	645	5,502	-224	81.0	18.6	64.4	15.3

11.3.10 Representative Unit 10, Brake Motor, NEMA Design B, T-Frame, 30 Horsepower, Four Poles, Enclosed Motor

11.3.10.1 Low Electricity Price Regions

Table 11.3.46 Representative Unit 10 Low Electricity Price Regions LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	48,394	3,837	37,515	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	47,178	3,746	37,062	95	7.3	14.8	20.9	5.8
2	93.6	2,133	45,999	3,668	36,431	635	5.9	79.4	4.8	2.0
3	94.1	2,378	45,934	3,672	36,715	350	35.6	64.4	20.4	5.3
4	94.5	3,639	45,777	3,670	37,955	-889	89.5	10.6	85.1	20.6

11.3.10.2 Small Businesses

Table 11.3.47 Representative Unit 10 Small Businesses LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	48,394	4,257	35,929	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	47,178	4,156	35,510	88	7.5	14.5	19.0	5.2
2	93.6	2,133	45,999	4,067	34,898	612	5.9	79.4	3.9	1.7
3	94.1	2,378	45,934	4,071	35,170	339	35.7	64.3	14.6	4.6
4	94.5	3,639	45,777	4,067	36,400	-891	90.1	9.9	63.2	18.1

11.3.10.3 Agricultural Sector

Table 11.3.48 Representative Unit 10 Agricultural Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	22,984	1,781	17,283	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	22,439	1,743	17,357	-18	15.1	6.9	81.8	13.3
2	93.6	2,133	21,863	1,714	17,206	110	22.9	62.4	17.2	4.9
3	94.1	2,378	21,843	1,723	17,524	-208	84.3	15.8	111	16.0
4	94.5	3,639	21,772	1,729	18,830	-1,514	99.9	0.1	244	68.6

11.3.10.4 Industrial Sector

Table 11.3.49 Representative Unit 10 Industrial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	80,227	5,925	53,091	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	78,282	5,787	52,293	178	4.8	17.2	17.2	3.8
2	93.6	2,133	76,298	5,657	51,262	1,057	1.8	83.5	2.2	1.1
3	94.1	2,378	76,212	5,661	51,538	780	20.8	79.2	10.9	3.2
4	94.5	3,639	75,958	5,653	52,731	-412	72.9	27.1	43.6	11.9

11.3.10.5 Commercial Sector

Table 11.3.50 Representative Unit 10 Commercial Sector LCC Results

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	37,094	3,672	37,578	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	36,140	3,581	37,101	104	6.6	15.4	19.5	5.5
2	93.6	2,133	35,241	3,506	36,473	640	5.4	79.9	5.1	1.9
3	94.1	2,378	35,186	3,510	36,753	360	35.3	64.7	24.1	5.2
4	94.5	3,639	35,063	3,508	37,990	-878	89.4	10.6	74.2	20.4

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE) is required to consider "the economic impact of the standard on the manufacturers and on the consumers of the products subject to such a standard." (42 U.S.C. 6312(a)(6)(B)(i)) The law also calls for an assessment of the impact of any lessening of competition as determined in writing by the Attorney General. *Id.* DOE conducted a manufacturer impact analysis (MIA) to estimate the financial impact of new and amended energy conservation standards on manufacturers of electric motors, and assessed the impact of such standards on direct employment and manufacturing capacity.

The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA primarily relies on the Government Regulatory Impact Model (GRIM), an industry cash-flow model adapted for the equipment in this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM's key output is the industry net present value (INPV). The model estimates the financial impact of more stringent energy conservation standards for each product by comparing changes in INPV between a base case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses equipment characteristics, manufacturer characteristics, market and product trends, as well as the impact of standards on subgroups of manufacturers.

12.2 METHODOLOGY

DOE conducted the MIA in three phases. Phase I, "Industry Profile," consisted of preparing an industry characterization for the electric motor industry, including data on market share, sales volumes and trends, pricing, employment, and financial structure. In Phase II, "Industry Cash Flow," DOE used the GRIM to assess the impacts of new and amended energy conservation standards on electric motors.

In Phase II, DOE created a GRIM for electric motors and an interview guide to gather information on the potential impacts on manufacturers. DOE presented the MIA results for electric motors based on a set of considered TSLs. These TSLs are described in Section 12.4.5 below.

In Phase III, "Subgroup Impact Analysis," DOE interviewed manufacturers representing more than 75 percent of electric motor sales. Interviewees included large and small manufacturers with various market shares and market focus, providing a representative cross-section of the industries. During interviews, DOE discussed financial topics specific to each manufacturer and obtained each manufacturer's view of the industry. The interviews provided DOE with valuable information for evaluating the impacts of new and amended energy conservation standards on manufacturer cash flows, investment requirements, and employment.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE prepared a profile of the electric motor industry that built upon the market and technology assessment prepared for this rulemaking (see chapter 3 of this Technical Support Document (TSD)). Before initiating the detailed impact studies, DOE collected information on the present and past structure and market characteristics of each industry. This information included market share data, unit shipments, manufacturer markups, and the cost structure for various manufacturers. The industry profile includes: (1) further detail on the overall market and equipment characteristics; (2) estimated manufacturer market shares; (3) financial parameters such as net plant, property, and equipment; selling, general and administrative (SG&A) expenses; cost of goods sold, etc.; and (4) trends in the number of firms, market, and equipment characteristics. The industry profile included a top-down cost analysis of electric motor manufacturers that DOE used to derive preliminary financial inputs for the GRIM (e.g., revenues, depreciation, SG&A, and research and development (R&D) expenses).

DOE also used public information to further calibrate its initial characterization of the electric motor industry, including Securities and Exchange Commission (SEC) 10–K reports,[1] Standard & Poor's (S&P) stock reports,[2] and corporate annual reports. DOE supplemented this public information with data released by privately held companies.

12.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

Phase II focused on the financial impacts of potential new and amended energy conservation standards on manufacturers of electric motors. More stringent energy conservation standards can affect manufacturer cash flows in three distinct ways: (1) create a need for increased investment, (2) raise production costs per unit, and (3) alter revenue due to higher per-unit prices and/or possible changes in sales volumes. To quantify these impacts, DOE used the GRIM to perform a cash-flow analysis for electric motors. In performing these analyses, DOE used the financial values derived during Phase I and the shipment scenarios used in the national impact analysis (NIA). In Phase II, DOE performed these preliminary industry cash-flow analyses and prepared written guides for manufacturer interviews.

12.2.2.1 Industry Cash-Flow Analysis

The GRIM uses several factors to determine a series of annual cash flows from the announcement year of new and amended energy conservation standards until several years after the standards' compliance date. These factors include annual expected revenues, costs of sales, SG&A, taxes, and capital expenditures related to the new and amended standards. Inputs to the GRIM include manufacturing production costs, selling prices, and shipments forecasts developed in other analyses. DOE derived the manufacturing costs from the engineering analysis and information provided by the industry and estimated typical manufacturer markups from public financial reports and interviews with manufacturers. DOE developed alternative markup scenarios for the GRIM based on discussions with manufacturers. DOE's shipments analysis, presented in chapter 9 of this TSD, provided the basis for the shipment projections in the GRIM. The financial parameters were developed using publicly available manufacturer data and were revised with information submitted confidentially during manufacturer interviews. The GRIM results are compared to base case projections for the industry. The financial impact of new and amended energy conservation standards is the difference between the discounted annual cash flows in the base case and standards case at each TSL.

12.2.2.2 Interview Guides

During Phase III of the MIA, DOE interviewed manufacturers to gather information on the effects of new and amended energy conservation on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE distributed an interview guide for the electric motor industry. The interview guide provided a starting point to identify relevant issues and help identify the impacts of new and amended energy conservation standards on individual manufacturers or subgroups of manufacturers. Most of the information DOE received from these meetings is protected by non-disclosure agreements and resides with DOE's contractors. Before each telephone interview or site visit, DOE provided company representatives with an interview guide that included the topics for which DOE sought input. The MIA interview topics included (1) key issues to this rulemaking; (2) engineering; (3) company overview and organizational characteristics; (4) manufacturer production costs and scaling prices; (5) manufacturer markups and profitability; (6) shipment projections and market shares; (7) equipment mix; (8) financial parameters; (9) conversion costs; (10) cumulative regulatory burden; (11) direct employment impact assessment; (12) exports, foreign competition, and outsourcing; (13) consolidation; and (12) impacts on small business. The interview guides are presented in Appendix 12A.

12.2.3 Phase III: Subgroup Analysis

Using average cost and financial assumptions to develop an industry cash flow model is not adequate for assessing differential impacts among a potential subgroup of manufacturers. Small manufacturers, niche players, or manufacturers exhibiting a cost structure that differs largely from the industry average could be more negatively impacted. During interviews, DOE identified one potential manufacturer subgroup (small manufacturers) that could be disproportionately impacted by new and amended energy conservation standards. As a result, DOE will analyze small business manufacturers as a subgroup.

12.2.3.1 Manufacturing Interviews

The information gathered in Phase I and the cash flow analysis performed in Phase II are supplemented with information gathered from manufacturer interviews in Phase III. The interview process provides an opportunity for interested parties to express their views on important issues privately, allowing confidential or sensitive information to be considered in the rulemaking process.

DOE used these interviews to tailor the GRIM to reflect unique financial characteristics for electric motor manufacturers. DOE contacted companies from its database of manufacturers and interviewed small and large companies, subsidiaries and independent firms, and public and private corporations to provide an accurate representation of the industry. Interviews were scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire was acceptable, DOE sought interactive interviews, which helped clarify responses and identify additional issues. The resulting information provides valuable inputs to the GRIM developed for the equipment classes.

12.2.3.2 Revised Industry Cash-Flow Analysis

In Phase II of the MIA, DOE provided manufacturers with preliminary GRIM input financial figures for review and evaluation. During the interviews, DOE requested comments on the values it selected for the parameters. DOE revised its industry cash flow models based on this feedback. Section 12.4.3 provides more information on how DOE calculated the parameters.

12.2.3.3 Small-Business Manufacturer Subgroup

DOE investigated whether small business manufacturers should be analyzed as a manufacturer subgroup. DOE used the Small Business Administration (SBA) small business size standards published on January 7, 2013, as amended, and the North American Industry Classification System (NAICS) code, presented in Table 12.2.1, to determine whether any small entities would be affected by the rulemaking.[a] For the equipment classes under review, the SBA bases its small business definition on the total number of employees for a business, its subsidiaries, and its parent companies. An aggregated business entity with fewer employees than the listed limit is considered a small business.

Table 12.2.1 SBA and NAICS Classification of Small Businesses Potentially Affected by This Rulemaking

Industry Description	Revenue Limit	Employee Limit	NAICS
Motor and Generator Manufacturing	N/A	1,000	335312

DOE used the National Electrical Manufacturers Association (NEMA)[3] member directory to identify manufacturers of electric motors. DOE also utilized information from previous rulemakings, UL (Underwriters Laboratories) qualification directories, individual company websites, and market research tools (e.g., Hoover's reports) to create a list of companies that potentially manufacture electric motors covered by this rulemaking. Additionally, DOE also asked interested parties and industry representatives if they were aware of other small business manufacturers. DOE contacted select companies on its list, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered electric motors. DOE screened out companies that did not offer equipment covered by this rulemaking, did not meet the definition of a "small business," or are foreign owned and operated.

During its research, DOE identified approximately 13 companies which manufacture equipment covered by this rulemaking and qualify as small businesses per the applicable SBA definition. DOE contacted the small businesses to solicit feedback on the potential impacts of energy conservation standards. Two of the small businesses consented to being interviewed during the MIA interviews. In addition to posing the standard MIA interview questions, DOE solicited data from manufacturers on differential impacts that these small companies might experience from new and amended energy conservation standards. Because DOE was not able to certify that the proposed rulemaking would not have a significant economic impact on a

[a] The size standards are available on the SBA's website at http://www.sba.gov/content/table-small-business-size-standards

substantial number of small entities, DOE has analyzed small manufacturers as a subgroup. The results of this subgroup analysis are presented in section 12.6.

12.2.3.4 Manufacturing Capacity Impact

One significant outcome of new and amended energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and investment. The manufacturer interview guides have a series of questions to help identify impacts of new and amended standards on manufacturing capacity, specifically capacity utilization and plant location decisions in the United States and North America, with and without new and amended standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time changes to existing plant, property, and equipment (PPE). DOE's estimates of the one-time capital changes and stranded assets affect the cash flow estimates in the GRIM. These estimates can be found in section 12.4.8; DOE's discussion of the capacity impact can be found in section12.7.2.

12.2.3.5 Employment Impact

The impact of new and amended energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic direct employment patterns might be affected, the interviews explored current employment trends in the electric motor industry. The interviews also solicited manufacturer views on changes in employment patterns that may result from more stringent standards. The employment impacts section of the interview guide focused on current employment levels associated with manufacturers at each production facility, expected future employment levels with and without new and amended energy conservation standards, and differences in workforce skills and issues related to the retraining of employees. The employment impacts are reported in section 12.7.1.

12.2.3.6 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers due to new and amended energy conservation standards and other regulatory actions affecting the same equipment. DOE analyzed the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified regulations relevant to electric motor manufacturers, such as State regulations and other Federal regulations that impact other equipment made by the same manufacturers. Discussion of the cumulative regulatory burden can be found in section 12.7.3.

12.3 MANUFACTURER IMPACT ANALYSIS KEY ISSUES

Each MIA interview starts by asking: "What are the key issues for your company regarding the energy conservation standard rulemaking?" This question prompts manufacturers to identify the issues they believe DOE should explore and discuss further during the interview. The following sections describe the most significant issues identified by manufacturers. These summaries are provided in aggregate to protect manufacturer confidentiality.

12.3.1 Efficiency Levels above NEMA Premium

Several manufacturers are concerned with the difficulties associated with increasing motor efficiency levels (ELs) above NEMA Premium. Manufacturers stated that even increasing the efficiency of motors to one band above NEMA Premium would require each manufacturer to make a significant capital investment to retool their entire production line. It would also require manufacturers to completely redesign almost every motor configuration offered, which could take several years of engineering time.

According to manufacturers, another potential problem with setting an electric motors standard to efficiency levels above NEMA Premium is that this would misalign U.S. electric motor standards with global motor standards (e.g. International Electrotechnical Commission (IEC) motor standards). There has been an effort to harmonize global motor standards recently and manufacturers are concerned that new U.S. electric motor standards that increase motor efficiency levels above NEMA Premium would cause U.S. electric motor markets to be out of synchronization with the rest of the world's efficiency standards.

Several manufacturers also commented they believe any standard requiring die-casting copper rotors is infeasible. The two main manufacturer concerns are the rising cost of copper and the potential health and safety risks of die-casting copper. Copper prices have fluctuated greatly over the past five to ten years and if standards required manufacturers to use copper rotors manufacturers would be at the mercy of the volatile copper market. Manufacturers noted that motor efficiency standards that requiring copper rotors for all electric motors would likely increase the price of copper due to the increase in demand from the motors industry. Manufacturers also stated that since copper has a much higher melting temperature than aluminum and the pressure required to die-cast copper is much higher than aluminum, there is a much greater chance that a significant accident or injury could occur with copper than with aluminum. Lastly, several manufacturers stated they would not be able to produce copper die-cast rotors in-house and therefore would have to outsource this production. Manufacturers went on to say that if the entire motor industry was forced to outsource their rotor production, due to copper requirements, there would be significant supply chain problems in the motor manufacturing process. In summary, manufacturers emphasized during interviews that the capacity to produce copper rotors on a large commercial scale does not exist and would be very difficult to implement in even a three year time period.

12.3.2 Increase in the Equipment Repair

Manufacturers have stated that as energy conservation standards increase customers are more likely to rewind old, less efficient motors, as opposed to purchasing newer more efficient compliant motors. Therefore, if motor standards significantly increase the price of motors, manufacturers believe rewinding older motors might become a more attractive option for some customers. These customers would in turn be using more energy than if they simply purchased a currently compliant motor, since rewound motors may not always operate at their original efficiency level after being rewound. Manufacturers believe that DOE must take the potential consumer rewinding decision into account when deciding on an electric motors standard.

12.3.3 Enforcement

Manufacturers have stated that one of their biggest concerns with additional energy conservation standards is the lack of enforcement of current electric motor standards. The large domestic manufacturers have stated they comply with the current electric motor regulations and will continue to comply with any future standards. However, these manufacturers believe there are several foreign motor manufacturers that do not comply with the current electric motor regulations and certainly will not comply with any future standards if the efficiency standards are increased. This would cause compliant manufacturers to be placed at a competitive disadvantage, since complying with any increased efficiency standards will be very costly. Some domestic manufacturers believe the most cost effective way to reduce energy consumption of electric motors is to more strictly enforce the existing electric motor standards rather than increase the efficiency standards of electric motors.

12.4 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to new and amended energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. Data and assumptions from these sources are then fed into an accounting model that calculates the industry cash flow both with and without new and amended energy conservation standards.

12.4.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 12.4.1, is an annual cash flow analysis that uses manufacturer prices, manufacturing costs, shipments, and industry financial information as inputs, and accepts a set of regulatory conditions such as changes in costs, investments, and associated margins. The GRIM spreadsheet uses a number of inputs to arrive at a series of annual cash flows, beginning with the base year of the analysis, 2013, and continuing to 2045. The model calculates the INPV by summing the stream of annual discounted cash flows during this period and adding a discounted terminal value.[4]

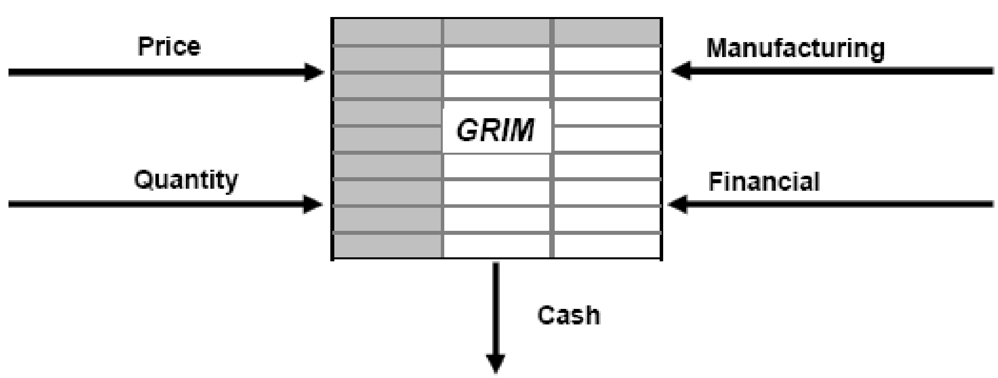

Figure 12.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the base case and the standard-case scenario induced by new and amended energy conservation standards. The difference in INPV between the base case and the standard case(s) represents the estimated financial impact of the new and amended energy conservation standard on manufacturers. Appendix 12B provides more technical details and user information for the GRIM.

12.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include corporate annual reports, company profiles, Census data, credit ratings, the shipments model, the engineering analysis, and the manufacturer interviews.

12.4.2.1 Corporate Annual Reports

Corporate annual reports to the SEC (SEC 10-Ks) provided many of the initial financial inputs to the GRIM. These reports exist for publicly held companies and are freely available to the general public. DOE developed initial financial inputs to the GRIM by examining the annual SEC 10-K reports filed by publicly-traded manufacturers that manufacture electric motors, among other equipment. Since these companies do not provide detailed information about their individual product lines, DOE used financial information at the parent company level as its initial estimates of the financial parameters in the GRIM analysis. These figures were later revised using feedback from interviews to be representative of electric motor manufacturing. DOE used corporate annual reports to derive the following initial inputs to the GRIM:

- Tax rate
- Working capital
- SG&A
- R&D
- Depreciation
- Capital expenditures
- Net PPE

12.4.2.2 Standard and Poor Credit Ratings

S&P provides independent credit ratings, research, and financial information. DOE relied on S&P reports to determine the industry's average cost of debt when calculating the cost of capital.

12.4.2.3 Shipment Model

The GRIM used shipment projections derived from DOE's shipments model in the NIA. The model relied on historical shipments data for electric motors. Chapter 9 of the TSD describes the methodology and analytical model DOE used to forecast shipments.

12.4.2.4 Engineering Analysis

The engineering analysis establishes the relationship between manufacturer production cost (MPC) and energy efficiency for electric motors covered in this rulemaking. DOE began its analysis by conducting industry research to determine equipment class groupings, select baseline electric motors, and select representative electric motors for further testing and analysis. Next DOE selected specific efficiency levels based on the efficiency levels published in the tables contained in NEMA Standards Publication MG 1-2011, *Motors and Generators*. DOE generated a bill of materials (BOM) either by tearing down representative electric motors or by using a computer software model. DOE also estimated labor costs based on tear downs or computer software modeling. Finally, DOE calculated the necessary scrap costs and overhead costs (including depreciation) based on markups applied to the BOM to arrive at a final MPC for all directly analyzed representative electric motors across all analyzed efficiency levels. See chapter 5 of this TSD for a complete discussion of the engineering analysis.

12.4.2.5 Manufacturer Interviews

During the course of the MIA, DOE conducted interviews with a representative cross-section of manufacturers. DOE also interviewed manufacturers representing a significant portion of sales in every equipment class. During these discussions, DOE obtained information to determine and verify GRIM input assumptions in each industry. Key topics discussed during the interviews and reflected in the GRIM include:

- capital conversion costs (one-time investments in PPE);
- product conversion costs (one-time investments in research, product development, testing, certification, and marketing);
- product cost structure, or the portion of the MPCs related to materials, labor, overhead, and depreciation costs;
- possible profitability impacts;
- impacts on small businesses; and
- cost-efficiency curves calculated in the engineering analysis.

12.4.3 Financial Parameters

Table 12.4.1 below provides financial parameters for six public companies engaged in manufacturing and selling electric motors. The values listed are averages over an 8-year period (2004 to 2011).

Table 12.4.1 GRIM Financial Parameters Based on 2004–2011 Weighted Company Financial Data

Parameter	Weighted Average	Manufacturer					
		A	B	C	D	E	F
Tax Rate ***% of taxable income***	33.3%	37.5%	32.7%	28.0%	30.9%	28.1%	26.5%
Working Capital ***% of revenues***	20.7%	24.8%	23.6%	20.2%	20.1%	7.5%	52.8%
SG&A ***% of revenues***	17.0%	16.5%	13.9%	18.2%	21.3%	16.1%	15.8%
R&D ***% of revenues***	2.6%	2.2%	2.2%	2.5%	2.0%	5.2%	2.3%
Depreciation ***% of revenues***	4.2%	4.0%	3.2%	2.8%	3.3%	4.3%	4.1%
Capital Expenditures ***% of revenues***	3.6%	2.6%	2.3%	3.1%	2.8%	4.1%	6.5%
Net PPE ***% of revenues***	22.5%	21.7%	18.8%	20.1%	15.6%	14.7%	46.1%

During interviews, electric motor manufacturers were asked to provide their own figures for the parameters listed in Table 12.4.1. Where applicable, DOE adjusted the parameters in the

GRIM using this feedback, more recent data from publicly traded companies, and values used during the small electric motors rulemaking at 75 FR 10874 (March 9, 2010) to reflect the current electric motor industry. Table 12.4.2 presents the revised parameters used for electric motor manufacturers for this notice of proposed rulemaking (NOPR).

Table 12.4.2 GRIM Revised Electric Motor Industry Financial Parameters

Parameter	Revised Estimates
Tax Rate *% of taxable income*	33.3%
Working Capital *% of revenues*	16.0%
SG&A *% of revenues*	15.0%
R&D *% of revenues*	4.8%
Depreciation *% of revenues*	4.2%
Capital Expenditures *% of revenues*	4.8%
Net PPE *% of revenues*	18.4%

12.4.4 Corporate Discount Rate

DOE used the weighted-average cost of capital (WACC) as the discount rate to calculate the INPV. A company's assets are financed by a combination of debt and equity. The WACC is the total cost of debt and equity weighted by their respective proportions in the capital structure of the industry. DOE estimated the WACC for the electric motor industry based on several representative companies, using the following formula:

WACC = After-Tax Cost of Debt x (Debt Ratio) + Cost of Equity x (Equity Ratio) *Eq. 1*

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The capital asset pricing model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

Cost of Equity = Riskless Rate of Return + β x Risk Premium *Eq. 2*

where:

Riskless rate of return is the rate of return on a "safe" benchmark investment, typically considered the short-term Treasury Bill (T-Bill) yield.

Risk premium is the difference between the expected return on stocks and the riskless rate.

Beta (β) is the correlation between the movement in the price of the stock and that of the broader market. In this case, Beta equals one if the stock is perfectly correlated with the S&P 500 market index. A Beta lower than one means the stock is less volatile than the market index.

DOE determined that the industry average cost of equity for the electric motor industry is 13.4 percent.

Table 12.4.3 Cost of Equity Calculation

Parameter	Industry-Weighted Average %	Manufacturer					
		A	B	C	D	E	F
(1) Average Beta	1.4	na	1.27	0.83	1.21	1.58	na
(2) Yield on 10-Year T-Bill (1928-2011)	5.2	-	-	-	-	-	
(3) Market Risk Premium (1928-2011)	6.0	-	-	-	-	-	
Cost of Equity (2)+[(1)*(3)]	13.4	-	-	-	-	-	
Equity/Total Capital	1.2	1.28	1.30	0.95	0.90	0.62	0.63

Bond ratings are a tool to measure default risk and arrive at a cost of debt. Each bond rating is associated with a particular spread. One way of estimating a company's cost of debt is to treat it as a spread (usually expressed in basis points) over the risk-free rate. DOE used this method to calculate the cost of debt for all six manufacturers by using S&P ratings and adding the relevant spread to the risk-free rate.

In practice, investors use a variety of different maturity Treasury bonds to estimate the risk-free rate. DOE used the 10-year Treasury bond return because it captures long-term inflation expectations and is less volatile than short-term rates. The risk free rate is estimated to be approximately 5.2 percent, which is the average 10-year Treasury bond return between 1928 and 2011.

For the cost of debt, S&P's Credit Services provided the average spread of corporate bonds for the six public manufacturers. DOE added the industry-weighted average spread to the average T-Bill rate. Since proceeds from debt issuance are tax deductible, DOE adjusted the gross cost of debt by the industry average tax rate to determine the net cost of debt for the industry. Table 12.4.4 presents the derivation of the cost of debt and the capital structure of the industry (i.e. the debt ratio (debt/total capital)).

Table 12.4.4 Cost of Debt Calculation

Parameter	Industry-Weighted Average %	Manufacturer					
		A	B	C	D	E	F
S&P Bond Rating	-	B+	AAA	AAA	A	A+	AAA
(1) Yield on 10-Year T-Bill (1928-2011)	5.2%	-	-	-	-	-	-
(2) Gross Cost of Debt	7.0%	9.0%	5.7%	5.7%	6.2%	6.1%	5.7%
(3) Tax Rate	33.2%	37.5%	32.7%	28.0%	30.9%	28.1%	26.5%
Net Cost of Debt (2) x (1-(3))	4.7%	-	-	-	-	-	-
Debt/Total Capital	94.1%	160.6%	65.1%	38.6%	37.0%	30.1%	28.7%

Using public information for these six companies, the initial estimate for the electric motor industry's WACC was approximately 9.9 percent. Subtracting an inflation rate of 3.1 percent between 1928 and 2011, the inflation-adjusted WACC and the initial estimate of the discount rate used in the straw-man GRIM was 6.8 percent. DOE asked for feedback on the 6.8

percent discount during manufacturer interviews and used this feedback and the WACC used in the small electric motors rulemaking to revise this WACC to be 9.1 percent for electric motor manufacturers.

12.4.5 Trial Standard Levels

DOE developed TSLs for electric motors. Consistent with the engineering analysis, DOE analyzed four equipment class groups (ECGs), consisting of 10 representative units. Table 12.4.5 shows the efficiency levels at each TSL for the ECGs analyzed by DOE. For more information regarding the creation of TSL see chapter 5 of this TSD.

Table 12.4.5 Trial Standard Levels for Electric Motors

ECG	Equipment Class Group Description	TSL 1	TSL 2	TSL 3	TSL 4
1	NEMA Design A & B; 1-500 horsepower	EL 1	EL 2	EL 3	EL 4
2	NEMA Design C: 1-200 horsepower	EL 1	EL 1	EL 2	EL 2
3	Fire Pump	Baseline	Baseline	EL 1	EL 3
4	Brake	EL 1	EL 2	EL 3	EL 4

TSL 1 represents efficiency levels equivalent to NEMA MG 1 table 12-11 for all covered NEMA Design A and B (ECG 1) and brake (ECG 4) electric motors; efficiency levels equivalent to NEMA MG 1 table 12-12 for all covered NEMA Design C (ECG 2) electric motors; and no standards for all covered fire pump (ECG 3) motors.

TSL 2 represents efficiency levels equivalent to NEMA MG 1 table 12-12 for all covered NEMA Design A and B (ECG 1), NEMA Design C (ECG 2), and brake (ECG 4) electric motors and no standards for all covered fire pump (ECG 3) motors.

TSL 3 represents efficiency levels equivalent to NEMA MG 1 table 12-12 for all covered fire pump (ECG 3) electric motors; efficiency levels equivalent to one band above NEMA MG 1 table 12-12 for all covered NEMA Design A and B (ECG 1) electric motors, all covered brake (ECG 4) electric motors, and NEMA Design C (ECG 2) electric motors between 25 to 200 horsepower; efficiency levels equivalent to two bands above NEMA MG 1 table 12-12 for NEMA Design C (ECG 2) electric motors between 1 and 20 horsepower. All NEMA Design C electric motors require the use of copper rotors at this TSL; however, no other motors require copper rotors.

TSL 4 represents max-tech efficiency levels for all covered electric motors. This TSL is equivalent to one band above NEMA MG 1 table 12-12 for NEMA Design C (ECG 2) electric motors between 25 and 200 horsepower and efficiency levels equivalent to two bands above NEMA MG 1 table 12-12 for all covered NEMA Design A and B (ECG 1) electric motors, NEMA Design C (ECG 2) electric motors between 1 and 20 horsepower, all covered fire pump (ECG 3) electric motors, and all covered brake (ECG 4) electric motors. All electric motors require the use of copper rotors at this TSL.

12.4.6 NIA Shipment Forecast

The GRIM estimates manufacturer revenues based on total-unit-shipment forecasts and the distribution of these values by efficiency level. Changes in the efficiency mix at each standard level are a key driver of manufacturer finances. For this analysis, the GRIM used the NIA's annual shipment forecasts from 2013 to 2045, the end of the analysis period. The shipments analysis assumes that growth in electric motors shipments will be driven by private fixed investment in specific equipment and structure. The assumptions and methodology that drive this analysis are described in chapter 9 of this NOPR TSD.

12.4.7 Production Costs

During the engineering analysis, DOE developed the MPCs for the representative units at each EL analyzed either by teardowns or by software modeling. For units DOE tore down, DOE purchased, tested and then tore down a motor to create a BOM for the motor. If DOE could not find or purchase specific representative units at specific efficiency levels, DOE created a BOM based on a computer software model for a specific motor that complies with the associated efficiency level. Once DOE created a BOM for a specific motor, either by tear downs or software modeling, DOE then estimated the labor hours and the associated scrap and overhead costs necessary to produce a motor with that BOM. DOE was then able to create an aggregated MPC based on the material costs from the BOM and the associated scrap costs, the labor costs based on an average labor rate and the labor hours necessary to manufacture the motor, and the overhead costs, including depreciation, based on a markup applied to the material, labor, and scrap costs based on the materials used.

Table 12.4.6 through Table 12.4.15 show the average production cost estimates used in the GRIM for each representative unit at each efficiency level.

Table 12.4.6 Manufacturer Production Cost Breakdown (2012$) for NEMA Design B, 5 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$154.80	$50.19	$13.86	$-	$22.01	$240.86	1.37	$329.98
EL 1	$158.99	$52.70	$14.31	$-	$22.73	$248.74	1.37	$340.77
EL 2	$172.93	$55.33	$15.43	$-	$24.51	$268.21	1.37	$367.45
EL 3	$182.37	$58.10	$16.89	$11.06	$25.19	$293.61	1.37	$402.25
EL 4	$249.29	$150.56	$28.15	$17.36	$43.83	$489.18	1.37	$670.18

Table 12.4.7 Manufacturer Production Cost Breakdown (2012$) for NEMA Design B, 30 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$393.40	$104.05	$35.60	$-	$51.46	$584.51	1.45	$847.54
EL 1	$527.59	$109.26	$45.57	$-	$65.88	$748.29	1.45	$1,085.02
EL 2	$564.08	$114.72	$48.57	$-	$70.22	$797.58	1.45	$1,156.50
EL 3	$611.68	$120.46	$54.39	$32.89	$73.73	$893.15	1.45	$1,295.07
EL 4	$932.17	$225.84	$86.36	$51.61	$122.08	$1,418.07	1.45	$2,056.20

Table 12.4.8 Manufacturer Production Cost Breakdown (2012$) for NEMA Design B, 75 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$918.55	$191.38	$79.42	$-	$114.81	$1,304.17	1.45	$1,891.04
EL 1	$1,000.85	$200.95	$86.00	$-	$124.32	$1,412.11	1.45	$2,047.56
EL 2	$1,155.37	$210.52	$97.74	$-	$141.29	$1,604.92	1.45	$2,327.13
EL 3	$1,351.06	$222.00	$116.59	$66.18	$158.69	$1,914.53	1.45	$2,776.07
EL 4	$1,648.06	$379.41	$152.02	$103.86	$212.92	$2,496.27	1.45	$3,619.60

Table 12.4.9 Manufacturer Production Cost Breakdown (2012$) for NEMA Design C, 5 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$152.73	$52.86	$13.90	$-	$22.08	$241.57	1.37	$330.95
EL 1	$164.82	$55.51	$14.90	$-	$23.66	$258.88	1.37	$354.66
EL 2	$217.97	$151.90	$26.08	$16.75	$40.50	$453.20	1.37	$620.88

Table 12.4.10 Manufacturer Production Cost Breakdown (2012$) for NEMA Design C, 50 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$768.20	$133.83	$64.55	$-	$93.31	$1,059.89	1.45	$1,536.84
EL 1	$949.34	$301.12	$89.48	$-	$129.35	$1,469.29	1.45	$2,130.47
EL 2	$1,114.78	$316.18	$108.62	$95.08	$148.95	$1,783.61	1.45	$2,586.24

Table 12.4.11 Manufacturer Production Cost Breakdown (2012$) for Fire Pump, 5 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$158.99	$52.70	$14.31	$-	$22.73	$248.74	$1.37	$340.77
EL 1	$172.93	$55.33	$15.43	$-	$24.51	$268.21	$1.37	$367.45
EL 2	$182.37	$58.10	$16.89	$11.06	$25.19	$293.61	$1.37	$402.25
EL 3	$249.29	$150.56	$28.15	$17.36	$43.83	$489.18	$1.37	$670.18

Table 12.4.12 Manufacturer Production Cost Breakdown (2012$) for Fire Pump, 30 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$527.59	$109.26	$45.57	$-	$65.88	$748.29	$1.45	$1,085.02
EL 1	$564.08	$114.72	$48.57	$-	$70.22	$797.58	$1.45	$1,156.50
EL 2	$611.68	$120.46	$54.39	$32.89	$73.73	$893.15	$1.45	$1,295.07
EL 3	$932.17	$225.84	$86.36	$51.61	$122.08	$1,418.07	$1.45	$2,056.20

Table 12.4.13 Manufacturer Production Cost Breakdown (2012$) for Fire Pump, 75 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$1,000.85	$200.95	$86.00	$-	$124.32	$1,412.11	$1.45	$2,047.56
EL 1	$1,155.37	$210.52	$97.74	$-	$141.29	$1,604.92	$1.45	$2,327.13
EL 2	$1,351.06	$222.00	$116.59	$66.18	$158.69	$1,914.53	$1.45	$2,776.07
EL 3	$1,648.06	$379.41	$152.02	$103.86	$212.92	$2,496.27	$1.45	$3,619.60

Table 12.4.14 Manufacturer Production Cost Breakdown (2012$) for Brake, 5 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$154.80	$50.19	$13.86	$-	$22.01	$240.86	1.37	$329.98
EL 1	$158.99	$52.70	$14.31	$-	$22.73	$248.74	1.37	$340.77
EL 2	$172.93	$55.33	$15.43	$-	$24.51	$268.21	1.37	$367.45
EL 3	$182.37	$58.10	$16.89	$11.06	$25.19	$293.61	1.37	$402.25
EL 4	$249.29	$150.56	$28.15	$17.36	$43.83	$489.18	1.37	$670.18

Table 12.4.15 Manufacturer Production Cost Breakdown (2012$) for Brake, 30 Horsepower, 4 Pole, Enclosed Electric Motor

EL	Materials	Labor	Depr.	Dev.	Overhead	MPC	Markup	MSP
Baseline	$393.40	$104.05	$35.60	$-	$51.46	$584.51	1.45	$847.54
EL 1	$527.59	$109.26	$45.57	$-	$65.88	$748.29	1.45	$1,085.02
EL 2	$564.08	$114.72	$48.57	$-	$70.22	$797.58	1.45	$1,156.50
EL 3	$611.68	$120.46	$54.39	$32.89	$73.73	$893.15	1.45	$1,295.07
EL 4	$932.17	$225.84	$86.36	$51.61	$122.08	$1,418.07	1.45	$2,056.20

12.4.8 Product and Capital Conversion Costs

DOE expects new and amended energy conservation standards to cause manufacturers to incur one-time conversion costs to bring their production facilities and equipment designs into compliance with new and amended standards. For the MIA, DOE classified these one-time conversion costs into two major groups: (1) product conversion costs and (2) capital conversion costs. Product conversion costs are one-time investments in research, development, testing, marketing, and other non-capitalized costs necessary to make equipment designs comply with new and amended standards. Capital conversion costs are one-time investments in property, plant, and equipment necessary to adapt or change existing production facilities such that new equipment designs can be fabricated and assembled.

DOE calculated the product and capital conversion costs using both a top-down approach and a bottom-up approach based on feedback from manufacturers during manufacturer interviews and manufacturer submitted comments. DOE then adjusted these conversion costs if there were any discrepancies in the final costs using the two methods to arrive at a final product and capital conversion cost estimate for each representative unit at each EL.

During manufacturer interviews, DOE asked manufacturers for their estimated total product and capital conversion costs needed to produce electric motors at specific ELs. To arrive at top-down industry wide product and capital conversion cost estimates for each representative unit at each EL, DOE calculated a market share weighted average value for product and capital conversion costs based on the data submitted during interviews and the market share of the interviewed manufacturers.

DOE also calculated bottom-up conversion costs based on manufacturer input on the types of costs and the dollar amounts necessary to convert a single electric motor frame size to each EL. Some of the types of capital conversion costs manufacturers identified were the purchase of lamination die sets, winding machines, frame casts, and assembly equipment as well as other retooling costs. The two main types of product conversion costs manufacturers shared with DOE during interviews were number of engineer hours necessary to re-engineer frames to meet higher efficiency standards and the testing and certification costs to comply with higher efficiency standards. DOE then took average values (i.e. costs or number of hours) based on the range of responses given by manufacturers for each product and capital conversion costs necessary for a manufacturer to increase the efficiency of one frame size to a specific EL. DOE multiplied the conversion costs associated with manufacturing a single frame size at each EL by the number of frames each interviewed manufacturer produces. DOE finally scaled this number based on the market share of the manufacturers DOE interviewed, to arrive at industry wide bottom-up product and capital conversion cost estimates for each representative unit at each EL. The bottom-up conversion costs estimates DOE created were consistent with the manufacturer top down estimates provided, so DOE used the bottom-up conversion cost estimates as the final values for each representative unit in the MIA.

DOE’s estimates of the product and capital conversion costs for each representative unit can be found in Table 12.4.16 through Table 12.4.25 below. Table 12.4.26 summarizes product and conversion costs for all electric motors.

Table 12.4.16 Product and Capital Conversion Costs for NEMA Design B, 5 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	4.5	-
TSL 2	44.6	7.9
TSL 3	446.4	66.0
TSL 4	446.4	214.8

Table 12.4.17 Product and Capital Conversion Costs for NEMA Design B, 30 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	1.0	-
TSL 2	10.0	7.9
TSL 3	100.4	66.0
TSL 4	100.4	214.8

Table 12.4.18 Product and Capital Conversion Costs for NEMA Design B, 75 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.2	-
TSL 2	1.8	9.9
TSL 3	18.3	82.4
TSL 4	18.3	251.7

Table 12.4.19 Product and Capital Conversion Costs for NEMA Design C, 5 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.4	0.0
TSL 2	38.2	0.2

Table 12.4.20 Product and Capital Conversion Costs for NEMA Design C, 50 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.0	0.0
TSL 2	4.0	0.2

Table 12.4.21 Product and Capital Conversion Costs for Fire Pump, 5 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.1	0.0
TSL 2	7.3	0.0
TSL 3	7.3	0.1

Table 12.4.22 Product and Capital Conversion Costs for Fire Pump, 30 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.0	0.0
TSL 2	1.6	0.0
TSL 3	1.6	0.1

Table 12.4.23 Product and Capital Conversion Costs for Fire Pump, 75 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.0	0.0
TSL 2	0.3	0.0
TSL 3	0.3	0.1

Table 12.4.24 Product and Capital Conversion Costs for Brake, 5 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	-	-
TSL 2	0.4	0.4
TSL 3	3.8	3.4
TSL 4	3.8	10.9

Table 12.4.25 Product and Capital Conversion Costs for Brake, 30 Horsepower, 4 Pole, Closed, Electric Motors by TSL

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*
TSL 1	0.0	-
TSL 2	0.1	0.3
TSL 3	0.7	2.3
TSL 4	0.7	7.2

Table 12.4.26 Product and Capital Conversion Costs for all Electric Motors

TSL	Product Conversion Costs *2012$ millions*	Capital Conversion Costs *2012$ millions*	Total Conversion Costs *2012$ millions*
TSL 1	6.1	0.0	6.2
TSL 2	57.4	26.4	83.7
TSL 3	611.7	220.5	832.3
TSL 4	620.6	699.8	1,320.4

12.4.9 Markup Scenarios

DOE used several standards case markup scenarios to represent the uncertainty about the impacts of new and amended energy conservation standards on prices and profitability. In the base case, DOE used the same baseline markups calculated in the engineering analysis for all representative units. In the standards case, DOE modeled three markup scenarios to represent the uncertainty about the potential impacts on prices and profitability following the implementation of new and amended energy conservation standards: (1) flat markup scenario, (2) two-tiered markup scenario, and (3) a preservation of operating profit markup scenario. These scenarios lead to different markup values, which, when applied to the inputted MPCs, result in varying revenue and cash flow impacts.

12.4.9.1 Flat Markup Scenario

Under the flat markup scenario, DOE applied a single uniform markup across all efficiency levels. As production costs increase with efficiency, this scenario implies that the absolute dollar markup will increase as well. Based on publicly available financial information for manufacturers of electric motors and comments from manufacturer interviews, DOE assumed the non-production cost markup—which includes SG&A expenses; research and development expenses; interest; and profit—to be 1.37 for the 5 horsepower electric motor representative unit and 1.47 for all other electric motor representative units. Because this markup scenario assumes that manufacturers would be able to maintain their gross margin percentage as production costs increase in response to energy conservation standards, it represents a high bound to industry profitability under energy conservation standards.

12.4.9.2 Two-Tiered Markup Scenario

DOE also modeled two possible lower bound profitability scenario, a two-tiered markup scenario and a preservation of operating profit markup scenario. DOE implemented the two-tiered markup scenario because during interviews, multiple manufacturers stated they offer two tiers of equipment lines that are differentiated, in part, by efficiency level. The high efficiency tiers typically earn a premium over the baseline efficiency tier. For electric motors the high efficiency tier is typically one or two bands above NEMA Premium efficient motors. Several manufacturers suggested that the premium currently earned by the high efficiency tiers would erode under new and amended standards due to the disappearance of the baseline efficiency tier, which would harm profitability. Because of this pricing dynamic described by manufacturers, DOE modeled a two-tier markup scenario. In this scenario, DOE assumed that the markup on electric motors varies according to two efficiency tiers in both the base case and the standards case. During the MIA interviews, manufacturers provided information on the range of typical efficiency levels in those two tiers and the change in profitability at each level. DOE used this information and industry average gross margins to estimate markups for electric motors under a two-tier pricing strategy in the base case. In the standards case, DOE modeled the situation in which portfolio reduction squeezes the margin of high efficiency equipment as they become the new baseline, and presumably higher volume equipment.

Table 12.4.27 through Table 12.4.36 lists the representative units DOE analyzed with the corresponding two-tier markups at each selected EL.

Table 12.4.27 Two-Tiered Markups for NEMA Design B, 5 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL				
	Baseline	**EL 1**	**EL 2**	**EL 3**	**EL 4**
Baseline	1.370				
EL 1	1.370	1.369			
EL 2	1.370	1.370	1.361		
EL 3	1.370	1.370	1.370	1.340	
EL 4	1.370	1.370	1.370	1.370	1.318

Table 12.4.28 Two-Tiered Markups for NEMA Design B, 30 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL				
	Baseline	**EL 1**	**EL 2**	**EL 3**	**EL 4**
Baseline	1.450				
EL 1	1.450	1.442			
EL 2	1.450	1.450	1.432		
EL 3	1.450	1.450	1.450	1.398	
EL 4	1.450	1.450	1.450	1.450	1.367

Table 12.4.29 Two-Tiered Markups for NEMA Design B, 75 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL				
	Baseline	EL 1	EL 2	EL 3	EL 4
Baseline	1.450				
EL 1	1.450	1.446			
EL 2	1.450	1.450	1.424		
EL 3	1.450	1.450	1.450	1.398	
EL 4	1.450	1.450	1.450	1.450	1.383

Table 12.4.30 Two-Tiered Markups for NEMA Design C, 5 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL		
	Baseline	EL 1	EL 2
Baseline	1.370		
EL 1	1.370	1.362	
EL 2	1.370	1.370	1.313

Table 12.4.31 Two-Tiered Markups for NEMA Design C, 75 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL		
	Baseline	EL 1	EL 2
Baseline	1.450		
EL 1	1.450	1.409	
EL 2	1.450	1.450	1.381

Table 12.4.32 Two-Tiered Markups for Fire Pump, 5 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL			
	Baseline	EL 1	EL 2	EL 3
Baseline	1.370			
EL 1	1.370	1.362		
EL 2	1.370	1.370	1.370	
EL 3	1.370	1.370	1.370	1.311

Table 12.4.33 Two-Tiered Markups for Fire Pump, 30 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL			
	Baseline	EL 1	EL 2	EL 3
Baseline	1.450			
EL 1	1.450	1.439		
EL 2	1.450	1.450	1.450	
EL 3	1.450	1.450	1.450	1.356

Table 12.4.34 Two-Tiered Markups for Fire Pump, 75 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL			
	Baseline	EL 1	EL 2	EL 3
Baseline	1.450			
EL 1	1.450	1.427		
EL 2	1.450	1.450	1.450	
EL 3	1.450	1.450	1.450	1.366

Table 12.4.35 Two-Tiered Markups for Brake, 5 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL				
	Baseline	EL 1	EL 2	EL 3	EL 4
Baseline	1.370				
EL 1	1.370	1.368			
EL 2	1.370	1.370	1.359		
EL 3	1.370	1.370	1.370	1.337	
EL 4	1.370	1.370	1.370	1.370	1.311

Table 12.4.36 Two-Tiered Markups for Brake, 30 Horsepower, 4 Pole, Closed Electric Motors

EL	Markups by Selected EL				
	Baseline	EL 1	EL 2	EL 3	EL 4
Baseline	1.450				
EL 1	1.450	1.432			
EL 2	1.450	1.450	1.418		
EL 3	1.450	1.450	1.450	1.385	
EL 4	1.450	1.450	1.450	1.450	1.350

12.4.9.3 Preservation of Operating Profit Markup Scenario

DOE implemented the preservation of operating profit markup scenario because manufacturers stated that they do not expect to be able to markup the full cost of production given the highly competitive market, in the standards case. The preservation of operating profit markup scenario assumes that manufacturers are able to maintain only the base case total operating profit in absolute dollars in the standards case, despite higher production costs and investment. The base case total operating profit is derived from marking up the cost of goods sold for each product by a flat percentage (the flat markup, discussed above) to cover standard SG&A expenses, R&D expenses, and profit. DOE adjusted the manufacturer markups in the GRIM at each TSL to yield approximately the same earnings before interest and taxes in the standards case in the year after the compliance date of the new and amended standards as in the base case. DOE assumed that the industry-wide impacts would occur under the new minimum efficiency levels. DOE altered the markups only for the minimally compliant equipment in this scenario, with margin impacts not occurring for equipment that already exceed the new and amended energy conservation standards. The preservation of operating profit markup scenario represents one of the possible lower bound markup scenarios of industry profitability following new and amended energy conservation standards. Under this scenario, while manufacturers are not able to earn additional operating profit on higher production costs and the investments required to comply with the new and amended energy conservation standards, like they are in the flat markup scenario, they are able to maintain the same operating profit in the standards case as was earned in the base case.

12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, the GRIM estimated indicators of financial impacts on the electric motor industry. The following sections detail additional inputs and assumptions for electric motors. The main results of the MIA are also reported in this section. The MIA consists of two key financial metrics: INPV and annual cash flows.

12.5.1 Impacts on Industry Net Present Value

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE's net present value, which is applied to the U.S. economy. The INPV is the sum of all net cash flows discounted at the industry's cost of capital, or discount rate. The electric motors GRIM estimates cash flows from 2013 to 2045. This timeframe models both the short-term impacts on the industry from the announcement of the standard until the compliance date (2013 until an estimated compliance date of December 15, 2015[b]) and a long-term assessment over the 30-year analysis period used in the NIA (2016 – 2045).

In the MIA, DOE compares the INPV of the base case (no new or amended energy conservation standards) to that of each TSL in the standards case. The difference between the base case and a standards case INPV is an estimate of the economic impacts that implementing that particular TSL would have on the industry. For the electric motor industry, DOE examined the three markup scenarios described above, the flat markup scenario (preservation of gross margin percentage), the two-tiered markup scenario, and the preservation of operating profit markup scenario. Table 12.5.1 through Table 12.5.3 provide the INPV estimates for the three markup scenarios for the electric motor industry.

Table 12.5.1 Changes in Industry Net Present Value for Electric Motors – Flat Markup Scenario

	Units	Base Case	Trial Standard Level			
			1	2	3	4
INPV	(2012$ millions)	$3,371.2	$3,378.7	$3,759.2	$4,443.7	$5,241.3
Change in INPV	(2012$ millions)	-	$7.5	$388.0	$1,072.5	$1,870.1
	(%)	-	0.2%	11.5%	31.8%	55.5%

[b] For the purposes of this TSD, the estimated compliance date of December 15, 2015 is approximated to January 1, 2016. Therefore, the compliance date is rounded to 2016 and the analysis period extends to 2045.

Table 12.5.2 Changes in Industry Net Present Value for Electric Motors – Two-Tiered Markup Scenario

	Units	Base Case	Trial Standard Level			
			1	2	3	4
INPV	(2012$ millions)	$3,371.2	$3,374.3	$3,087.6	$2,979.6	$3,335.7
Change in INPV	(2012$ millions)	-	$3.2	$(283.5)	$(391.6)	$(35.5)
	(%)	-	0.1%	-8.4%	-11.6%	-1.1%

Table 12.5.3 Changes in Industry Net Present Value for Electric Motors – Preservation of Operating Profit Markup Scenario

	Units	Base Case	Trial Standard Level			
			1	2	3	4
INPV	(2012$ millions)	$3,371.2	$3,075.6	$3,189.6	$2,663.9	$1,869.2
Change in INPV	(2012$ millions)	-	$(295.6)	$(181.6)	$(707.3)	$(1,502.0)
	(%)	-	-8.8%	-5.4%	-21.0%	-44.6%

12.5.2 Impacts on Annual Cash Flow

While INPV is useful for evaluating the long-term effects of new and amended energy conservation standards, short-term changes in cash flow are also important indicators of the industry’s financial situation. For example, a large investment over one or two years could strain the industry’s access to capital. Consequently, the sharp drop in financial performance could cause investors to flee, even though recovery may be possible. Thus, a short-term disturbance can have long-term effects that the INPV cannot capture. To get an idea of the behavior of annual free cash flows, Figure 12.5.1 through Figure 12.5.3 below present the annual free cash flows from 2013 through 2045 for the base case and different TSLs in the standards case.

Annual cash flows are discounted to the base year, 2012. Between 2013 and the 2015 compliance date of the new and amended energy conservation standards, cash flows are driven by the level of conversion costs and the proportion of these investments spent every year. After the standard announcement date (i.e., the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the new and amended energy conservation standards. The more stringent the new and amended energy conservation standards, the greater the impact on industry cash flows in the years leading up to the compliance date, as product conversion costs lower cash inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the new and amended energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, new and amended energy conservation standards could create stranded assets, i.e., tooling and equipment that would have enjoyed longer use if the energy conservation standards had not made them obsolete. In this year, manufacturers write down the remaining book value of existing tooling and equipment whose value is affected by the new and amended energy conservation standards. This one-time write-down acts as a tax shield that alleviates decreases in cash flow from operations in the year of the write-down. In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital is needed due to more costly production components and materials, higher inventory carrying to sell more expensive equipment, and higher accounts receivable for more expensive equipment. Depending on these two competing factors, cash flow can either be positively or negatively affected in the year the standards takes effect.

In the years following the compliance date of the standards, the impact on cash flow depends on the operating revenue. In the flat markup scenario, the manufacture markup is held constant to yield the same gross margin percentage in the standards case at each TSL as in the base case in the year after the standards take effect. The implicit assumption is that manufacturers can freely pass on and mark up higher cost units. The result under this scenario is that operating cash flow increases (in absolute terms) as revenue increases. At the highest TSLs where MPCs dramatically increase, this scenario drives large increases in operating cash flow relative to the base case. The larger the production cost increase, then, the more likely it is that the increase in operating cash flow after the standards take affect will outweigh the initial conversion costs.

Under the preservation of operating profit scenario, cash flow decreases at each TSL in the standards case compared to the base case because, since the absolute dollar amount of the gross margin does not change despite an increase in sales and cost of goods sold, the gross margin percentage is reduced. Figure 12.5.1 through Figure 12.5.3 present the annual free cash flows for the electric motor industry.

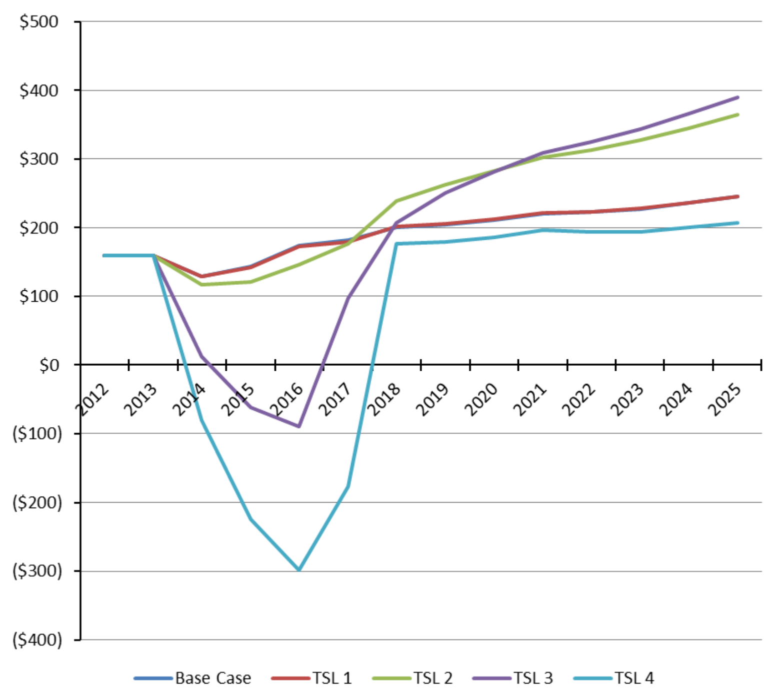

Figure 12.5.1 Annual Industry Free Cash Flows for Electric Motors - Flat Markup Scenario

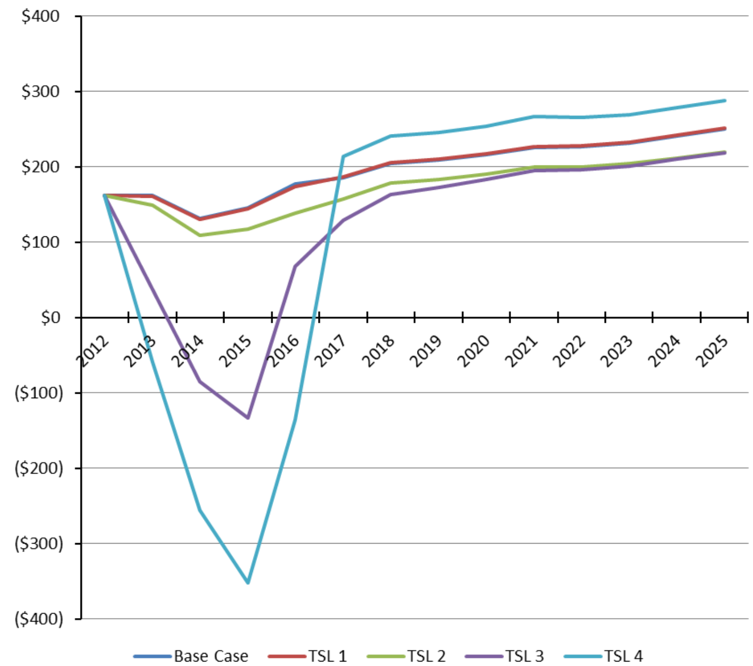

Figure 12.5.2 Annual Industry Free Cash Flows for Electric Motors – Two-Tiered Markup Scenario

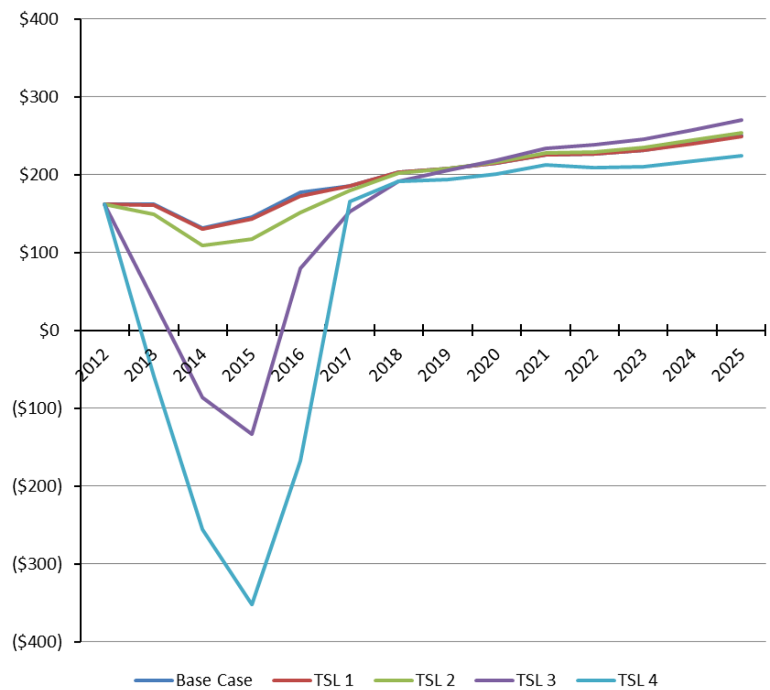

Figure 12.5.3 Annual Industry Free Cash Flows for Electric Motors - Preservation of Operating Profit Markup Scenario

12.6 IMPACTS ON MANUFACTURER SUBGROUPS

As described in Section 12.2.3 above, DOE identified one subgroup of electric motor manufacturers: small business manufacturers. The results of this subgroup analysis are described below.

12.6.1 Impacts on Small Business Manufacturers

12.6.1.1 Description and Estimated Number of Small Entities Regulated

DOE conducted a more focused inquiry of the companies that could be small business manufacturers of equipment covered by this rulemaking. During its market survey, DOE used all available public information to identify potential small business manufacturers. DOE's research involved industry trade association membership directories (including NEMA), the SBA's database, individual company websites, and market research tools (e.g. Hoover's and Dun and Bradstreet reports) to create a list of every company that manufactures or sells electric motors covered by this rulemaking. DOE also asked stakeholders and industry representatives if they were aware of any other small manufacturers during manufacturer interviews and at previous DOE public meetings. DOE attempted to contact every potential small electric motor manufacturer on its list to determine whether they met the SBA's definition of a small business manufacturer of covered electric motors. DOE screened out companies that did not offer equipment covered by this rulemaking, did not meet SBA's definition of a "small business," or are foreign owned and operated.

DOE initially identified 60 potential manufacturers of electric motors sold in the U.S. After reviewing publically available information DOE contacted 27 of the companies that DOE believed were small business manufacturers to determine whether they met the SBA definition of a small business and whether they manufactured covered equipment. Based on these efforts, DOE estimates that there are 13 small business manufacturers of electric motors.

Before issuing this NOPR, DOE attempted to contact the small business manufacturers of electric motors it had identified to invite them to take part in a small business manufacturer impact analysis interview. Of the electric motor manufacturers DOE contacted, 10 responded and three did not. Eight of the 10 responding manufacturers declined to be interviewed. Therefore, DOE was able to reach and discuss potential standards with two of the 13 small business manufacturers. DOE also obtained information about small business manufacturers and potential impacts while interviewing large manufacturers.

Eight major manufacturers supply approximately 90 percent of the market for electric motors. None of the major manufacturers of electric motors covered in this rulemaking are a small business. DOE estimates that approximately 50 percent of the market is served by imports. Many of the small businesses that compete in the electric motor market produce specialized motors, many of which have been not been covered under previous standards. Most of these low-volume manufacturers do not compete directly with large manufacturers and try to find niche markets for their equipment. There are a few small business manufacturers that do produce general purpose motors; however, these motors are currently at NEMA Premium efficiency levels, the efficiency levels being proposed in today's notice.

12.6.1.2 Comparison Between Large and Small Entities

In its market survey, DOE identified three categories of small business electric motor manufacturers that may be impacted differently by today's proposed rule. The first group, which includes approximately five of the 13 small businesses, consists of manufacturers that produce specialty motors that were not covered under previous Federal energy conservation standards, but would be covered under the expanded scope of today's proposed rule. DOE believes that this group would likely be the most impacted by expanding the scope of equipment required to meet NEMA Premium. The second group, which includes approximately five small businesses, consists of manufacturers that offer a very limited number of covered equipment and primarily focus on other types of motors not covered in this rulemaking, such as single-phase or direct-current motors. Because generally less than 10 percent of these manufacturers' revenue comes from covered equipment, DOE does not believe new standards will substantially impact their business. The third group, which includes approximately three small businesses, consists of manufacturers that already offer NEMA premium general purpose motors. DOE believes that these manufacturers already have the design and production experience necessary to meet the standards in this proposed rule without incurring burdensome costs.

At TSL 2, the level proposed in today's notice, DOE estimates capital conversion costs of $1.88 million and product conversion costs of $3.75 million for a typical small manufacturer in the first group (manufacturers that produce specialized motors previously not covered by Federal energy conservation standards). Meanwhile, DOE estimates a typical large manufacturer would incur capital and product conversion costs of $3.29 million and $7.25 million, respectively, at the same TSL. Small manufacturers that predominately produce specialty motors would face higher relative capital conversion costs at TSL 2 than large manufacturers because large manufacturers have been independently pursuing higher efficiency motors and consequently have built up more design and production experience. Large manufacturers have also been innovating as a result of the small electric motors rulemaking at 75 FR 10874 (March 9, 2010), which did not cover many of the specialized equipment that these small business manufacturers produce. As a result, small manufacturers that produce a high percentage of equipment that are currently not covered have not upgraded their production lines with equipment necessary to produce NEMA Premium motors. As Table 12.6.1 illustrates, these manufacturers would have to drastically increase their capital expenditures to purchase new lamination die sets, and new winding and stacking equipment.

Table 12.6.1 Estimated Capital and Product Conversion Costs as a Percentage of Annual Capital Expenditures and R&D Expense

	Capital conversion cost as a percentage of annual capital expenditures	Product conversion cost as a percentage of annual R&D expense	Total conversion cost as a percentage of annual revenue
Typical Large Manufacturer	14%	31%	2%
Typical Small Manufacturer	188%	490%	75%

Table 12.6.1 also illustrates that small manufacturers whose production lines contain many motors which are not currently covered under Federal energy conservation standards face

high relative product conversion costs compared to large manufacturers, despite the lower dollar value. In interviews, these small manufacturers expressed concern that they would face a large learning curve relative to large manufacturers, due to the fact that the equipment they produce has not previously been covered under Federal energy conservation standards. In its market survey, DOE learned that for some manufacturers, the expanded scope of specialized motors that would have to meet NEMA Premium could affect nearly half the equipment they offer. They would need to hire additional engineers and would have to spend considerable time and resources redesigning their equipment and production processes. DOE does not expect the small businesses that already manufacture NEMA Premium equipment or those that offer very few alternating-current motors to incur these high costs.

Manufacturers also expressed concern about testing and certification costs associated with new and amended standards. They pointed out that these costs are particularly burdensome on small businesses that produce several types of different specialized equipment. As a result of their wide variety of equipment and relatively low output, small manufacturers are forced to certify multiple small batches of motors, the costs of which they have to spread out over far fewer units than large manufacturers.

Small manufacturers that produce equipment that is not currently covered also pointed out that they would face significant challenges supporting current business while making changes to their production lines. While large manufacturers could shift production of certain equipment to different plants or production lines while they made updates, small businesses would have limited options. Most of these small businesses have only one plant and therefore would have to find a way to continue to fulfill customer needs while redesigning production lines and installing new equipment. In interviews with DOE, small manufacturers said that it would be difficult to quantify the impacts of downtime and the possible need for external support could have on their business.

In summary, while the conversion costs required can be considered substantial for all electric motor manufacturers, the impacts could be relatively greater for a typical small manufacturer because of much lower production volumes and the relatively fixed nature of the R&D and capital investments required. DOE seeks comment on the potential impacts of amended standards on electric motor manufacturers.

12.7 OTHER IMPACTS

12.7.1 Employment

DOE quantitatively assessed the impact of potential new and amended energy conservation standards on direct employment. DOE used the GRIM to estimate the domestic labor expenditures and number of domestic production workers in the base case and at each TSL from the announcement of any potential new and amended energy conservation standards in2013 to the end of the analysis period in 2044. DOE used statistical data from the U.S. Census Bureau's 2011 Annual Survey of Manufacturers (ASM), the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels. Labor expenditures involved with the manufacturing of electric motors are a function of the labor intensity of the equipment, the sales volume, and an assumption that wages remain fixed in real terms over time.

In the GRIM, DOE used the labor content of each product and the manufacturing production costs to estimate the annual labor expenditures of the industry. DOE used Census data and interviews with manufacturers to estimate the portion of the total labor expenditures attributable to domestic labor.

The production worker estimates in this employment section cover only workers up to the line-supervisor level who are directly involved in fabricating and assembling an electric motor within a motor facility. Workers performing services that are closely associated with production operations, such as material handling with a forklift, are also included as production labor. DOE's estimates account for only production workers who manufacture the specific equipment covered by this rulemaking. For example, a worker on an electric motor line manufacturing a fractional horsepower motor (i.e. a motor with less than one horsepower) would not be included with this estimate of the number of electric motor workers, since fractional motors are not covered by this rulemaking.

The employment impacts shown in the tables below represent the potential production employment impact resulting from new and amended energy conservation standards. The upper bound of the results estimates the maximum change in the number of production workers that could occur after compliance with new and amended energy conservation standards when assuming that manufacturers continue to produce the same scope of covered equipment in the same production facilities. It also assumes that domestic production does not shift to lower-labor-cost countries. Because there is a real risk of manufacturers evaluating sourcing decisions in response to new and amended energy conservation standards, the lower bound of the employment results includes the estimated total number of U.S. production workers in the industry who could lose their jobs if all existing production were moved outside of the U.S. While the results present a range of employment impacts following 2015, the sections below also include qualitative discussions of the likelihood of negative employment impacts at the various TSLs. Finally, the employment impacts shown are independent of the indirect employment impacts from the broader U.S. economy, which are documented in chapter 16 of the NOPR TSD.

Based on 2011 ASM data and interviews with manufacturers, DOE estimates approximately 60 percent of electric motors sold in the U.S. are manufactured domestically. Using this assumption, DOE estimates that in the absence of new and amended energy conservation standards, there would be approximately 7,237 domestic production workers involved in manufacturing all electric motors covered by this rulemaking in 2015. The table below shows the range of potential impacts of new and amended energy conservation standards for all ECGs on U.S. production workers in the electric motor industry. However, because ECG 1 motors comprise more than 97 percent of the electric motors covered by this rulemaking, DOE believes that potential changes in domestic employment will be driven primarily by the standards that are selected for ECG 1, Design A and B electric motors.

Table 12.7.1 Potential Changes in the Total Number of All Domestic Electric Motor Production Workers in 2015

	Base Case	Trial Standard Level			
		1	2	3	4
Total Number of Domestic Production Workers in 2015 (without changes in production locations)	7,237	7,270	7,420	8,287	15,883
Potential Changes in Domestic Production Workers in 2015*		33 - 0	183 - (362)	1,050 - (3,619)	8,646 - (7,237)

* DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

Most manufacturers agree that any standards that involve expanding the scope of equipment required to meet NEMA Premium would not significantly change domestic employment levels. At this efficiency level (TSL 2), manufacturers would not be required to make major modifications to their production lines nor would they have to undertake new manufacturing processes. A few small business manufacturers who primarily make electric motors currently out of the scope of coverage, but whose equipment would be covered by new electric motor standards, could be impacted by efficiency standards at TSL 2. These impacts, including employment impacts, are discussed in section 12.6.1 of the TSD. Overall, DOE believes there would not be a significant decrease in domestic employment levels at TSL 2. DOE created a lower bound of the potential loss of domestic employment at 362 employees for TSL 2. DOE estimated only five percent of the electric motors market is comprised of manufacturers that do not currently produce any motors at NEMA Premium efficiency levels. DOE estimated that at most five percent of domestic electric motor manufacturing could potentially move abroad or exit the market entirely. DOE similarly estimated that all electric motor manufacturers produce some electric motors at or above TSL 1 efficiency levels. Therefore, DOE does not believe that any potential loss of domestic employment would occur at TSL 1.

Manufacturers, however, cautioned that any standard set above NEMA Premium would require major changes to production lines, large investments in capital and labor, and would result in extensive stranded assets. This is largely because manufacturers would have to design and build motors with larger frame sizes and could potentially have to use copper, rather than aluminum rotors. Several manufacturers pointed out that this would require extensive retooling, vast engineering resources, and would ultimately result in a more labor-intensive production process. Manufacturers generally agreed that a shift toward copper rotors would have uncertain impacts on energy efficiency and would cause companies to incur higher labor costs. These factors could cause manufacturers to consider moving production offshore to reduce labor costs or they may choose to exit the market entirely. Therefore, DOE believes it is more likely that efficiency standards set above NEMA Premium could result in a decrease of labor. Accordingly, DOE set the lower bound on the potential loss of domestic employment at 50 percent of the existing domestic labor market for TSL 3 and 100 percent of the domestic labor market for TSL 4. However, these values represent the worst case scenario DOE modeled. Manufacturers also stated that larger motor manufacturing (that is for motors above 200 horsepower) would be very unlikely to move abroad since the shipping costs associated with those motors are very large. Consequently, DOE does not currently believe standards set at TSL 3 and TSL 4 would likely result in a large loss of domestic employment.

12.7.2 Production Capacity

Most manufacturers agreed that any standard expanding the scope of equipment required to meet NEMA Premium would not have a significant impact on manufacturing capacity. Manufacturers pointed out, however, that a standard that required them to use copper rotors would severely disrupt manufacturing capacity. Most manufacturers emphasized they do not currently have the machinery, technology, or engineering resources to produce copper rotors in-house. Some manufacturers claim that the few manufacturers that do have the capability of producing copper rotors are not able to produce these motors in volumes sufficient to meet the demands of their customers. For manufacturers to either completely redesign their motor production lines or significantly expand their fairly limited copper rotor production line would require a massive retooling and engineering effort, which could take several years to complete. Most manufacturers stated they would have to outsource copper rotor production because they would not be able to modify their facilities and production processes to produce copper rotors in-house within a three year time period. Most manufacturers agreed that outsourcing rotor die casting would constrain capacity by creating a bottleneck in rotor production, as there are very few companies that produce copper rotors.

Manufacturers also pointed out that there is substantial uncertainty surrounding the global availability and price of copper, which has the potential to constrain capacity. Several manufacturers expressed concern that the combination of all of these factors would make it difficult to support existing business while redesigning production lines and retooling. The need to support existing business would also cause the redesign effort to take several years.

In summary, for those TSLs that require copper rotors, DOE believes there is a likelihood of capacity constraints in the near term due to fluctuations in the copper market and limited copper die casting machinery and expertise. However, for the levels proposed in this rule, DOE does not foresee any capacity constraints.

12.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or an entire industry. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. For the cumulative regulatory burden analysis, DOE looks at other significant equipment-specific regulations that could affect electric motor manufacturers that will take effect 3 years before or after the compliance date of new and amended energy conservation standards for this equipment.[c] In addition to the new and amended energy conservation regulations on electric motors, several other Federal regulations apply to this equipment and other equipment produced by the same manufacturers. While the cumulative regulatory burden focuses on the impacts on manufacturers of other Federal requirements, DOE also has described a number of other regulations in section 12.7.3.2 because it recognizes that these regulations also impact the equipment covered by this rulemaking.

[c] The estimated compliance date for electric motors is 2 years from the date of publication of the final rule (approximately December 2015).

Companies that produce a wide range of regulated equipment may be faced with more capital and product development expenditures than competitors with a narrower scope of equipment. Regulatory burdens can prompt companies to exit the market or reduce their equipment offerings, potentially reducing competition. Smaller companies in particular can be disproportionately affected by regulatory costs since these companies have lower sales volumes over which they can amortize the costs of meeting new regulations. A proposed standard is not economically justified if it contributes to an unacceptable level of cumulative regulatory burden.

12.7.3.1 DOE Regulations for Other Equipment Produced by Electric Motors Manufacturers

In addition to the new and amended energy conservation standards on electric motors, several other Federal regulations and pending regulations apply to other equipment produced by the same manufacturers. DOE recognizes that each regulation can significantly affect a manufacturer's financial operations. Multiple regulations affecting the same manufacturer can quickly strain manufacturers' profits and possibly cause an exit from the market. Table 12.7.2 lists the other DOE energy conservation standards that could also affect manufacturers of electric motors in the 3 years leading up to and after the compliance date of new and amended energy conservation standards for this equipment.

Table 12.7.2 Other DOE and Federal Actions Affecting the Electric Motors Industry

Regulation	Approximate Compliance Date	Number of Impacted Companies from the Market and Technology Assessment (MTA) (See Chapter 3)	Estimated Industry Total Conversion Expenses
General Service Incandescent Lamps	2012; 2013; & 2014	1	N/A†
Ranges and Ovens	2012	1	$22.6 million (2006$)[d]
General Service Fluorescent Lamps and Incandescent Reflector Lamps	2012	1	$363.1 million (2008$)[e]
Dehumidifiers	2012	1	N/A†
Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps	2012	1	$17.3 million (2007$)[f]
Commercial Clothes Washers	2013	1	$20.4 million (2008$)[g]
Direct Heating Equipment	2013 & 2015	1	$5.39 million (2009$)[h]
Residential Furnaces & Residential Central Air Conditioners and Heat Pumps	2013 & 2015	1	$45.7 million (2009$)[i]
Dishwashers	2013	1	$85.3 million (2010$)[j]
Commercial Package Air-Conditioning and Heating Equipment	2013 & 2014	1	N/A††
Room Air Conditioners	2014	1	$171 million (2009$)[k]
Residential Refrigerators and Freezers	2014	1	$1,245 million (2009$)[l]

[d] Estimated industry conversion expenses were published in the TSD for the April 2009 residential cooking products final rule. 74 FR 16040.

[e] Estimated industry conversion expenses were published in the TSD for the July 2009 general service fluorescent lamps and incandescent reflector lamps final rule. 74 FR 34080.

[f] Estimated industry conversion expenses were published in the TSD for the October 2008 packaged terminal air conditioners and packaged terminal heat pumps final rule. 73 FR 58772.

[g] Estimated industry conversion expenses were published in the TSD for the January 2010 commercial clothes washers final rule. 75 FR 1122.

[h] Estimated industry conversion expenses were published in the TSD for the April 2010 heating products final rule. 75 FR 20112.

[i] Estimated industry conversion expenses were published in the TSD for the June 2011 furnaces, central air conditioners and heating pumps direct final rule. 76 FR 37408.

[j] Estimated industry conversion expenses were published in the TSD for the May 2012 dishwashers direct final rule. 77 FR 31918.

[k] Estimated industry conversion expenses were published in the TSD for the April 2011 AHAM direct final rule. 76 FR 22454.

[l] Estimated industry conversion expenses were published in the TSD for the September 2011 refrigerators final rule. 76 FR 57516.

Fluorescent Lamp Ballasts	2014	1	$82 million (2010$)[m]
Residential Clothes Dryers	2015	1	$95 million (2009$)[n]
Residential Clothes Washers	2015 & 2018	1	$418.5 million (2010$)[o]
Small Electric Motors	2015	16	$51.2 million (2009$)[p]
Residential Water Heaters	2015	2	$95.9 million (2009$)[q]
Commercial Distribution Transformers	2016	2	$61.0 million (2011$)[r]
Microwave Ovens	2016	1	$43.1 million (2011$)[s]
ER, BR, and Small Diameter IRLs	2016*	1	N/A††
General Service Fluorescent Lamps and Incandescent Reflector Lamps Update	2017*	1	N/A††
Metal Halide Lamp Fixtures	2018*	1	N/A††
HID Lamps	2018*	1	N/A††
Commercial Packaged Air-Conditioning and Heating Equipment	2018*	1	N/A††
Commercial and Industrial Fans and Blowers	2018*	2	N/A††
Commercial and Industrial Pumps	2018*	1	N/A††
Commercial Clothes Washers Update	2018*	1	N/A††

*The dates listed are an approximation. The exact dates are pending final DOE action.

† For minimum performance requirements prescribed by the Energy Independence and Security Act of 2007 (EISA 2007), DOE did not estimate total industry conversion costs because an MIA was not completed as part of a rulemaking. Pub. L. 110-140. EISA 2007 made numerous amendments to the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, (42 U.S.C. 6291–6309), which established an energy conservation program for major household appliances and industrial and commercial equipment.

†† For energy conservation standards for rulemakings awaiting DOE final action, DOE does not have a finalized estimated total industry conversion cost.

Some Federal energy conservation regulations have a more significant impact on manufacturers of electric motors than others because manufacturers hold a significant market share of those covered equipment. Several manufacturers expressed concern about the proximity

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[m] Estimated industry conversion expenses were published in the TSD for the April 2011 AHAM direct final rule. 76 FR 70548.

[n] Estimated industry conversion expenses were published in the TSD for the November 2011 fluorescent lamp ballasts final rule. 76 FR 70548.

[o] Estimated industry conversion expenses were published in the TSD for the May 2012 residential clothes washers direct final rule. 77 FR 32308.

[p] Estimated industry conversion expenses were published in the TSD for the March 2010 small electric motors final rule. 75 FR 10874.

[q] Estimated industry conversion expenses were published in the TSD for the April 2010 heating products final rule. 75 FR 20112.

[r] Estimated industry conversion expenses were published in the TSD for the April 2013distribution transformers final rule. 78 FR 23336.

[s] Estimated industry conversion expenses were published in the TSD for the May 2013 microwave ovens final rule. 78 FR 36316.

between the compliance date of this rulemaking and that of the small electric motors rulemaking at 75 FR 10874 (March 9, 2010). Most manufacturers of electric motors covered by this rulemaking also produce electric motors that are covered by the small electric motors rulemaking. Manufacturers stated that adopting these two regulations in a potentially short timeframe could strain R&D and capital expenditure budgets for motor manufacturers. Table 12.7.3 below shows the DOE energy conservation standards with compliance dates within three years of electric motors where manufacturers are expected to be most impacted due to their market positions. For these rulemakings, electric motors manufacturers would likely be burdened by a significant portion of the estimated industry conversion costs. In some cases, specific market share data was not available, but manufacturers were identified as major or minor manufacturers in the given market when this information was publicly available.

Table 12.7.3 DOE Regulations on Equipment for Which Electric Motor Manufacturers Hold Significant Market Share

		Manufacturer Market Share in DOE Regulated Product				
Regulation	**Estimated Industry Total Conversion Expenses**	**General Electric**	**Baldor**	**Regal Beloit**	**Siemens**	**Toshiba**
General Service Incandescent Lamps	N/A					
Residential Gas Kitchen Ranges and Ovens	$22.6 million (2006$)	47% (electric) 37% (gas)				
General Service Fluorescent Lamps and Incandescent Reflector Lamps	$363.1 million (2008$)	N/A (major)				
Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps	$17.3 million (2007$)	N/A (major)				
Commercial Clothes Washers	$20.4 million (2008$)	N/A (major)				
Direct Heating Equipment	$5.39 million (2009$)			N/A (major)		
Residential Furnaces & Residential Central Air Conditioners and Heat Pumps	$45.7 million (2009$)					N/A (major)
Dishwashers	$94.0 million (2010$)	N/A (major)				
Room Air Conditioners	$171 million (2009$)	N/A (major)				
Residential Refrigerators and Freezers	$1,245 million (2009$)	27% (refrigerators)				
Fluorescent Lamp Ballasts	$82 million (2010$)	N/A (major)				
Residential Clothes Dryers	$95 million (2009$)	16% (electric) 10% (gas)				
Small Electric Motors	$51.2 million (2009$)		N/A (major)	N/A (major)		
Residential Water Heaters	$95.9 million (2009$)			N/A (major)		
Commercial Distribution Transformers	$61.0 million (2011$)	N/A (major)			N/A (major)	
ER, BR, and Small Diameter IRLs	N/A	N/A (major)				
General Service Fluorescent Lamps and Incandescent	N/A	N/A (major)				

Reflector Lamps Update						
Metal Halide Lamp Fixtures	N/A	N/A (major)				
HID Lamps	N/A	N/A (major)				
Commercial Clothes Washers Update	N/A	N/A (major)				

12.7.3.2 Other Regulations That Could Impact Electric Motors Manufacturers

European Commission Ecodesign Directive for Lot 30

The European Commission (EC) is currently evaluating expanding conservation standards to motor types with no existing standards. The expanded scope being considered includes some of the special and definite purpose motors (i.e. brake motors) that DOE has included in the expanded scope of the NOPR. The EC is also evaluating standards for several motor types not included in the NOPR by DOE, such as permanent magnet motors, switched reluctance motors, and motors operating in conjunction with inverter drives. This could be an additional burden for manufacturers that sell motors in Europe.

NFPA 70 and NFPA 20

The National Fire Protection Association (NFPA) has issued two codes that impact manufacturers of fire pump electric motors – *NFPA 70: National Electric Code* and *NFPA 20: Standard for the Installation of Stationary Pumps for Fire Protection*. To comply with these standards, manufacturers of fire pump electric motors must undergo additional design and engineering efforts and incur increased testing and certification costs. These testing and certification costs could add to the compliance costs of new and amended Federal energy conservation standards for covered fire pump motors.

12.8 CONCLUSION

The following section summarizes the impacts for the scenarios DOE believes are most likely to capture the range of impacts on electric motor manufacturers as a result of new and amended energy conservation standards. DOE also notes that while these scenarios bound the range of most plausible impacts on manufacturers, there potentially could be circumstances which cause manufacturers to experience impacts outside of this range.

TSL 1 represents EL 1 for ECG 1, ECG 2 and ECG 4 motors and baseline for ECG 2 motors. At TSL 1, DOE estimates impacts on INPV to range from $7.5 million to -$295.6 million, or a change in INPV of 0.2 percent to -8.8 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 1.1 percent to $164.9 million, compared to the base case value of $166.7 million in the year leading up to the proposed energy conservation standards.

The INPV impacts at TSL 1 range from slightly positive to moderately negative, however DOE does not anticipate that manufacturers would lose a significant portion of their INPV at this TSL. This is because the vast majority of shipments already meet or exceed efficiency levels prescribed at TSL 1. DOE estimates that in the year of compliance, 90 percent of all electric motor shipments (90 percent of ECG 1, eight percent of ECG 2, 100 percent of ECG 3, and 67 percent of ECG 4 shipments) would meet the efficiency levels at TSL 1 or higher in the base case. Since ECG 1 shipments account for over 97 percent of all electric motor shipments the effects on those motors are the primary driver for the impacts at this TSL. Only a few ECG 1 shipments not currently covered by the existing electric motors rule and a small amount of ECG 2 and ECG 4 shipments would need to be converted at TSL 1 to meet this efficiency standard.

DOE expects conversion costs to be small compared to the industry value because most of the electric motor shipments, on a volume basis, already meet the efficiency levels analyzed at this TSL. DOE estimates product conversion costs of $6.1 million due to the proposed expanded scope of this rulemaking which includes motors previously not covered by the current electric motor energy conservation standards. DOE believes that at this TSL, there will be some engineering costs as well as testing and certification costs associated with this proposed scope expansion. DOE estimates the capital conversion costs to be minimal at TSL 1. This is mainly because almost all manufacturers currently produce some motors that are compliant at TSL 1 efficiency levels and it would not be much of a capital investment to bring all motor production to this efficiency level.

TSL 2 represents EL 2 for ECG 1 and ECG 4 motors; EL 1 for ECG 2 motors; and baseline for ECG 3 motors. At TSL 2, DOE estimates impacts on INPV to range from $388 million to -$283.5 million, or a change in INPV of 11.5 percent to -8.4 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 17.2 percent to $138 million, compared to the base case value of $166.7 million in the year leading up to the proposed energy conservation standards.

The INPV impacts at TSL 2 range from moderately positive to moderately negative. DOE estimates that in the year of compliance, 59 percent of all electric motor shipments (60 percent of ECG 1, eight percent of ECG 2, 100 percent of ECG 3, and 30 percent of ECG 4 shipments) would meet the efficiency levels at TSL 2 or higher in the base case. The majority of shipments are currently covered by an electric motors standard that requires general purpose Design A and B motors to meet this TSL. Therefore, only previously non-covered Design A and B motors and a few ECG 2 and ECG 4 motors would have to be converted at TSL 2 to meet this efficiency standard.

DOE expects conversion costs to increase significantly from TSL 1, however, these conversion costs do not represent a large portion of the base case INPV, since again the majority of electric motor shipments already meet the efficiency levels analyzed at this TSL. DOE estimates product conversion costs of $57.4 million due to the proposed expanded scope of this rulemaking, which includes motors previously not covered by the current electric motor energy conservation standards and the inclusion of ECG 2 and ECG 4 motors. DOE believes there will be sizable engineering costs as well as testing and certification costs at this TSL associated with this proposed scope expansion. DOE estimates the capital conversion costs to be approximately $26.4 million at TSL 2. While most manufacturers already produce at least some motors that are compliant at TSL 2, these manufacturers would likely have to invest in expensive machinery to bring all motor production to these efficiency levels.

TSL 3 represents EL 3 for ECG 1 and ECG 4 motors, EL 2 for ECG 2 motors and EL 1 for ECG 3 motors. At TSL 3, DOE estimates impacts on INPV to range from $1,072.5 million to -$1,014.4 million, or a change in INPV of 31.8 percent to -30.1 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 167.5 percent to -$112.5 million, compared to the base case value of $166.7 million in the year leading up to the proposed energy conservation standards.

The INPV impacts at TSL 3 range from significantly positive to significantly negative. DOE estimates that in the year of compliance, 23 percent of all electric motor shipments (24 percent of ECG 1, less than one percent of ECG 2, 19 percent of ECG 3, and four percent of ECG 4 shipments) would meet the efficiency levels at TSL 3 or higher in the base case. The majority of shipments would need to be converted to meet energy conservation standards at this TSL.

DOE expects conversion costs to increase significantly at TSL 3 and become a substantial investment for manufacturers. DOE estimates product conversion costs of $611.7 million at TSL 3, since most electric motors in the base case do not exceed the current motor standards set at NEMA Premium for Design A and B motors, which represent EL 2 for ECG 1. DOE believes there would be a massive reengineering effort that manufacturers would have to undergo to have all motors meet this TSL. Additionally, motor manufacturers would have to increase the efficiency levels for ECG 2, ECG 3, and ECG 4 motors. DOE estimates the capital conversion costs to be approximately $220.5 million at TSL 3. Most manufacturers would have to make significant investments to their production facilities in order to convert all their motors to be compliant at TSL 3.

TSL 4 represents EL 4 for ECG 1 and ECG 4 motors, EL 3 for ECG 3 motors and EL 2 for ECG 2 motors. At TSL 4, DOE estimates impacts on INPV to range from $1,870.1 million to -$1,988.1 million, or a change in INPV of 55.5 percent to -59.0 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 298.4 percent to -$330.8 million, compared to the base case value of $166.7 million in the year leading up to the proposed energy conservation standards.

The INPV impacts at TSL 4 range from significantly positive to significantly negative. DOE estimates that in the year of compliance only eight percent of all electric motor shipments (nine percent of ECG 1, less than one percent of ECG 2, zero percent of ECG 3, and less than one percent of ECG 4 shipments) would meet the efficiency levels at TSL 2 or higher in the base case. Almost all shipments would need to be converted to meet energy conservation standards at this TSL.

DOE expects conversion costs again to increase significantly from TSL 3 to TSL 4. Conversion costs at this TSL now represent a massive investment for electric motor manufacturers. DOE estimates product conversion costs of $620.6 million at TSL 4, which are the same conversion costs at TSL 3. DOE believes that manufacturers would need to completely reengineer almost all electric motors sold as well as test and certify those motors. DOE estimates capital conversion costs of $699.8 million at TSL 4. This is a significant increase in capital conversion costs from TSL 3 since manufacturers would need to adopt copper die-casting at this

TSL. This technology requires a significant level of investment because the majority of the machinery would need to be replaced or significantly modified.

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

13.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extracting, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE's FFC Statement of Policy. 76 FR 51282 (August 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors derived from runs of DOE's NEMS-BT model, described in Chapter 15. DOE used the version of NEMS based on the *Annual Energy Outlook 2013 (AEO 2013).*[1] Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2013* generally represents current Federal and State legislation and final implementation regulations in place as of the end of December 2012. Site emissions of CO_2 and NO_X are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[2]

Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA, GHG Emissions Factors Hub.[a] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[3] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The emissions intensity factors are expressed in terms of physical units per MWh or MMBtu of site energy savings. Total emissions reductions are estimated using the energy savings calculated in the national impact analysis (chapter 10).

13.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) but parts of it remained in effect. On July 6, 2011 EPA issued a replacement for CAIR,

[a] http://www.epa.gov/climateleadership/guidance/ghg-emissions.html

the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. The *AEO 2013* emissions factors used for this analysis assume that CAIR remains a binding regulation through 2040.

The attainment of emissions caps is typically flexible among affected EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2015, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21, 2011. 77 FR 9304 (February 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2013* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, NEMS shows a reduction in SO_2 emissions when electricity demand decreases (e.g., as a result of energy efficiency standards). Emissions will be far below the cap established by CAIR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2015 and beyond.

CAIR established a cap on NO_X emissions in 28 eastern States and the District of Columbia. Energy conservation standards are expected to have little effect on NO_X emissions in those States covered by CSAPR because excess NO_X emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_X emissions. However, standards would be expected to reduce NO_X emissions in the States not affected by CAIR, so DOE estimated NO_X emissions reductions from potential standards for those States.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. DOE estimated mercury emissions reductions using the NEMS-BT based on *AEO 2013*, which incorporates the MATS.

13.3 POWER SECTOR EMISSIONS FACTORS

The analysis of power sector emissions uses marginal emissions intensity factors derived from runs of DOE's NEMS-BT model, using the version updated to the *Annual Energy Outlook 2013* (*AEO 2013*) for emissions from power plants and the version updated to the *Annual Energy Outlook 2012* (*AEO 2012*) for the upstream emissions. To model the impact of a standard, DOE inputs a reduction to annual energy demand for the corresponding end use in the appropriate start year. The NEMS-BT model is run with the decremented energy demand to determine the modified build-out of capacity, fuel use and power sector emissions. A marginal emissions intensity factor is defined by dividing the reduction in the total emissions of a given pollutant by the reduction in total generation (in billion kWh). DOE uses the site energy savings multiplied by a transmission-and-distribution (T&D) loss factor to estimate the reduction in generation for each TSL. Details on the approach used may be found in Coughlin (2013).[3]

Table 13.3.1 presents power plant emissions factors for selected years. These power plant emissions factors are derived from the emissions factors of the plant types used to supply electricity to customers so they can operate motor driven systems. DOE did not have data on the load shape of electric motors, so it used the load shape corresponding to commercial lighting as a proxy to the load shape of electric motors. The rationale is that when motor driven systems in industry and commercial buildings – which represent together most of the projected shipments – are operating lights are likely to be on, and vice-versa. Therefore, electric motors and lighting in industry and commercial buildings follow similar daily operational timeframes. The factors presented in Table 13.3.1 for each year are weighted averages that take into account the projected shares of each of the sources used to generate electricity to support commercial lighting.

The power plant emissions factor for NO_X is an average for the entire U.S. The marginal calculation based on the NEMS-BT model accounts for the fact that NO_X emissions are capped in some States.

Table 13.3.1 Power Plant Emissions Factors

	Unit*	**2016****	**2020**	**2025**	**2030**	**2035**	**2040**
CO_2	kg/MWh	664	664	616	579	529	459
SO_2	g/MWh	664	664	802	854	632	843
NOx	g/MWh	391	391	362	288	216	214
Hg	g/MWh	0.0016	0.0016	0.0007	0.0011	0.0009	0.0010
N_2O	g/MWh	6.9	7.2	7.2	7.1	7.1	6.9
CH_4	g/MWh	48	50	50	50	49	48

* Refers to site electricity savings.
** The analysis uses January 1st, 2016 to represent the compliance date of December 19, 2015.

13.4 UPSTREAM FACTORS

The upstream emissions accounting uses the same approach as the upstream energy accounting described in appendix 10-B. See also Coughlin (2013).[3] When demand for a particular fuel is reduced, there is a corresponding reduction in the emissions from combustion of that fuel at either the building site or the power plant. The associated reduction in energy use for upstream activities leads to further reductions in emissions. These upstream emissions are defined to include the combustion emissions from the fuel used upstream, the fugitive emissions associated with the fuel used upstream, and the fugitive emissions associated with the fuel used on site.

Fugitive emissions of CO_2 occur during oil and gas production, but are small relative to combustion emissions. They comprise about 2.5 percent of total CO_2 emissions for natural gas and 1.7 percent for petroleum fuels. Fugitive emissions of CH_4 occur during oil, gas and coal production. Combustion emissions of CH_4 are very small, while fugitive emissions (particularly for gas production) may be relatively large. Hence, fugitive emissions make up over 99 percent of total CH_4 emissions for natural gas, about 95 percent for coal, and 93 percent for petroleum fuels.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. For ease of application in its analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table 13.4.1 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_X emissions do not apply to upstream combustion sources.

Table 13.4.1 Electricity Upstream Emissions Factors

	Unit*	2016**	2020	2025	2030	2035	2040
CO_2	kg/MWh	28.5	27.3	26.9	26.8	26.9	26.3
SO_2	g/MWh	4.9	5.3	5.3	5.2	5.2	5.1
NOx	g/MWh	361	340	334	333	336	329
Hg	g/MWh	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
N_2O	g/MWh	0.25	0.25	0.25	0.25	0.24	0.24
CH_4	g/MWh	2142	2025	2008	2025	2057	1999

* Refers to site electricity savings.
** The analysis uses January 1st, 2016 to represent the compliance date of December 19, 2015.

13.5 EMISSIONS IMPACT RESULTS

Table 13.5.1 presents the estimated, for each TSL, cumulative emissions reductions for the lifetime of equipment sold over the 30-year analysis period.

Table 13.5.1 Cumulative Emissions Reduction Estimated for Electric Motors Trial Standard Levels

	Trial Standard Level			
	1	2	3	4
Primary Emissions				
CO_2 (million metric tons)	62.4	374.1	576.0	733.3
NO_X (thousand tons)	105.3	669.7	1,034.7	1,315.5
SO_2 (thousand tons)	33.5	196.3	301.9	384.5
Hg (tons)	0.1	0.8	1.3	1.6
N_2O (thousand tons)	1.2	8.3	12.9	16.4
CH_4 (thousand tons)	7.3	46.3	71.6	91.0
Upstream Emissions				
CO_2 (million metric tons)	3.5	22.0	34.0	43.2
NO_X (thousand tons)	0.8	4.7	7.3	9.3
SO_2 (thousand tons)	48.6	303.1	467.8	595.0
Hg (tons)	0.0	0.0	0.0	0.0
N_2O (thousand tons)	0.0	0.2	0.3	0.4
CH_4 (thousand tons)	294.8	1,841.4	2,841.9	3,614.6
Total Emissions				
CO_2 (million metric tons)	65.9	396.1	610.0	776.5
NO_X (thousand tons)	106.0	674.4	1,042.0	1,324.8
SO_2 (thousand tons)	82.1	499.4	769.6	979.5
Hg (tons)	0.1	0.8	1.3	1.6
N_2O (thousand tons)	1.3	8.5	13.2	16.8
CH_4 (thousand tons)	302.2	1,887.7	2,913.5	3,705.5

Figure 13.5.1 through Figure 13.5.6 show total annual emissions reductions for each pollutant and TSL. The reductions reflect the lifetime impacts of equipment sold over the 30-year analysis period.

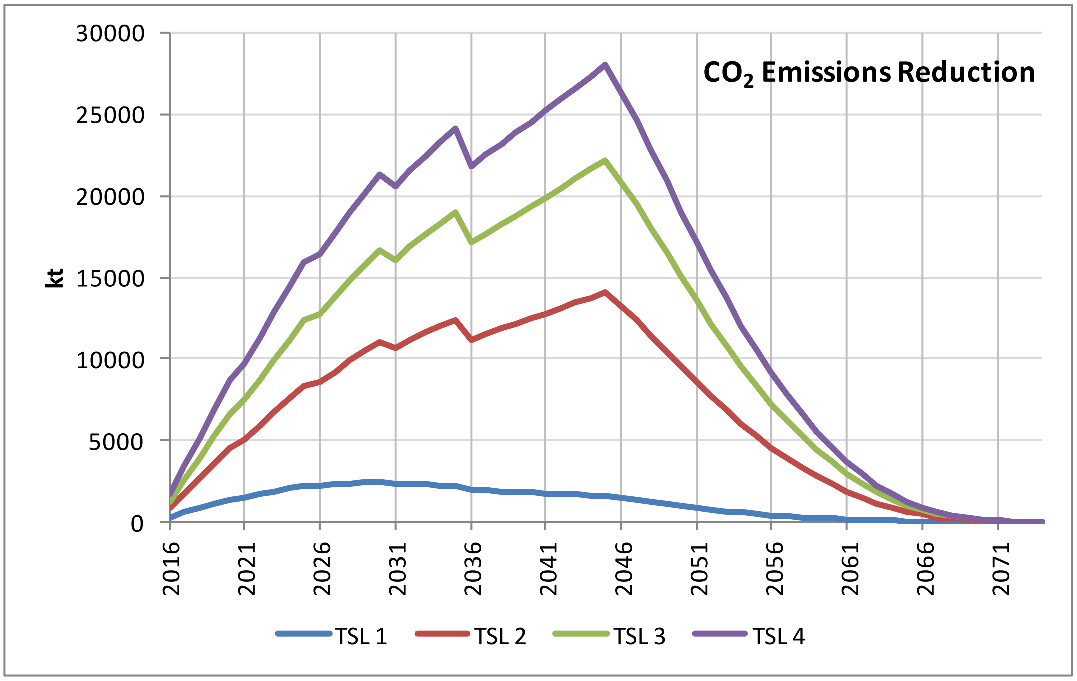

Figure 13.5.1 Electric Motors: CO_2 Total Emissions Reduction

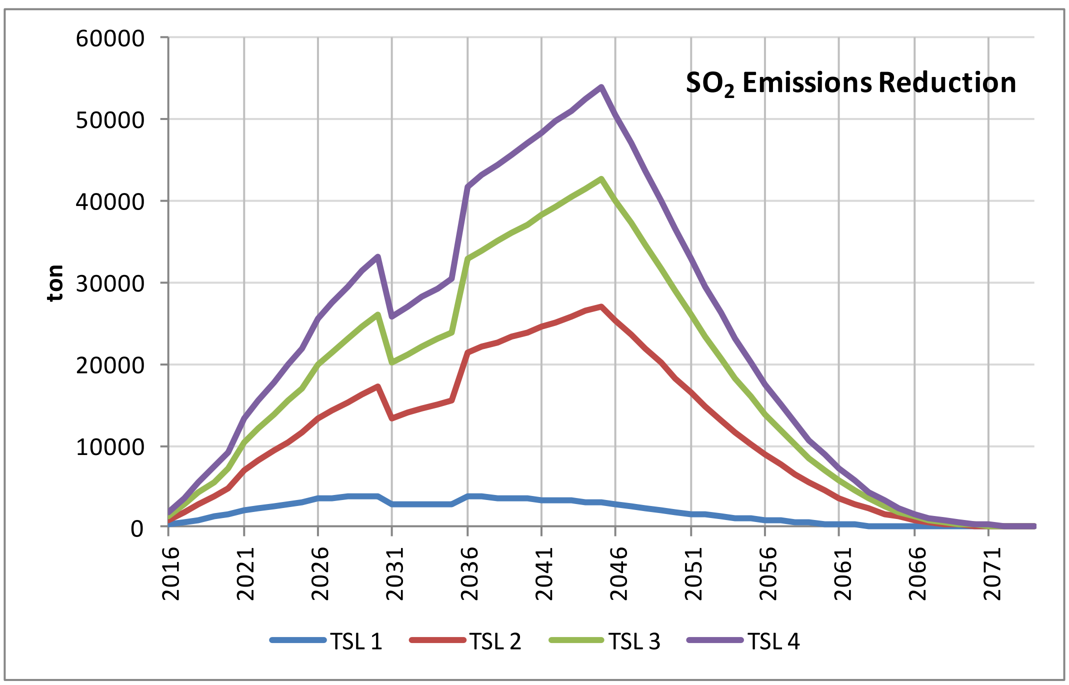

Figure 13.5.2 Electric Motors: SO_2 Total Emissions Reduction

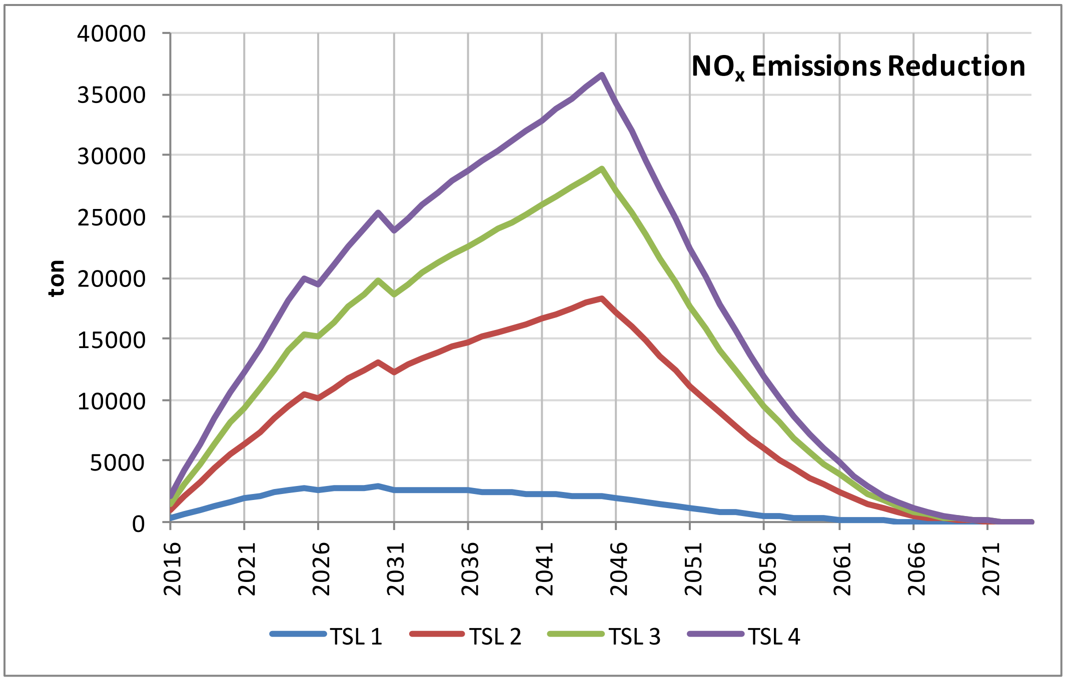

Figure 13.5.3 Electric Motors: NO_X Total Emissions Reduction

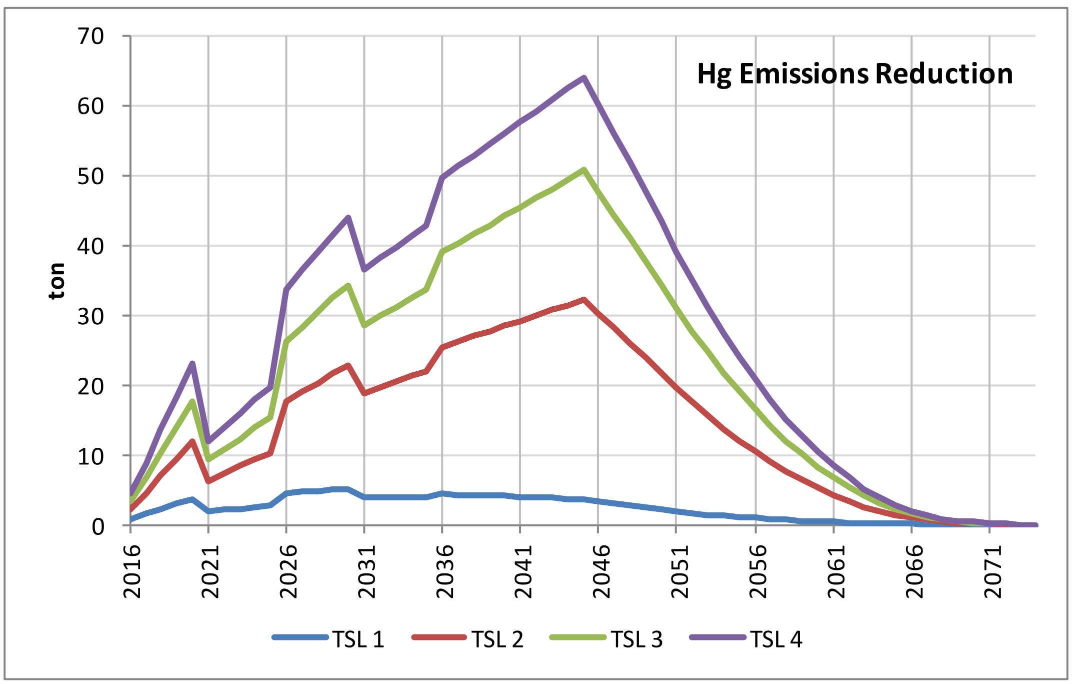

Figure 13.5.4 Electric Motors: Hg Total Emissions Reduction

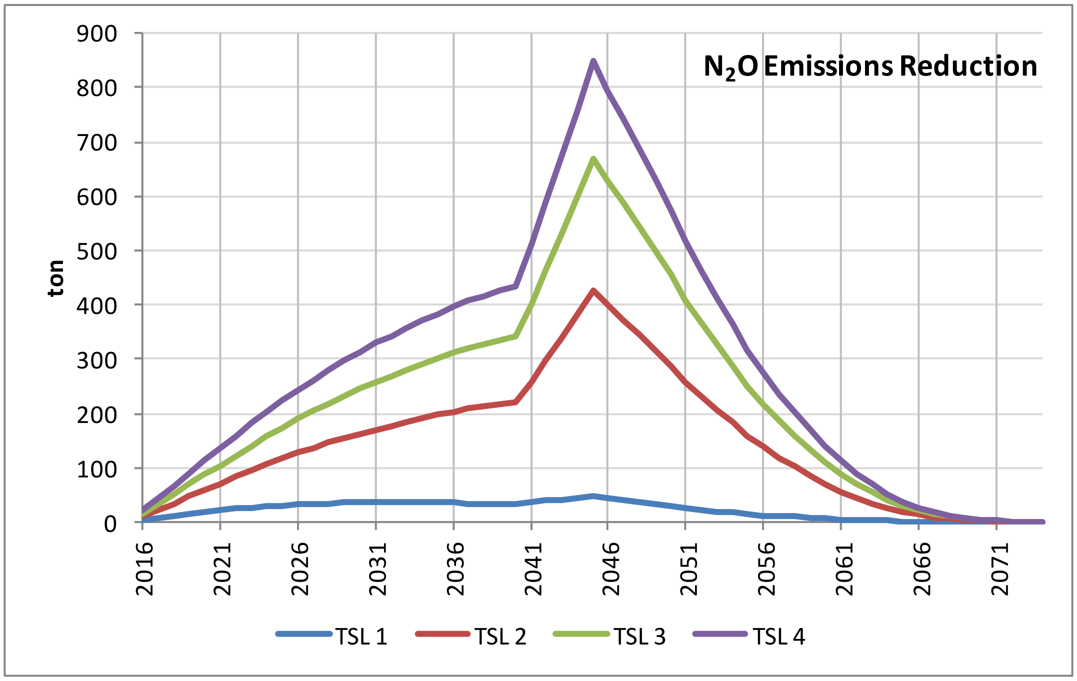

Figure 13.5.5 Electric Motors: N_2O Total Emissions Reduction

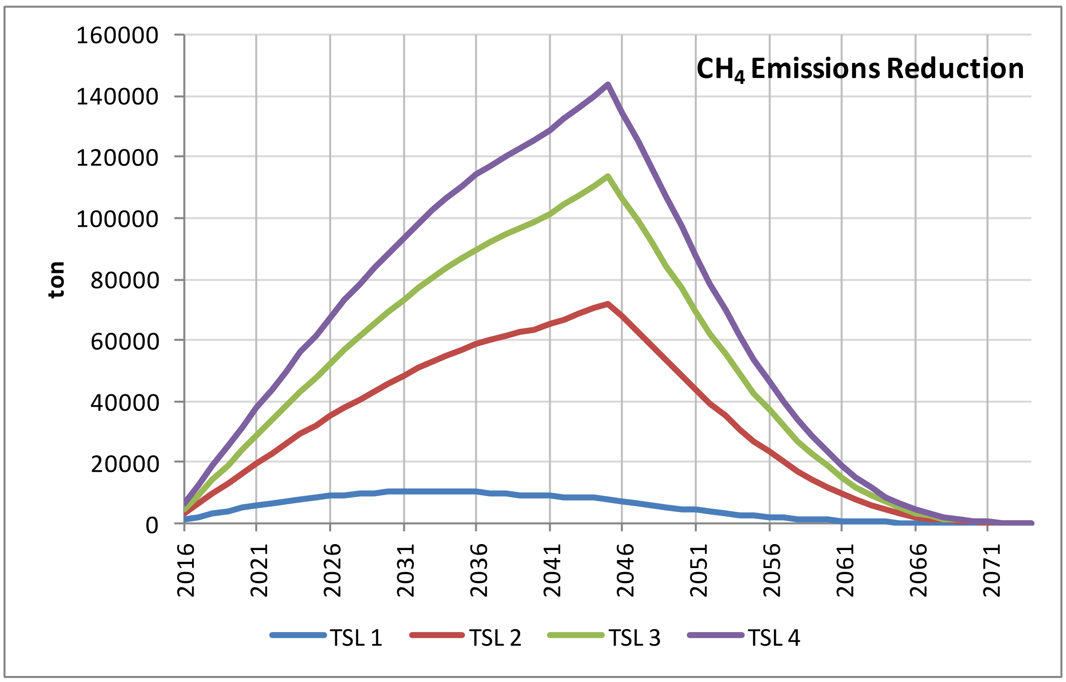

Figure 13.5.6 Electric Motors: CH_4 Total Emissions Reduction

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3. Coughlin, K., *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*, 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E.

CHAPTER 14. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

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CHAPTER 14. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

14.1 INTRODUCTION

As part of its assessment of energy conservation standards for electric motors DOE estimated the monetary benefits from the potential reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X) that are expected to result from each of the trial standard levels (TSL) considered. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the estimated benefits.

14.2 MONETIZING CARBON DIOXIDE EMISSIONS

14.2.1 Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of carbon dioxide. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

Under section 1(b) of Executive Order 12866, agencies must, to the extent permitted by law, "assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented in the Executive Order is to allow agencies to incorporate the monetized social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

14.2.2 Monetizing Carbon Dioxide Emissions

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Research Council[1] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions. For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2.[2] These interim values represented the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules.

14.2.3 Current Approach and Key Assumptions

After the release of the interim values, the interagency group reconvened on a regular basis to generate improved SCC estimates, which were considered for this proposed rule. Specifically, the group considered public comments and further explored the technical literature in relevant fields. The interagency group relied on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[a] These models are frequently cited in the peer-reviewed literature and were used in the last assessment of the

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[a] The models are described in appendix 14-A of the TSD.

Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed. The SCC values used for in this TSD were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature.[3]

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: (1) climate sensitivity; (2) socio-economic and emissions trajectories; and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although preference is given to consideration of the global benefits of reducing CO_2 emissions. Table 14.2.1 presents the values in the 2010 interagency group report,[b] which is reproduced in appendix 14-A of the TSD.

The SCC values used for this analysis were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature, as described in the 2013 update[3] from the interagency working group (revised November 2013).[c] Table 14.2.2 shows the updated sets of SCC estimates in five year increments from 2010 to 2050. The full set of annual SCC estimates between 2010 and 2050 is reported in appendix 14-B of the TSD. The central value that emerges is the average SCC across models at the 3 percent discount rate. However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance of including all four sets of SCC values.

[b] *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, February 2010. http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf.

[c] *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. Interagency Working Group on Social Cost of Carbon, United States Government*. May 2013; revised November 2013. http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

Table 14.2.1 Annual SCC Values from 2010 Interagency Report, 2010-2050 (in 2007 dollars per metric ton)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Table 14.2.2 Annual SCC Values from 2013 Interagency Update, 2010-2050 (in 2007 dollars per metric ton CO_2)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	11	32	51	89
2015	11	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned above points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC. The interagency group intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

In summary, in considering the potential global benefits resulting from reduced CO_2 emissions, DOE used the values from the 2013 interagency report, escalated to 2012$ using the GDP price deflator. For each of the four cases specified, the values used for emissions in 2015 are $11.8, $39.7, $61.2, and $117 per metric ton avoided.

DOE multiplied the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SCC values in each case.

14.3 VALUATION OF OTHER EMISSIONS REDUCTIONS

DOE considered the potential monetary benefit of reduced NO_X emissions from the TSLs it considered. As noted in chapter 13, new or amended energy conservation standards would reduce NO_X emissions in those States that are not affected by caps. DOE estimated the monetized value of NO_X emissions reductions resulting from each of the TSLs considered based on environmental damage estimates found in the relevant scientific literature. Available estimates suggest a very wide range of monetary values, ranging from $468 to $4,809 per ton (in 2012$).[4] In accordance with OMB guidance, DOE calculated a range of monetary benefits using each of the economic values for NO_X and real discount rates of 3 percent and 7 percent.[5]

DOE is still evaluating appropriate values to use to monetize avoided SO_2 and Hg emissions. It did not monetize these emissions for this analysis.

14.4 RESULTS

Table 14.4.1 presents the global values of CO_2 emissions reductions for each considered TSL. DOE calculated domestic values as a range from 7 percent to 23 percent of the global values, and these results are presented in Table 14.4.2.

Table 14.4.1 Estimates of Global Present Value of CO_2 Emissions Reduction under Electric Motors Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95th percentile*
	Million 2012$			
Primary Energy Emissions				
1	433	1,961	3,113	6,040
2	2,366	11,179	17,876	34,552
3	3,622	17,159	27,452	53,047
4	4,622	21,871	34,985	67,609
Upstream Emissions				
1	24	110	174	338
2	136	650	1,042	2,012
3	209	1,001	1,604	3,097
4	266	1,274	2,042	3,943
Total Emissions				
1	457	2,071	3,287	6,378
2	2,502	11,829	18,918	36,564
3	3,831	18,159	29,056	56,143
4	4,888	23,145	37,027	71,552

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is $11.8, $39.7, $61.2, and $117 per metric ton (2012$).

Table 14.4.2 Estimates of Domestic Present Value of CO_2 Emissions Reduction under Electric Motors Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95th percentile*
	Million 2012$			
Primary Energy Emissions				
1	30.3 to 99.5	137.3 to 451.1	217.9 to 715.9	422.8 to 1389.1
2	165.6 to 544.2	782.5 to 2571.1	1251.3 to 4111.5	2418.6 to 7946.9
3	253.5 to 833.1	1201.1 to 3946.5	1921.6 to 6313.9	3713.3 to 12200.7
4	323.5 to 1063.1	1531.0 to 5030.4	2449.0 to 8046.6	4732.6 to 15550.0
Upstream Emissions				
1	1.7 to 5.5	7.7 to 25.2	12.2 to 40.1	23.7 to 77.8
2	9.5 to 31.3	45.5 to 149.6	72.9 to 239.6	140.9 to 462.8
3	14.6 to 48.1	70.0 to 230.1	112.3 to 368.9	216.8 to 712.2
4	18.7 to 61.3	89.2 to 293.0	142.9 to 469.6	276.0 to 906.9
Total Emissions				
1	32.0 to 105.0	145.0 to 476.3	230.1 to 756.1	446.5 to 1466.9
2	175.2 to 575.5	828.0 to 2720.6	1324.3 to 4351.2	2559.5 to 8409.7
3	268.2 to 881.1	1271.1 to 4176.6	2033.9 to 6682.8	3930.0 to 12913.0
4	342.2 to 1124.3	1620.2 to 5323.4	2591.9 to 8516.3	5008.6 to 16456.9

* For each of the four cases, the corresponding SCC value for emissions in 2015 is $11.8, $39.7, $61.2, and $117 per metric ton (2012$).

Table 14.4.3 presents the present value of cumulative NO_X emissions reductions for each TSL, calculated using the average dollar-per-ton values at 7 percent and 3 percent discount rates.

Table 14.4.3 Estimates of Present Value of NO_X Emissions Reduction under Electric Motors Trial Standard Levels

TSL	3% discount rate	7% discount rate
	Million 2012$	
Power Sector Emissions		
1	49.5	26.4
2	257.1	120.2
3	392.2	181.6
4	501.3	233.2
Upstream Emissions		
1	68.0	33.8
2	378.4	164.8
3	579.9	250.3
4	739.7	320.6
Total Emissions		
1	117.5	60.2
2	635.4	285.0
3	972.2	432.0
4	1241.0	553.8

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL).

The utility impact analysis uses a variant of the DOE Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). DOE uses a variant of this model, referred to as NEMS-BT,[b] to account for selected utility impacts from energy conservation standards. DOE's analysis consists of a comparison between model results for the most recent AEO Reference Case and for cases in which energy use is decremented to reflect the impact of standards. For the analysis of standards for electric motors, DOE used the version of NEMS based on *AEO 2013*.[2]

NEMS-BT has a number of advantages that have led to its use in the analysis of energy conservation standards:

- NEMS-BT uses a set of assumptions that are well known and fairly transparent, due to the exposure and scrutiny each *AEO* receives.
- NEMS-BT is updated each year, with each edition of the AEO, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS-BT permits the modeling of interactions among the various energy supply and demand sectors.

15.2 METHODOLOGY

DOE uses NEMS-BT to estimate the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. In practice, the numerical differences between marginal and average values may turn out to be smaller than the intrinsic uncertainties in the AEO.

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[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview*.[1]

[b] DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on DOE/EIA assumptions, DOE refers to it by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed).

NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the AEO reference case, in general there are three inter-related effects: the annual generation (terawatt hours, TWh) from the stock of electric generating capacity changes, the total generation capacity itself (gigawatts, GW) may change, and the mix of capacity by fuel type may change. Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use.

To model the impact of a standard, DOE inputs a reduction to annual energy demand for the corresponding end use in the appropriate start year. The NEMS-BT model is run with the decremented energy demand to determine the modified build-out of capacity and total generation. Regional effects of a standard can be accounted for by defining the energy demand decrement as a function of census division.

The output of the NEMS-BT analysis includes the effective marginal heat rate (ratio of the change in energy consumption in quads to the change in generation in TWh), and the capacity reduction by plant type for a given reduction in total generation. DOE uses the site energy savings multiplied by a transmission-and-distribution (T&D) loss factor to estimate the reduction in generation for each TSL. The relationship between a reduction[c] in electricity generation (TWh) and the reduction in capacity (GW) is estimated based on the output of NEMS-BT model runs using the end-use specific energy demand decrement. Details on the approach used may be found in Coughlin (2013).[3]

NEMS-BT provides output for the following capacity types: coal, nuclear, combined cycle (natural gas), renewable sources, oil and natural gas steam, combustion turbine/diesel, pumped storage, fuel cells, and distributed generation (natural gas). DOE grouped oil and natural gas steam and combustion turbine/diesel into a “peaking” category, and grouped pumped storage, fuel cells, and distributed generation (natural gas) into an “other” category.

In general, energy conservation standards impact primarily fossil combustion (coal, natural gas and diesel) and renewables. Pumped storage and nuclear power are very insensitive to small changes in demand, while fuel cells and distributed generation make up a very small fraction (less than 1 percent) of the generation capacity base.

15.3 UTILITY IMPACT RESULTS

This section presents results of the analysis for all of the capacity types except “Other”, for which the impacts are very small.

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[c] These reductions are defined relative to the AEO Reference case.

15.3.1 Installed Capacity

The figures in this section show the changes in U.S. electricity installed capacity that result for each TSL by major plant type for selected years. The changes have been calculated based on factors (megawatts (MW) of capacity reduction per gigawatt hours (GWh) of generation reduction) estimated from a NEMS-BT model run that simulated a decrement in energy demand for a load shape that approximates electric motors. Note that a positive change means a reduction in capacity under a TSL.

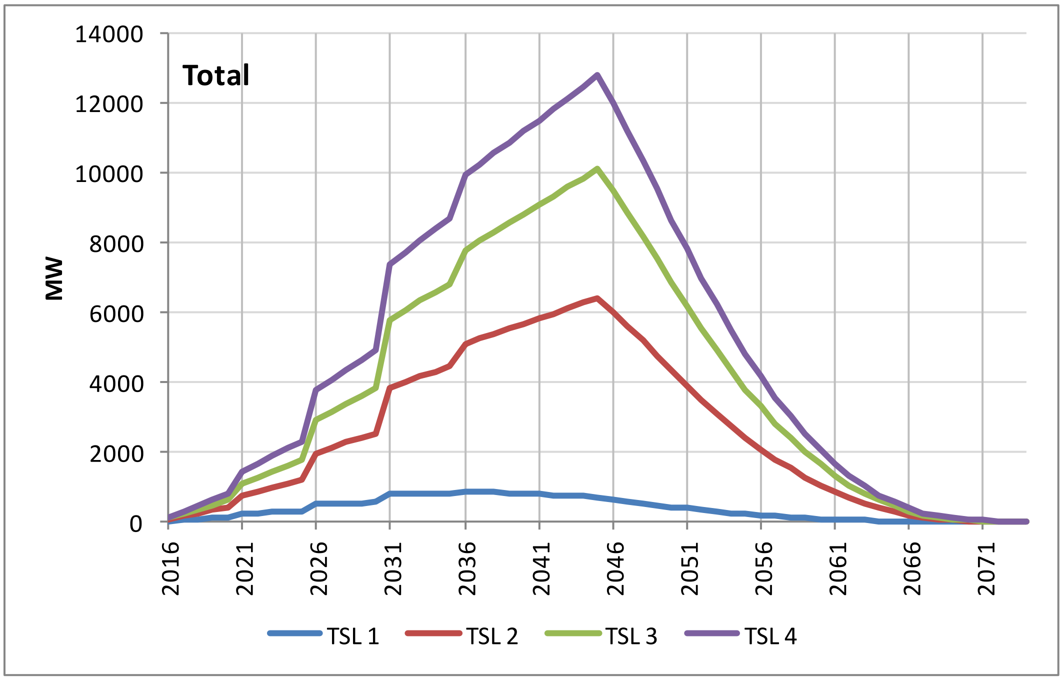

Figure 15.3.1 Electric Motors: Total Electric Capacity Reduction

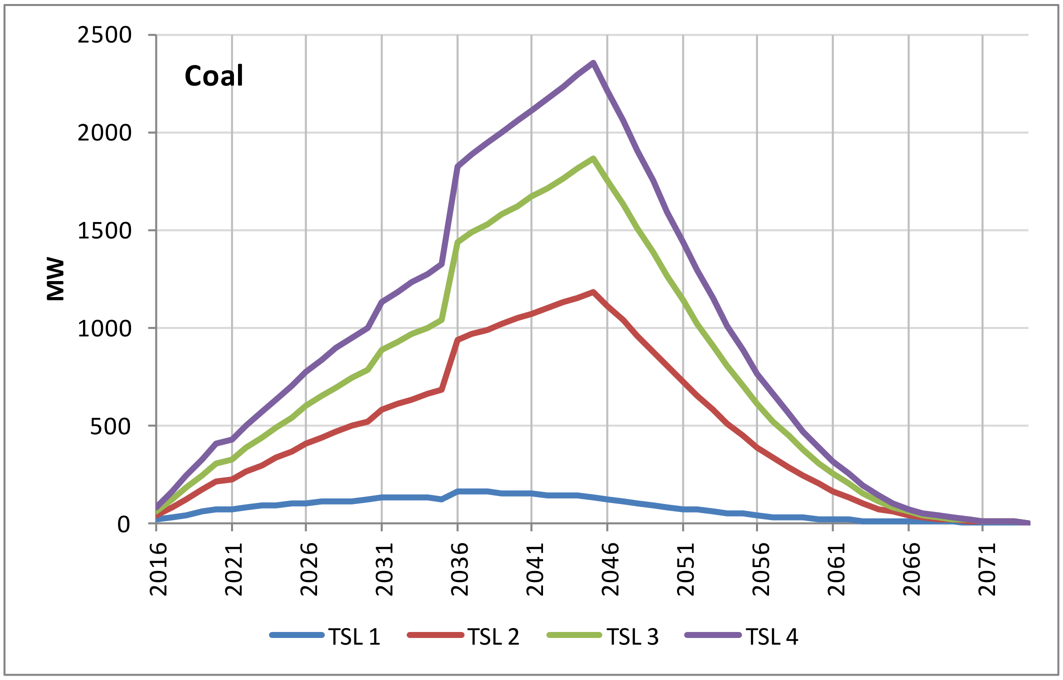

Figure 15.3.2 Electric Motors: Coal Capacity Reduction

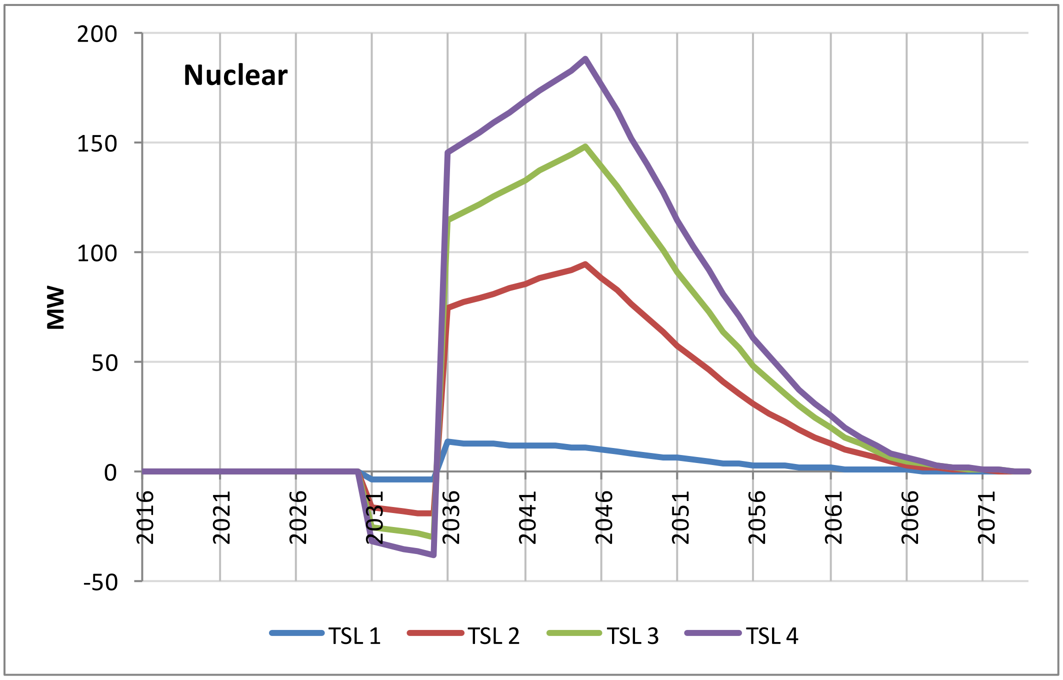

Figure 15.3.3 Electric Motors: Nuclear Capacity Reduction

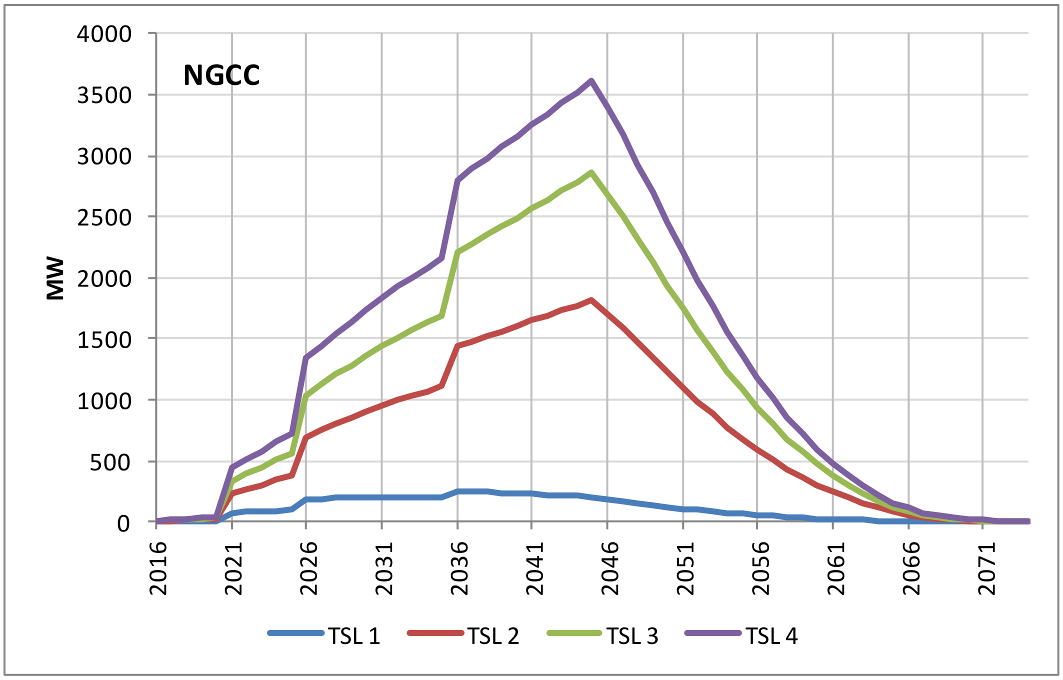

Figure 15.3.4 Electric Motors: Gas Combined Cycle Capacity Reduction

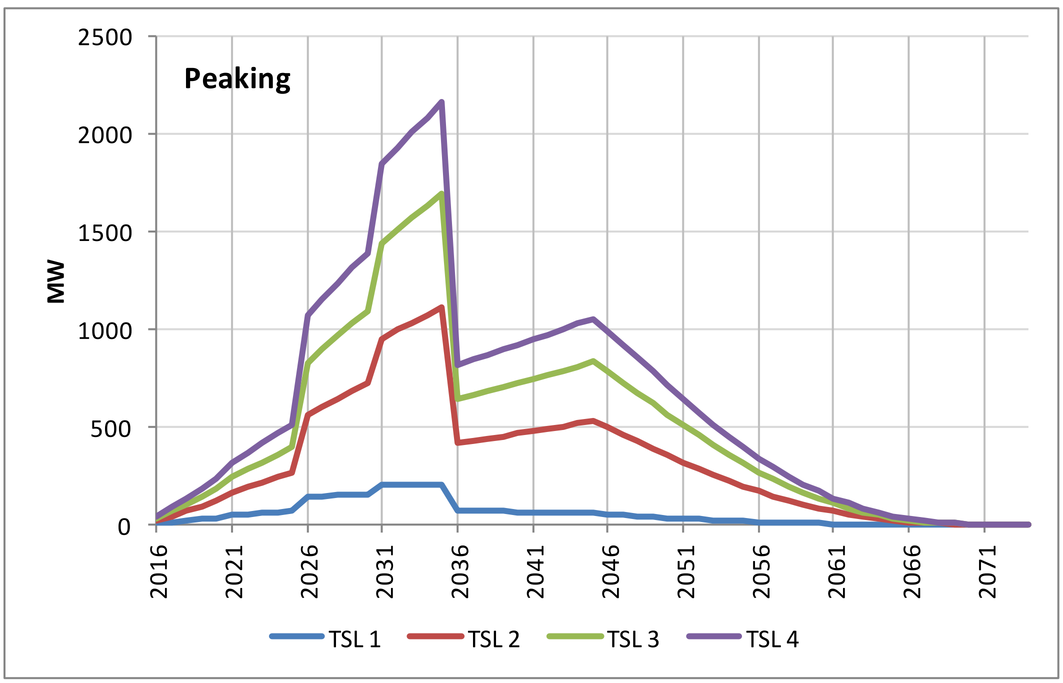

Figure 15.3.5 Electric Motors: Peaking Capacity Reduction

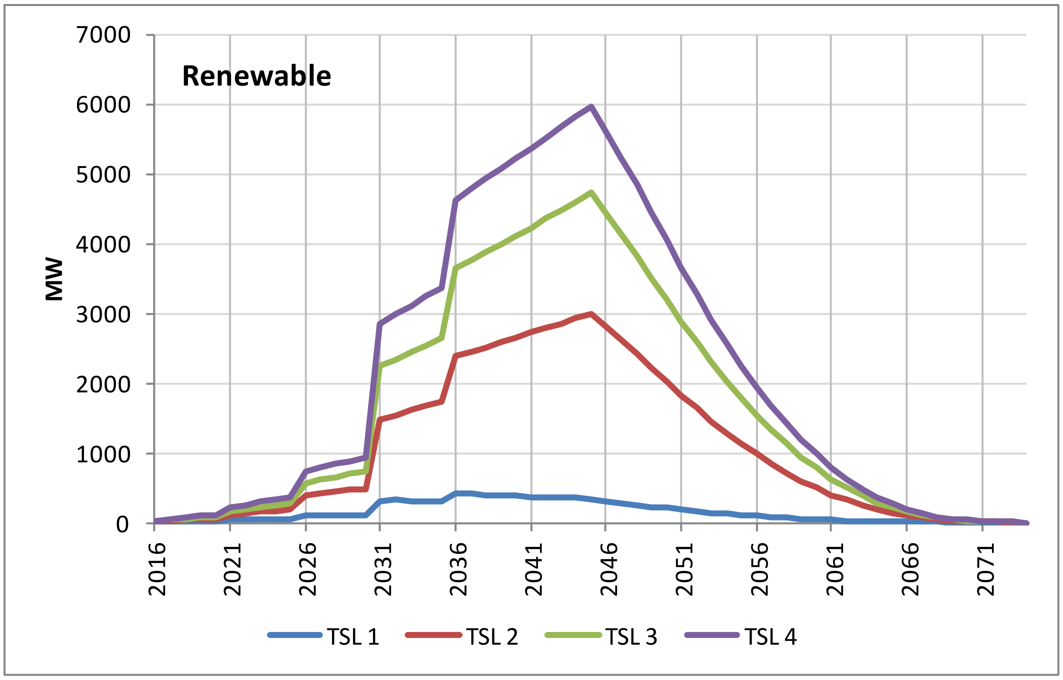

Figure 15.3.6 Electric Motors: Renewables Capacity Reduction

15.3.2 Electricity Generation

The figures in this section show the annual change in electricity generation that result for each TSL by plant type. The change by capacity type has been calculated based on shares (percentage of generation reduction for each capacity type over total generation reduction) estimated from a NEMS-BT model run that simulated a decrement in energy demand for a load shape that approximates electric motors. Note that a positive change means a reduction in generation under a TSL. Coal-fired power plants account for most of the generation reduction.

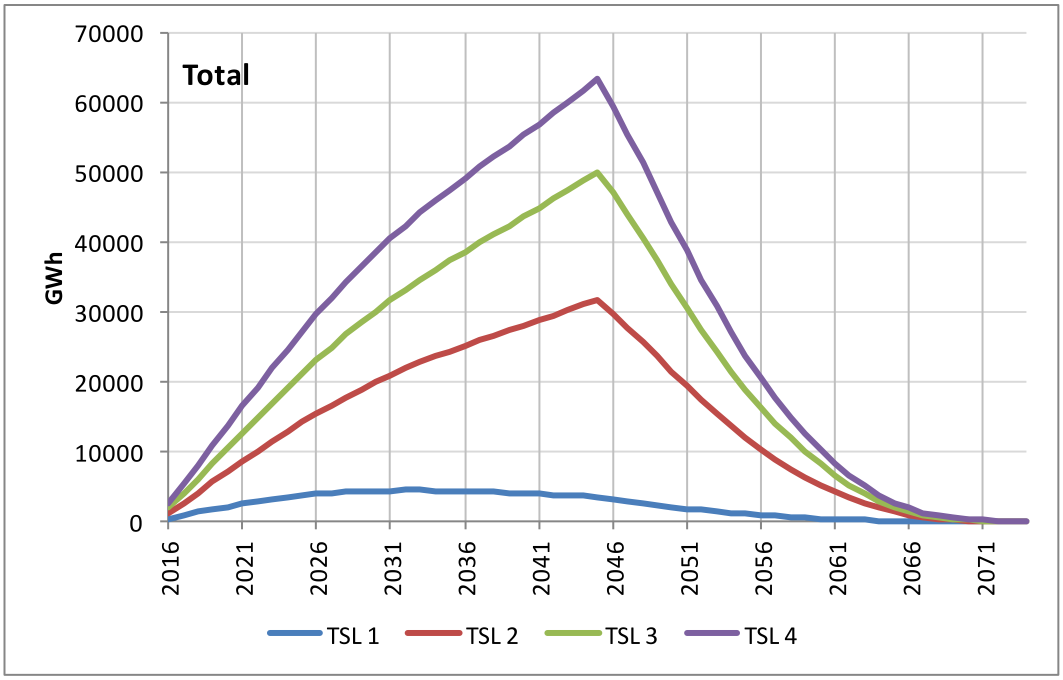

Figure 15.3.7 Electric Motors: Total Generation Reduction

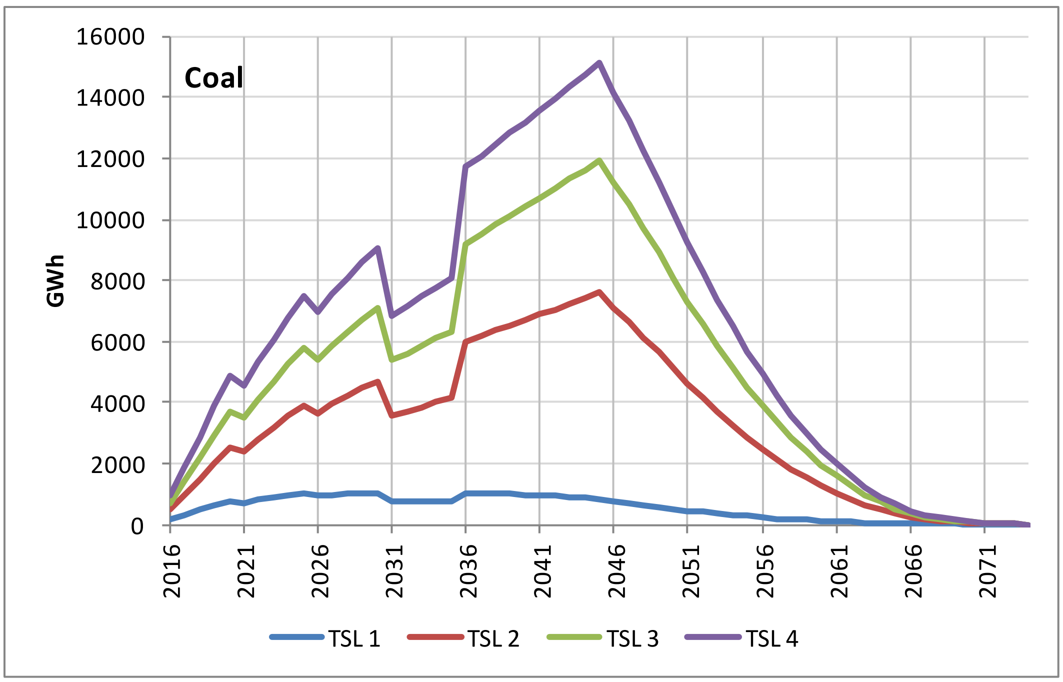

Figure 15.3.8 Electric Motors: Coal Generation Reduction

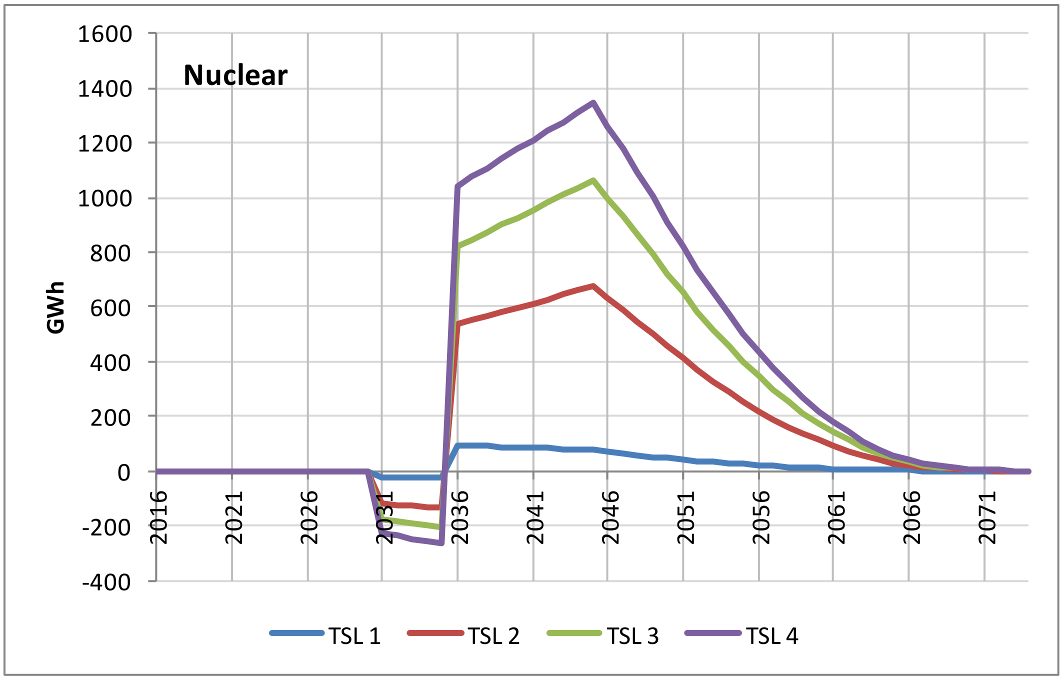

Figure 15.3.9 Electric Motors: Nuclear Generation Reduction

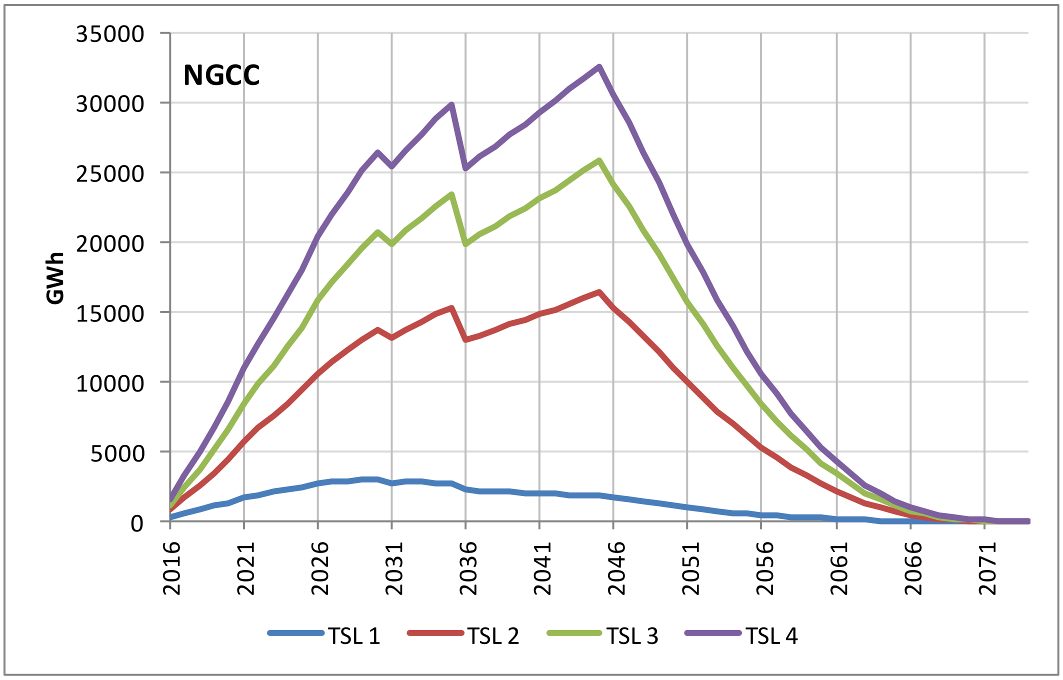

Figure 15.3.10 Electric Motors: Gas Combined Cycle Generation Reduction

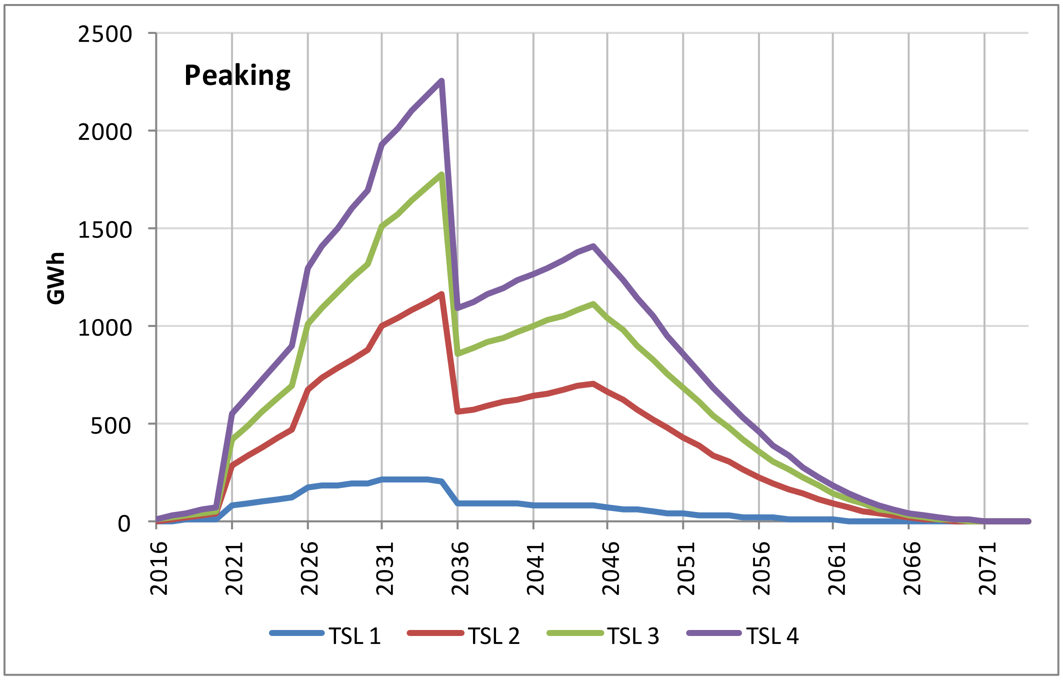

Figure 15.3.11 Electric Motors: Peaking Generation Reduction

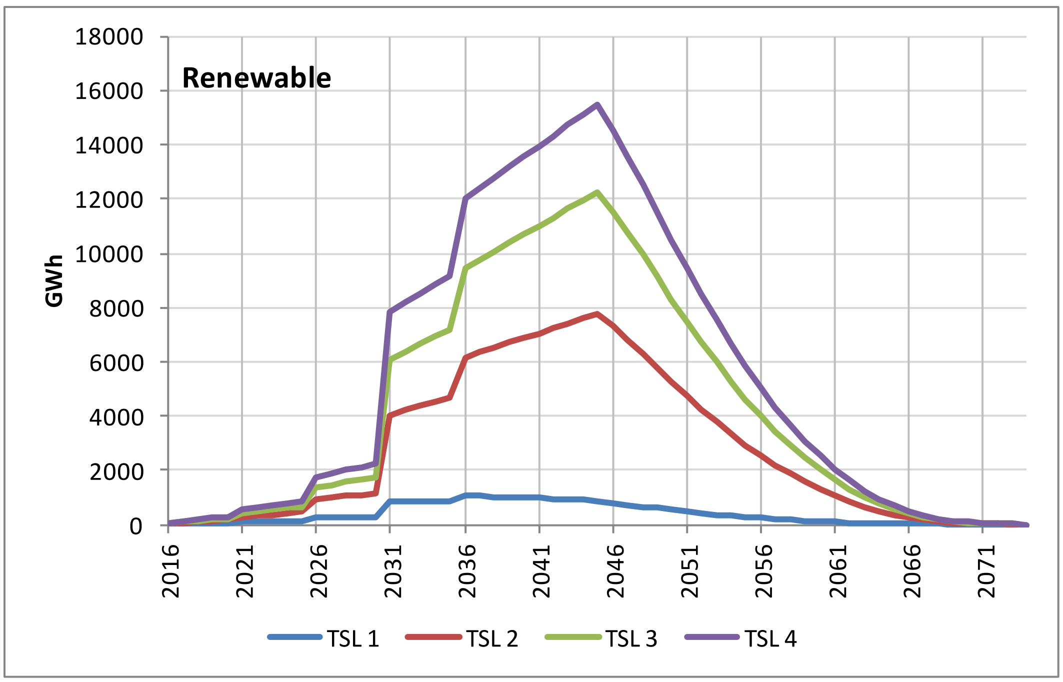

Figure 15.3.12 Electric Motors: Renewables Generation Reduction

15.3.3 Results Summary

Table 15.3.1 presents a summary of the utility impact results estimated for electric motors.

Table 15.3.1 Electric Motors: Summary of Utility Impact Results

	TSL			
	1	**2**	**3**	**4**
Installed Capacity Reduction (MW)				
2020	129	422	620	810
2025	321	1,212	1,799	2,320
2030	564	2,546	3,835	4,908
2035	810	4,469	6,830	8,697
2040	817	5,685	8,823	11,189
Electricity Generation Reduction (GWh)				
2020	2,203	7,192	10,563	13,809
2025	3,763	14,221	21,108	27,219
2030	4,438	20,047	30,193	38,646
2035	4,438	24,480	37,413	47,643
2040	4,050	28,181	43,739	55,468

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

16.1 INTRODUCTION

The U.S. Department of Energy's (DOE's) employment impact analysis is designed to estimate indirect national job creation or elimination resulting from possible standards, due to reallocation of the associated expenditures for purchasing and operating motors. Job increases or decreases reported in this chapter are separate from the direct manufacturing sector employment impacts reported in chapter 12, and reflect the employment impact of efficiency standards on all other sectors of the economy.

16.2 ASSUMPTIONS

DOE expects energy conservation standards to decrease energy consumption, and therefore to reduce energy expenditures. The savings in energy expenditures may be spent on other goods and services, or not at all (*i.e.*, they may remain "saved"). The standards may increase the purchase price of equipment and increase installation costs.

Using an input/output econometric model of the U.S. economy, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. DOE intends this analysis to quantify the indirect employment impacts of these expenditure changes. It evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see chapter 12).

16.3 METHODOLOGY

The Department based its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. The Pacific Northwest National Laboratory developed the model, ImSET 3.1.1[2] (Impact of Sector Energy Technologies) as a successor to ImBuild[3], a special-purpose version of the IMPLAN[4] national input/output model. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier approaches, ImSET allows for more a complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationship of different sectors of the economy and the spending flows among them. Different sectors have different levels of labor intensity, and changes in the level of spending (e.g., due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which will affect the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial buildings technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (e.g., changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input-output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy-efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient appliances. The increased cost of appliances leads to higher employment in the appliance manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, electric utility sector investment funds are released for use in other sectors of the economy. When consumers use less energy, electric utilities experience relative reductions in demand which leads to reductions in utility sector investment and employment.

DOE notes that ImSET is not a general equilibrium forecasting model, and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis.[1] Because ImSET does not incorporate price changes, the employment effects predicted by ImSET would over-estimate the magnitude of actual job impacts over the long run for this rule. As input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analyses. DOE therefore includes a qualitative discussion of how labor markets are likely to respond in the longer term. In future rulemakings, DOE may consider the use of other modeling approaches for examining long-run employment impacts.

DOE also notes that the employment impacts estimated with ImSET for the entire economy differ from the employment impacts in the motor manufacturing sector estimated in chapter 12 using the Government Regulatory Impact Model (GRIM). The methodologies used and the sectors analyzed in the ImSET and GRIM models are different.

16.4 SHORT-TERM RESULTS

The results in this section refer to impacts of motor standards relative to the base case. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy costs, and changes in operations and maintenance costs. DOE presents the summary impact.

Conceptually, one can consider the impact of the rule in its first year on three aggregate sectors: the motor production sector, the energy generation sector, and the general consumer good sector (as mentioned previously, ImSET's calculations are made at a much more disaggregate level). By raising energy efficiency, the rule increases the purchase price of motors; this increase in expenditures causes an increase in employment in this sector. At the same time, the improvements in energy efficiency reduce consumer expenditures on electricity. The reduction in electricity demand causes a reduction in employment in that sector. Finally, based on the net impact of increased expenditures on motors and reduced expenditures on electricity, consumer expenditures on everything else are either positively or negatively affected, increasing or reducing jobs in that sector accordingly. The model also captures any indirect jobs created or lost by changes in consumption due to changes in employment. (As more workers are hired, they consume more goods, in turn generating more employment; the converse is true for workers who are laid off.)

Table 16.4.1 presents the modeled net employment impact from the rule in 2016. It is assumed that 65% of motors are produced domestically and 35% are imported. The net employment impact estimate is sensitive to assumptions regarding the return to the U.S. economy of money spent on imported motors. The two scenarios bounding the ranges presented in Table 16.4.1 represent situations in which: 1) none of the money spent on imported motors returns to the U.S. economy and, 2) all of the money spent on imported motors returns to the U.S. economy (low and high bounds, respectively). The U.S. trade deficit in recent years suggests that between 50% and 75% of the money spent on imported motors is likely to return, with employment impacts falling within the ranges presented below.

Table 16.4.1 Net National Short-Term Change in Employment (Number of Jobs)

Trial Standard Level	2016*	2021
1	60 – 230	1,140 – 1,300
2	-380 – 660	2,780 – 4,350
3	-2,390 – 970	270 – 6,400
4	-11,600 – 1,320	-6,810 – 8,350

*December 19, 2015 was modeled using January 1st, 2016

For context, the unemployment rate was estimated to be 8.2% in June 2012; the Office of Management and Budget (OMB) currently projects that the official unemployment rate may decline to 7.3% in 2014 and drop further to 5.4% in 2018.[5] The unemployment rate in 2016 is projected to be close to "full employment." When an economy is at full employment, any effects on net employment are likely to be transitory as workers change jobs, rather than enter or exit longer-term employment.

16.5 LONG-TERM IMPACTS

Due to the short payback period of energy efficiency improvements mandated by this rule, over the long term DOE expects the energy savings to consumers to increasingly dominate the increase in appliance costs, resulting in increased aggregate savings to consumers. As a result, DOE expects demand for electricity to decline over time and demand for other goods to increase. As the electricity generation sector is relatively capital intensive compared to the consumer goods sector, the net effect will be an increase in labor demand. In equilibrium, this should lead to upward pressure on wages and a shift in employment away from electricity generation towards consumer goods. Note that in long-run equilibrium there is no net effect on total employment because wages adjust to bring the labor market into equilibrium. Nonetheless, even to the extent that markets are slow to adjust, DOE anticipates that net labor market impacts will be negligible over time due to the small magnitude of the short-term effects presented in Table 16.4.1. The ImSET model projections, assuming no price or wage effects until 2021, are included in the second column of Table 16.4.1.

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

The U.S. Department of Energy (DOE) has determined that energy conservation standards for electric motors constitute an "economically significant regulatory action" under Executive Order (E.O.) 12866, Regulatory Planning and Review. 58 FR 51735, Volume 58, No. 190, page 51735. (October 4, 1993). Under 10 CFR part 430, subpart C, appendix A, section III.12, DOE committed to evaluating non-regulatory alternatives to proposed standards by performing a regulatory impact analysis (RIA) of non-regulatory energy efficiency policy measures. 61 FR 36981, Volume 61, No. 136, page 36978. (November 15, 1996). This RIA, which DOE has prepared pursuant to E.O. 12866, evaluates potential non-regulatory alternatives, comparing the costs and benefits of each to those of the proposed standards. 58 FR 51735, page 51741. As noted in E.O. 12866, this RIA is subject to review by the Office of Management and Budget's Office of Information and Regulatory Affairs. 58 FR 51735, page 51740.

For this RIA, DOE used an integrated National Impact Analysis (NIA)-RIA model built on the NIA model discussed in Chapter 10. DOE studied the impacts of the non-regulatory policies on the medium electric motors equipment class group with the predominant market share, which is the NEMA Design A and B motors class group. Similar to the NIA model, the RIA model splits the calculations for the Nation into three sectors and six horsepower ranges. While the national energy savings and net present value impacts reported in section 17.4 show results for all sectors and horsepower ranges together, the inputs used to generate the changes in market share for each of the non-regulatory policies analyzed are reported separately for each sector and horsepower range in Section 17.3.

DOE identified six non-regulatory policy alternatives that possibly could provide incentives for the same energy efficiency levels as the standards proposed for electric motors. The non-regulatory policy alternatives are: Consumer Rebates, Consumer Tax Credits, Manufacturer Tax Credits, Voluntary Energy Efficiency Targets, Early Replacement and Bulk Government Purchases. Because in the base case efficiency distribution DOE accounted for the dynamic increase in market penetration of NEMA Premium motors that is likely to result from NEMA's NEMA Premium labeling program, DOE did not analyze impacts from Voluntary Energy Efficiency Targets for this RIA. For each of the five other alternatives, DOE evaluated its ability to achieve significant energy savings at a reasonable cost and compared the effectiveness of each to the effectiveness of standards set at the same efficiency level as NEMA Premium.

Sections 17.2 and 17.3 discuss the analysis of the five selected policies Section 17.4 presents the results of the policy alternatives.

17.2 NON-REGULATORY POLICIES

This section describes the method DOE used to analyze the energy savings and cost effectiveness of the five non-regulatory policy alternatives for NEMA Design A and B motors. This section also describes the assumptions underlying the analysis.

17.2.1 Methodology

DOE used its integrated NIA-RIA spreadsheet model to calculate the national energy savings (NES) and net present value (NPV) associated with each non-regulatory policy alternative. Appendix 10-A describes the NIA spreadsheet model. Appendix 17-A, section 17-A.3, discusses the NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of motors that meet the NEMA Premium efficiency level. After establishing the quantitative assumptions underlying each alternative, DOE appropriately revised inputs to the NIA-RIA spreadsheet model. The primary model inputs revised were market shares of motors meeting the NEMA Premium efficiency level. The shipments of motors for any given year reflect a distribution of efficiency levels. DOE assumed that the proposed standards would affect 100 percent of the shipments of motors that did not meet the NEMA Premium efficiency level in the base case,[a] whereas the non-regulatory policies would affect a smaller percentage of those shipments. DOE made certain assumptions about the percentage of shipments affected by each alternative policy. DOE used those percentages to calculate the shipment-weighted average energy consumption and costs of electric motors attributable to each policy alternative.

Increasing the efficiency of an electric motor often increases its purchase and lifetime repair costs. However, operating costs generally decrease because energy consumption declines. DOE calculated an NPV for each non-regulatory alternative in the same way it did for the proposed standards. In some scenarios, increases in purchase cost are mitigated by government rebates or tax credits. Because DOE assumed that consumers would re-pay credits and rebates in some way (such as additional taxes), DOE did not include the value of rebates or tax credits as a consumer benefit when calculating national NPV. DOE's analysis also excluded any administrative costs for the non-regulatory policies; including such costs would decrease the NPV slightly.

The following are key measures for evaluating the impact of each alternative.

- National Energy Savings, given in quadrillion Btus (quads), describes the cumulative national primary energy savings for motors purchased during the 30-year analysis period starting in 2016.[b]

[a] The base case for the NIA is a market-weighted average of units at several efficiency levels.
[b] The analysis uses January 1st, 2016 to represent the compliance date of December 19, 2015. Therefore, the 30-year analysis period 2015-2044 is referred to as 2016-2045 in this chapter.

- Net Present Value, represents the value in 2012$ (discounted to 2013) of net monetary savings from motors purchased during the 30-year analysis period starting in 2016.[b] DOE calculated the NPV as the difference between the present value of purchase and repair costs against energy expenditures in the base case and the present value of those costs in each alternative policy case. DOE calculated repair and energy expenses for the life of the motor considering the horsepower rate of the motor, as well as the sector where, and the application for which it is used.

17.2.2 Assumptions Regarding Non-Regulatory Policies

The effects of non-regulatory policies are by nature uncertain because they depend on program implementation, marketing efforts, and on consumers' responses to a program. Because the projected effects depend on assumptions regarding the rate of consumer participation, they are subject to more uncertainty than are the impacts of mandatory standards, which DOE assumes will meet with full compliance. To increase the robustness of the analysis, DOE conducted a literature review regarding each non-regulatory policy and consulted with recognized experts to gather information on similar incentive programs that have been implemented in the United States. By studying experiences with the various types of programs, DOE sought to make credible assumptions regarding potential market impacts. Section 17.3 presents the sources DOE relied on in developing assumptions about each alternative policy and reports DOE's conclusions as they affected the assumptions that underlie the modeling of each alternative policy.

Each non-regulatory policy that DOE considered would improve the average efficiency of motors purchased for new applications and for replacing motors in stock, relative to their base case efficiency scenario (which involves no new regulatory action). The analysis considered that each alternative policy would induce consumers to purchase units at NEMA Premium efficiency level. As opposed to the standards case, however, the alternative policy cases may not lead to 100 percent market penetration of units that would meet that efficiency level. DOE assumed that the effects of non-regulatory policies would last for the 30-year analysis period.

17.2.3 Policy Interactions

DOE calculated the effects of each non-regulatory policy separately from those of the other policies. In practice, some policies are most effective when implemented in combination, such as early replacement implemented with consumer rebates, or early replacement implemented with bulk government purchases. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are not additive; the combined effect of several or all policies cannot be inferred from summing their results. Section 17.4 presents graphs that show the market penetration estimated under each non-regulatory policy for NEMA Design A and B motors.

17.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the five non-regulatory policy alternatives to proposed standards for electric motors. DOE developed estimates of the market penetration of NEMA Premium motors both with and without each of the non-regulatory policy alternatives.

17.3.1 Consumer Rebates

DOE considered the scenario in which the Federal government would provide financial incentives in the form of rebates to consumers for purchasing more efficient motors. This policy provides a consumer rebate for purchasing motors rated at (or above) NEMA Premium efficiency.

17.3.1.1 Methodology

To inform its estimate of the market impacts of consumer rebates, DOE performed a thorough nationwide search for existing rebate programs for electric motors. It gathered data on utility or agency rebates throughout the nation for electric motors.

DOE based its evaluation methodology for consumer rebates on a comprehensive study of California's potential for achieving energy efficiency. This study, performed by XENERGY, Inc.,[c] summarized experiences with various utility rebate programs.[1] XENERGY's analytical method utilized graphs, or penetration curves, that estimate the market penetration of a technology based on its benefit/cost (B/C) ratio. DOE consulted with experts and reviewed other methods of estimating the effect of consumer rebate programs on the market penetration of efficient technologies. The other methods, developed after the referenced XENERGY report was published,[2, 3, 4, 5, 6, 7] used different approaches: other economic parameters (e.g., payback period), expert surveys, or model calibration based on specific utility program data rather than multi-utility data. Some models in use by energy efficiency program evaluation experts were so client-specific that generic relationships between economic parameters and consumer response could not be established.[5] DOE decided that the most appropriate available method for this RIA analysis was the XENERGY approach of penetration curves based on B/C ratio, which incorporates lifetime operating cost savings.

XENERGY's model estimates market impacts induced by financial incentives based on the premise that two types of information diffusion drive the adoption of new technologies. *Internal sources* of information encourage consumers to purchase new products primarily through word-of-mouth from early adopters. *External sources* affect consumer purchase decisions through marketing efforts and information from outside the consumer group. Appendix 17-A, section 17-A.4.1, contains additional details on internal and external information diffusion.

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[c] XENERGY is now owned by KEMA, Inc. (www.kema.com)

XENERGY’s model equation accounts for the influences of both internal and external sources of information by superimposing the two components. Combining the two mechanisms for information diffusion, XENERGY’s model generates a set of penetration (or implementation) curves for a measure. XENERGY then calibrated the curves based on participation data from utility rebate programs. The curves illustrate the increased penetration (i.e., increased market share) of efficient products driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived barriers (from no barriers to extremely high barriers) to consumer purchase of high-efficiency products.

DOE adjusted the XENERGY penetration curves based on expert advice founded on more recent utility program experience.[5,8] In addition, DOE used an interpolation method to create penetration curves based on relationships between the actual base case market penetrations and actual B/C ratios. The interpolation method DOE used is described in Blum *et al* (2011, Appendix A).[28]

DOE modeled the effects of a consumer rebate policy for electric motors by determining the increase in market penetration of motors meeting the NEMA Premium efficiency level relative to their market penetration in the base case. It did this using interpolated penetration curves[28] built to best reflect the market barrier level faced by NEMA Design A and B motors with different combinations of enclosure, number of poles and horsepower rate, to be used in industry, commercial buildings and agriculture. Section 17.3.2.2 shows the interpolated curves used in the analysis.

17.3.1.2 Analysis

DOE estimated the effect of increasing the B/C ratio of NEMA Design A and B motors via a rebate that would reduce the increased non-energy costs of a unit that meets the NEMA Premium efficiency level compared to one meeting the baseline efficiency level.[d] DOE based the rebate amounts on a sample of utility and agency rebate programs for electric motors. DOE gathered data on 37 rebate programs for electric motors available from 27 utilities or agencies in various States. (Appendix 17-A, section 17-A.5, identifies the rebate programs.) These rebates are offered for motors rated at or above the NEMA Premium efficiency level. Based on the rebate amounts offered by the surveyed programs, DOE calculated rebate values for each horsepower range as an amount of dollars per horsepower. To represent these rebate values, DOE first calculated, for each horsepower range, the shipment weighted average of the rebate amount per horsepower for each of the existing programs, and then used the simple average over all existing programs to estimate a rebate amount per horsepower for each horsepower range.

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[d] The baseline technology for each Design A and B equipment class is defined in the engineering analysis, Chapter 5, as the technology that represents the basic characteristics of products in that class. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

DOE assumed that rebates would remain in effect at the same levels throughout the 30-year analysis period.

For each combination of motors enclosure, number of poles and horsepower rate, used in each sector, DOE first calculated the B/C ratio without a rebate using the difference in total lifetime incremental non-energy costs and lifetime energy cost savings between a NEMA Premium motor and a motor meeting the efficiency level corresponding to a baseline unit. It then calculated the B/C ratio given a rebate for the NEMA Premium motor. Because the rebate reduced the incremental non-energy costs, the unit receiving the rebate had a larger B/C ratio. Table 17.3.1 shows the shipment weighted average effects of consumer rebates on the B/C ratio of NEMA Premium motors for the six horsepower ranges operating in the three covered sectors. The table also presents the level of market barriers to NEMA Premium motors. The levels of market barrier for each horsepower range and sector reported in Table 17.3.1 drive the market penetration curves for these motor categories presented in Figure 17.3.1 to Figure 17.3.3. Most of the market for NEMA Design A and B Premium motors has low market barrier level.

DOE used the B/C ratios in Table 17.3.1 along with the market penetration curves shown in Figure 17.3.1 to Figure 17.3.3 to estimate the percentage of consumers who would purchase NEMA Premium motors both with and without a rebate incentive.

Table 17.3.1 Benefit/Cost Ratios from and Market Barriers to NEMA Premium

	Horsepower Range (*hp*)					
	1-5	**6-20**	**21-50**	**51-100**	**101-200**	**201-500**
Industry						
B/C Ratio Without Rebate	8.7	5.2	6.3	5.1	4.7	2.5
Rebate Amount (2012$/hp)	16.54	8.38	6.70	5.44	5.49	6.08
B/C Ratio With Rebate	(infinite)	11.4	10.1	7.8	7.5	5.2
Market Barrier Level*	High-	Low+	Low+	Low+	Low+	Low+
Commercial						
B/C Ratio Without Rebate	5.6	5.1	4.7	4.2	3.6	1.7
Rebate Amount (2012$/hp)	16.54	8.38	6.70	5.44	5.49	6.08
B/C Ratio With Rebate	(infinite)	11.0	8.2	7.1	5.8	3.9
Market Barrier Level*	Low+	Low+	Low+	Low+	Low+	Low+
Agriculture						
B/C Ratio Without Rebate	1.6	1.8	1.5	1.1	0.9	0.2
Rebate Amount (2012$/hp)	16.54	8.38	6.70	5.44	5.49	6.08
B/C Ratio With Rebate	4.3	3.1	2.7	1.9	1.7	1.4
Market Barrier Level*	Low-	Low+	Low-	Low-	Low-	No

* "Low-" refers to no-to-low market barriers; "Low+" to low-to-moderate market barriers; and "High-" to moderate-to-high market barriers.

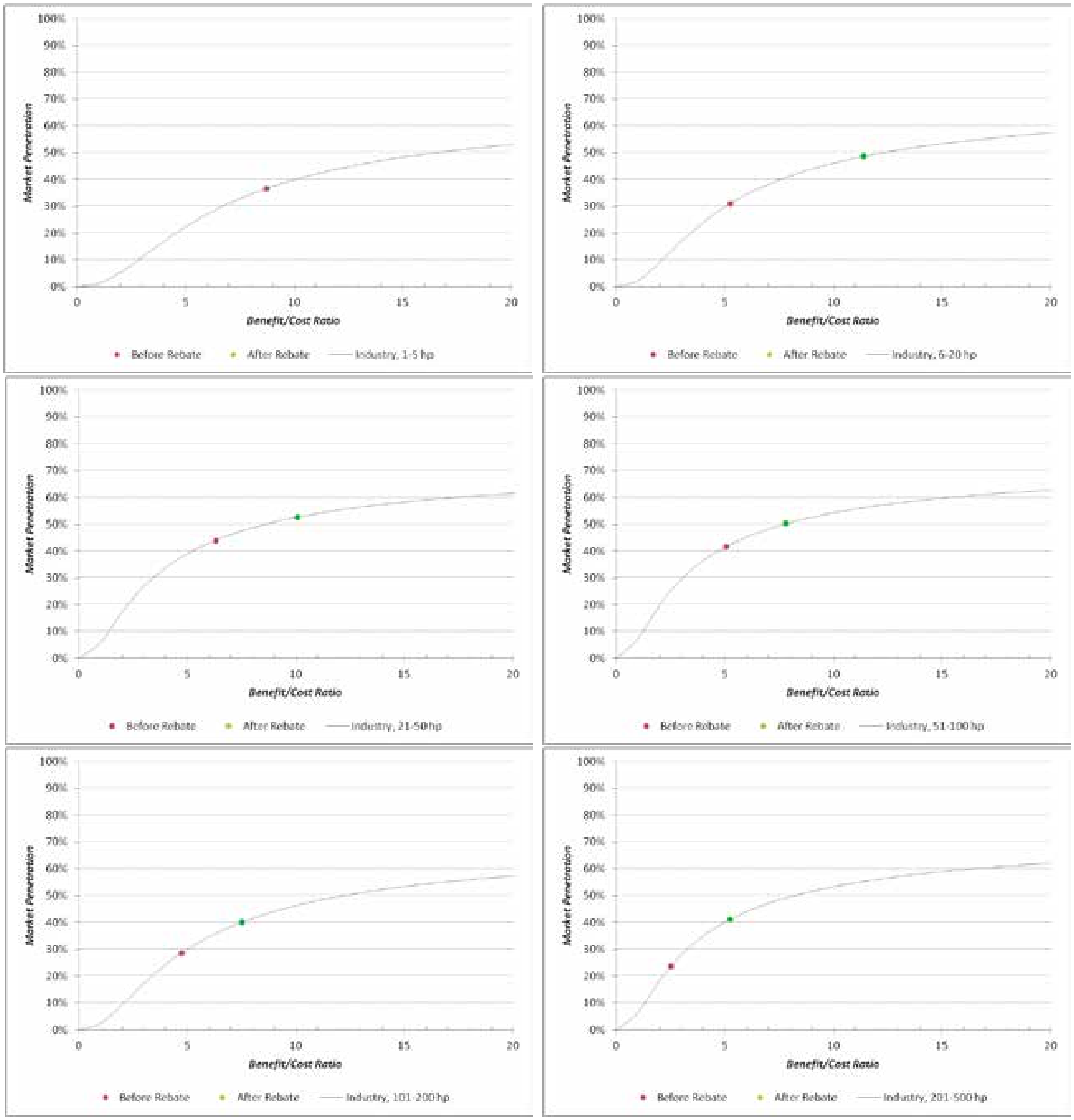

Figure 17.3.1 Market Penetration Curves for Industry

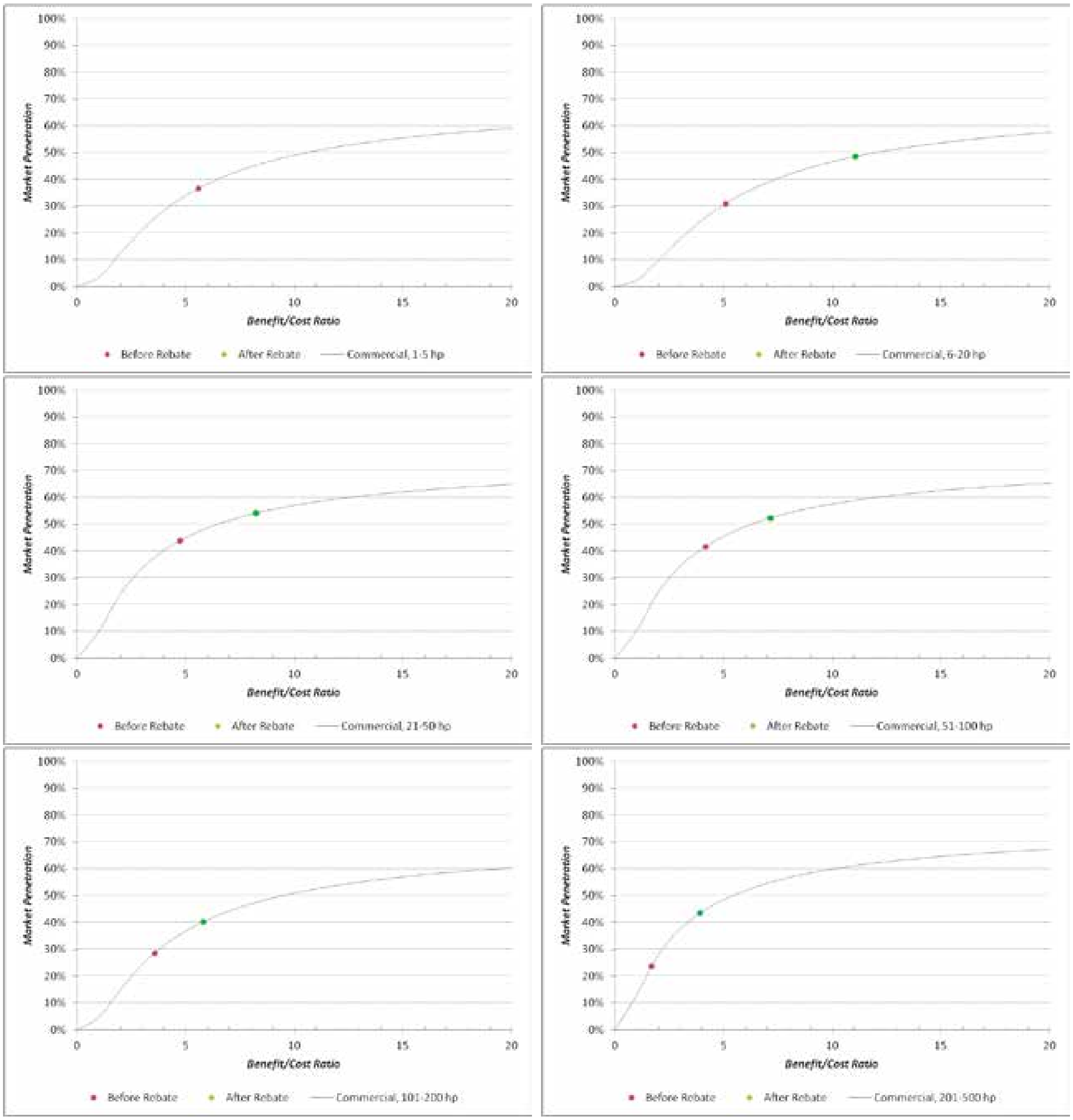

Figure 17.3.2 Market Penetration Curve for Commercial Sector

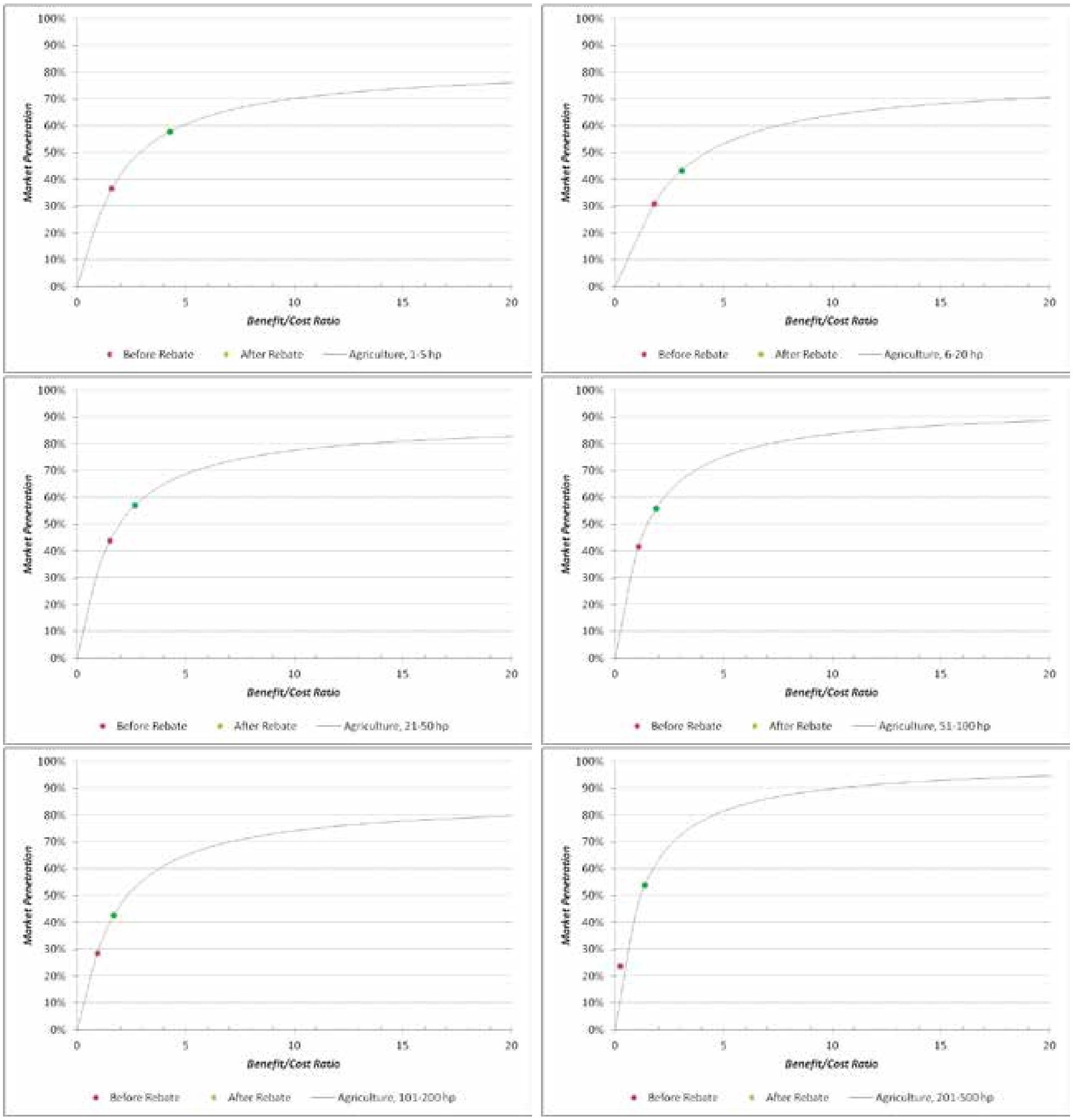

Figure 17.3.3 Market Penetration Curve for Agriculture

For each horsepower range and sector, DOE next estimated the percent increase represented by the change in penetration rate shown on the corresponding penetration curve. It then added this percent increase to the market share of NEMA Premium motors in the base case to obtain the market share of those motors in the rebate policy case. Table 17.3.2 summarizes the market penetrations of NEMA Premium motors in 2016. DOE used the resulting increased market shares in the rebate policy case as inputs to represent the rebate policy case scenario in its

NIA-RIA model. Appendix 17-A shows the annual market share increases due to this policy. Section 17.4 presents the resulting dynamic market penetration and cumulative savings for the policy case of consumer rebates for NEMA Premium motors.

Table 17.3.2 Market Penetrations in 2016 Attributable to Consumer Rebates

	Horsepower Range (*hp*)					
	1-5	**6-20**	**21-50**	**51-100**	**101-200**	**201-500**
Industry						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
Policy case market share	67.6%	48.7%	52.6%	50.3%	40.1%	41.1%
Commercial						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
Policy case market share	71.1%	48.6%	54.2%	52.3%	40.3%	43.5%
Agriculture						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
Policy case market share	57.8%	43.4%	57.0%	55.8%	42.7%	53.9%

17.3.2 Consumer Tax Credits

DOE estimated the effects of tax credits on consumer purchases based on its previous analysis of consumer participation in tax credits. DOE supported its approach using data from Oregon State's tax credit program for energy-efficient appliances. DOE also incorporated previous research that disaggregated the effect of rebates and tax credits into a *direct price effect*, which derives from the savings in purchase price, and an *announcement effect*, which is independent of the amount of the incentive.[9, 10] The announcement effect derives from the credibility that a technology receives from being included in an incentive program, as well as changes in product marketing and modifications in markup and pricing. DOE assumed that the rebate and consumer tax credit policies would encompass both direct price effects and announcement effects, and that half the increase in market penetration associated with either policy would be due to the direct price effect and half to the announcement effect.

In estimating the effects of a tax credit on purchases of NEMA Premium motors DOE assumed a financial incentive of 15 dollars per horsepower. This amount corresponds to the tax credit proposed by the National Electrical Manufacturers Association (NEMA) and the American Council for an Energy Efficient Economy (ACEEE) in NEMA's statement before the Senate Finance Subcommittee on Energy, Natural Resources in May 24, 2007.[27]

DOE estimated that fewer consumers would participate in a tax credit program than would take advantage of a direct, immediate (or quasi-immediate) financial incentive like a rebate. Research has shown that the delay required for a consumer to receive a tax credit, plus the added time and cost in preparing the tax return, make a tax credit incentive less effective than a rebate received at the time of purchase. Based on previous analyses, DOE assumed that only 60 percent of the consumers who would take advantage of a rebate would take advantage of a tax credit.[11]

In preparing its assumptions, DOE also reviewed other tax credit programs that have been offered at both the Federal and State levels for energy-efficient appliances.

The Energy Policy Act of 2005 (EPACT 2005) included Federal tax credits for consumers who purchase energy-efficient products.[12] Those tax credits were in effect in 2006 and 2007, expired in 2008, were reinstated for 2009–2010 by the American Recovery and Reinvestment Act of 2009 (ARRA), extended by Congress for 2011 with some modifications, and expired at the end of 2011.[13, 14] The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[15] DOE reviewed Internal Revenue Service data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. However, DOE did not find data specific enough to electric motors to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 17-A, section 17-A.6.1, contains more information on Federal and State tax credits.

DOE also reviewed its previous analysis of Oregon's tax credits for clothes washers to provide support for its assumptions.[16] In that previous analysis, DOE compared the market shares of ultra-high efficiency (UHE) residential clothes washers in Oregon, which offered both State tax credits and utility rebates, with those in Washington State, which offered only utility rebates during the same period. Based on this analysis, DOE estimated that in Oregon the impact of tax credits was 62 percent of the impact of rebates for UHE clothes washers having equivalent efficiency. This finding supports its original assumption that participation in a tax credit program would be about 60 percent of participation in a rebate program. Additional discussion of State tax credits for Oregon and other states is in Appendix 17-A, section 17-A.6.3.

DOE applied the assumed 60 percent participation described above to the penetration rates estimated for a rebate policy to estimate penetration rates attributable to consumer tax credits. DOE followed the approach described in Section 17.3.1 to develop a whole new rebate analysis with a rebate amount of 15 dollars per horsepower for all NEMA Design A and B motors. DOE then incorporated the assumptions for consumer response to financial incentives from the penetration curves developed for this new, 15 dollars per horsepower rebate scenario, along with the 60 percent participation assumption, to estimate the increase in market penetration resulting from a consumer tax credit of 15 dollars per horsepower.

Table 17.3.3 summarizes DOE's assumptions for market penetrations of NEMA Premium motors in 2016 given a consumer tax credit of 15 dollars per horsepower.

Table 17.3.3 Market Penetrations in 2016 Attributable to Consumer Tax Credits

	Horsepower Range (*hp*)					
	1-5	**6-20**	**21-50**	**51-100**	**101-200**	**201-500**
Industry						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
Policy case market share	55.2%	54.7%	61.0%	60.5%	53.7%	53.1%
Commercial						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
Policy case market share	57.3%	54.7%	62.2%	61.4%	54.5%	55.1%
Agriculture						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
Policy case market share	47.6%	59.4%	70.9%	73.2%	63.0%	69.5%

DOE assumed that this policy would transform the market permanently, so that the increase in market share seen in the first year of the program would be maintained throughout the analysis period. The resulting increased market shares attributable to consumer tax credits shown in Table 17.3.3 were used as inputs in the NIA-RIA model. Appendix 17-Ashows the annual market share increases due to this policy. Section 17.4 presents the resulting dynamic market penetration and cumulative savings for the policy case of consumer tax credits for NEMA Premium motors.

17.3.3 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce NEMA Premium motors DOE assumed that a manufacturer tax credit would lower the consumer's purchase cost by an amount equivalent to that provided by the consumer tax credits described above. DOE further assumed that manufacturers would pass on some of their reduced costs to consumers, causing a direct price effect. DOE assumed that no announcement effect would occur, because the program would not be visible to consumers.[e] Because the direct price effect is approximately equivalent to the announcement effect,[9] DOE estimated that a manufacturer tax credit would induce half the number of consumers assumed to take advantage of a consumer tax credit to purchase more efficient products. Thus the assumed participation rate is equal to 30 percent of the number of consumers who would participate in a rebate program.

DOE attempted to investigate manufacturer response to the Energy Efficient Appliance Credits for manufacturers mandated by EPACT 2005.[17] Those manufacturer tax credits have

[e] Note that this is a conservative assumption, since it is possible that manufacturers or utility/agency efficiency programs might promote the models for which manufacturers increase production due to the tax credits, which in turn might induce some announcement effect. However, DOE found no data on such programs on which to base an estimate of the magnitude of this possible announcement effect on consumer behavior.

been in effect for dishwashers, clothes washers and refrigerators produced beginning in 2009. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 17-A, section 17-A.6.2, presents details on Federal manufacturer tax credits.

DOE applied the assumption of 30 percent participation to the penetration rates predicted for the 15 dollars per horsepower rebate policy that DOE developed to support the consumer tax credit analysis, to estimate the effects of a manufacturer tax credit policy. In doing so, the Department incorporated the assumptions for consumer response to financial incentives from the same penetration curves DOE used in Section 17.3.2 for the consumer tax credit analysis.

Table 17.3.4 summarizes DOE's assumptions for market penetrations of NEMA Premium motors in 2016 given a manufacturer tax credit of 15 dollars per horsepower.

Table 17.3.4 Market Penetrations in 2016 Attributable to Manufacturer Tax Credits

	Horsepower Range (*hp*)					
	1-5	**6-20**	**21-50**	**51-100**	**101-200**	**201-500**
Industry						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
Policy case market share	45.9%	42.8%	52.5%	51.1%	41.2%	38.4%
Commercial						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
Policy case market share	46.9%	42.9%	53.1%	51.6%	41.6%	39.4%
Agriculture						
Base case market share	36.6%	31.0%	44.0%	41.7%	28.6%	23.8%
Market share increase	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
Policy case market share	42.1%	45.2%	57.4%	57.4%	45.8%	46.7%

DOE assumed that this policy would transform the market permanently, so that the increases in market share seen in the first year of the program would be maintained throughout the analysis period. The resulting increased market shares attributable to a manufacturer tax credit shown in Table 17.3.4 were used as inputs in the NIA-RIA model. Appendix 17-Ashows the annual market share increases due to this policy. Section 17.4 presents the resulting dynamic market penetration and cumulative savings for the policy case of manufacturer tax credits for NEMA Premium motors.

17.3.4 Early Replacement

The non-regulatory policy of early replacement refers to a program to replace medium electric motors before the ends of their useful lives. The purpose of such a policy is to replace old, inefficient units with NEMA Premium units. The economic feasibility of early replacement depends on the energy efficiency of the unit being replaced, the purchase cost of a new, NEMA Premium unit, and the energy cost savings. Because electric motors are operated under different regimes – depending on their size (horsepower rating) and the sector in which they are used – and energy cost savings depend of motors usage, the feasibility of early replacements needs to be evaluated for each horsepower rating, motor configuration, and sector where the motor is used.

DOE started the feasibility analysis of early replacements estimating the stock of existing medium electric motors by vintage, sector and horsepower range. To estimate the stock of existing motors DOE estimated historical shipments from 1987 to 2015, and disaggregated these shipments by sector and horsepower range using the same distributions of shipments across sectors and horsepower ranges used in the NIA (Chapter 10). DOE then used the same lifetime distributions by sector and horsepower range used in the NIA (Chapter 10) to estimate, for each sector and horsepower range, the existing stock by vintage for the 30-year analysis period. Figure 17.3.4 presents DOE's projection of the existing stock of motors by sector and horsepower range.

The second step that DOE performed in this analysis was the estimate of historical market efficiency distributions. DOE relied on the works of Boteler (2009) and Lowe et al (2010) for these estimates. Table 17.3.5 shows the historical market efficiency distributions that DOE estimated for selected years. DOE applied these historical market efficiency distributions to the stock by vintage that DOE projected for each sector and horsepower range. Figure 17.3.5 presents examples of the resulting projections of market efficiency distribution of the existing stock across efficiency levels over the 30-year analysis period for the three sectors. In Figure 17.3.5, EL 0 corresponds to motors with efficiency level below NEMA Efficient; EL 1 corresponds to NEMA Efficient motors; and EL 2 corresponds to NEMA Premium motors.

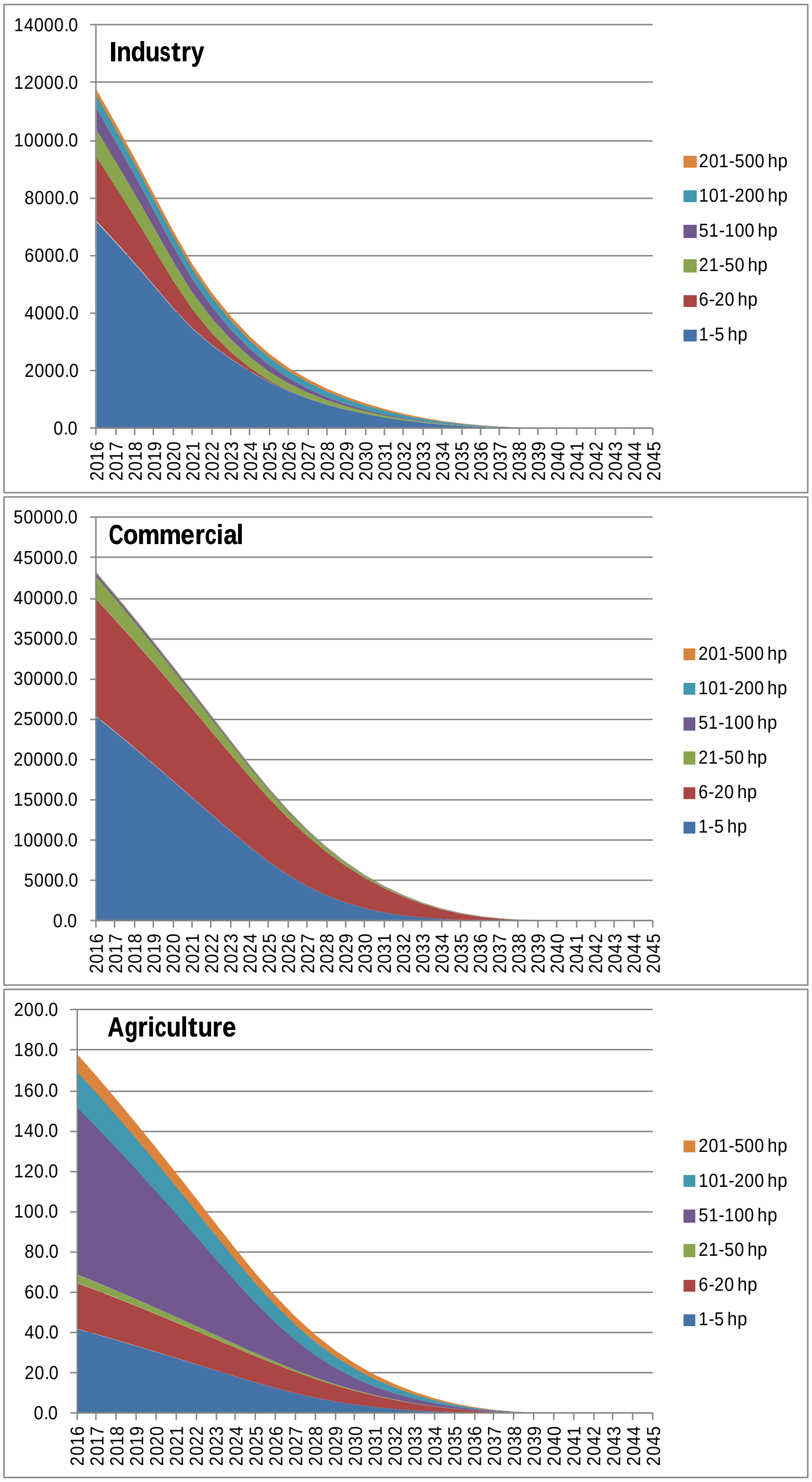

Figure 17.3.4 Estimates of Existing Stock of Motors (thousands of units)

Table 17.3.5 Historical Market Efficiency Distributions

Efficiency Level	**1987**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Below NEMA Efficient	82%	75%	50%	30%	23%	20.7%	18.1%
NEMA Efficient	18%	25%	50%	63%	53%	47.8%	46.9%
NEMA Premium	-	-	-	7%	24%	31.5%	35.1%

In the following, DOE calculated average annual unit energy consumptions across efficiency levels for motors of each horsepower range, used in each sector. With these unit energy consumptions by efficiency level and the efficiency distributions of the existing stock (described above) DOE was able to estimate: (a) the market average unit lifetime energy cost of a motor from the existing stock, and (b) the unit lifetime energy cost of a replacement, NEMA Premium motor. DOE calculated both values as the discounted sum of the corresponding stream of energy costs, taking into account the age of the motor in the replacement year and a stream of annual probabilities that the motor will be in operation until the expected end of its life. The difference between the two lifetime energy costs DOE calculated reflects the estimated energy cost savings that a consumer is likely to enjoy from the early replacement of motors in the existing stock by NEMA Premium motors. DOE calculated these savings in each year of the 30-year analysis period for motors from all vintages in the existing stock, by horsepower range and sector. Table 17.3.6 presents an example of energy cost savings that a consumer can achieve by replacing a unit in the range of 101 horsepower to 200 horsepower operating in industry. The table shows that the earlier the replacement the greater the savings.

Table 17.3.6 Lifetime Energy Cost Savings from Replacing a 101-200 hp Unit in the Existing Stock in Industry by a NEMA Premium Motor (2012$)*

Shipment Year	**Year of Replacement**									
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
1990	2985	2309	1583	813	-	-	-	-	-	-
1991	3474	2867	2218	1521	781	-	-	-	-	-
1992	3880	3332	2750	2127	1458	749	-	-	-	-
1993	4207	3714	3189	2632	2036	1396	717	-	-	-
1994	4462	4019	3548	3047	2515	1945	1334	685	-	-
1995	4649	4253	3831	3382	2905	2397	1854	1271	653	-
1996	4823	4467	4086	3681	3249	2791	2303	1781	1221	627
1997	4999	4675	4330	3961	3568	3150	2705	2233	1727	1184
1998	5107	4814	4502	4170	3814	3436	3033	2605	2150	1663
1999	4996	4741	4469	4179	3870	3541	3189	2815	2418	1996
2000	4832	4610	4374	4123	3856	3571	3267	2943	2598	2231
2001	4619	4428	4224	4008	3778	3533	3272	2993	2696	2380
2002	4695	4519	4332	4132	3921	3696	3456	3201	2928	2638
2003	4609	4452	4285	4107	3918	3718	3505	3277	3035	2777
2004	4540	4398	4248	4089	3920	3739	3548	3345	3128	2897
2005	4597	4466	4327	4179	4022	3856	3678	3490	3290	3077

* Values discounted at 7 percent discount rate.

Savings from early replacements, however, come at a cost. Anticipating the time of replacement of a motor in stock either (a) prevents consumers from realizing financial benefits from investing the money they would pay for the new, replacement motor; or (b) imposes financial costs to those consumers who do not hold – and therefore would have to loan – funds to purchase the new, replacement motor. In either case, there is an economic value in delaying the time of replacement. DOE calculated such value for motors in each horsepower range, from all vintages in the existing stock and for each year in the 30-year analysis period. Table 17.3.7 shows an example of the financial costs a consumer would incur by replacing a unit in the range of 101 horsepower to 200 horsepower. The table shows that (a) the older the unit the lower the financial cost, and (b) the earlier the replacement the greater the financial cost.

Table 17.3.7 Financial Costs from Replacing a 101-200 hp Unit in the Existing Stock by a NEMA Premium Motor (2012$)*

Shipment Year	Year of Replacement									
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
1990	1756	1361	938	485	-	-	-	-	-	-
1991	2126	1756	1361	938	485	-	-	-	-	-
1992	2472	2126	1756	1361	938	485	-	-	-	-
1993	2795	2472	2126	1756	1361	938	485	-	-	-
1994	3096	2795	2472	2126	1756	1361	938	485	-	-
1995	3378	3096	2795	2472	2126	1756	1361	938	485	-
1996	3642	3378	3096	2795	2472	2126	1756	1361	938	485
1997	3888	3642	3378	3096	2795	2472	2126	1756	1361	938
1998	4119	3888	3642	3378	3096	2795	2472	2126	1756	1361
1999	4334	4119	3888	3642	3378	3096	2795	2472	2126	1756
2000	4535	4334	4119	3888	3642	3378	3096	2795	2472	2126
2001	4723	4535	4334	4119	3888	3642	3378	3096	2795	2472
2002	4899	4723	4535	4334	4119	3888	3642	3378	3096	2795
2003	5063	4899	4723	4535	4334	4119	3888	3642	3378	3096
2004	5216	5063	4899	4723	4535	4334	4119	3888	3642	3378
2005	5360	5216	5063	4899	4723	4535	4334	4119	3888	3642

* Values discounted at 7 percent discount rate.

Whereas the energy cost savings are an incentive for early replacing a unit in the existing stock (*benefits from replacing*), the financial costs underlying the early replacement (*benefits from waiting*) may hinder the initiative. DOE considered the net-result from the *benefits from replacing* and the *benefits from waiting* as an indicator of the decision that consumers would make towards anticipating the replacement of a unit in the existing stock by a NEMA Premium motor. The comparison of the two benefits for the ranges of shipment and replacement years listed in Table 17.3.6 and Table 17.3.7 shows that the early replacement of a unit in the range of 101-200 horsepower operating in industry would be cost-effective for units shipped before 2001.

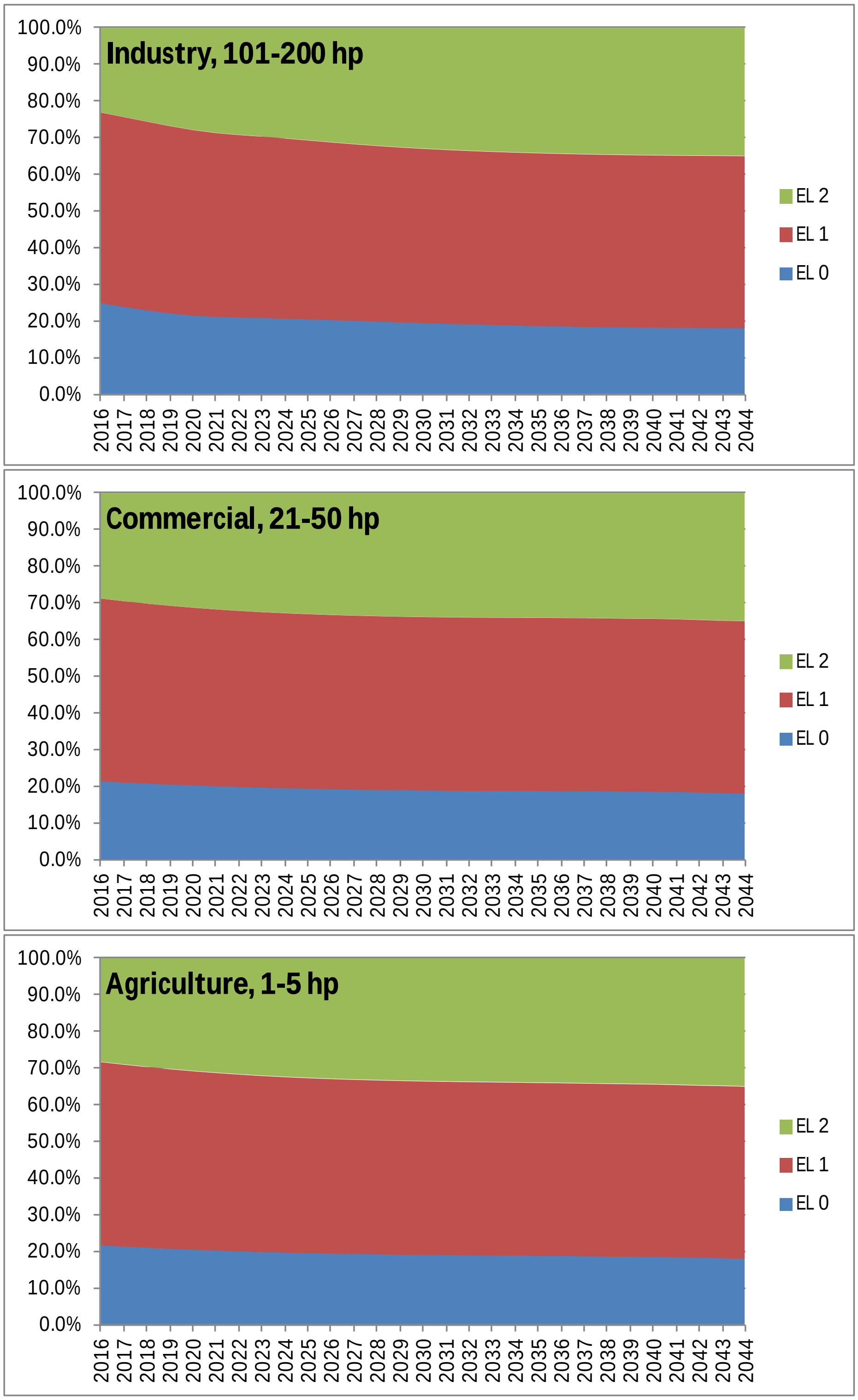

Figure 17.3.5 Estimates of Market Efficiency Distributions of Existing Stock

Based on the stock by vintage that DOE projected over the 30-year analysis period, and the net-results from the *benefits from replacing* and the *benefits from waiting* for each motor vintage, DOE projected – for each horsepower range and sector – the number of potential units in the existing stock to be (early) replaced in each of the 30 years of the analysis period. For this projection DOE further considered that, because of lack of information on the benefits from early replacements or any transaction costs involved in the process of early replacing a motor in operation, not all consumers would be informed to or willing to decide for the replacement. DOE then assumed that 10 percent of the potential replacements would be undertaken. Table 17.3.8 shows DOE's projection of units to be early replaced by sector and horsepower range. No units operating in agriculture would be cost-effective to be early replaced by a NEMA Premium motor.

Table 17.3.8 Number of Units in the Existing Stock Projected to be Early Replaced by a NEMA Premium Motor (thousands of units)

	Year of Replacement				
	2016	**2017**	**2018**	**2019**	**2020**
Industry					
1-5 hp	18.711	11.616	6.282	1.538	0.000
6-20 hp	0.003	0.000	0.000	0.000	0.000
21-50 hp	18.795	13.040	8.445	4.741	0.152
51-100 hp	6.890	4.390	2.533	1.175	0.000
101-200 hp	8.471	6.140	3.682	0.734	0.000
201-500 hp	0.315	0.123	0.000	0.000	0.000
Commercial					
1-5 hp	0.000	0.000	0.000	0.000	0.000
6-20 hp	0.089	0.000	0.000	0.000	0.000
21-50 hp	1.115	0.569	0.230	0.000	0.000
51-100 hp	0.023	0.011	0.002	0.000	0.000
101-200 hp	0.000	0.000	0.000	0.000	0.000
201-500 hp	0.000	0.000	0.000	0.000	0.000

The units in the existing stock projected to be early replaced represent additional shipments of NEMA Premium motors. DOE used the additional shipments for early replacements to calculate the increase in market penetration of NEMA Premium motors that would result from an early replacement policy. Table 17.3.9 shows the market penetration of NEMA Premium motors attributable to early replacements. The resulting increased market shares attributable to early replacements shown in Table 17.3.9 were used as inputs in the NIA-RIA model. Appendix 17-A shows the annual market share increases due to this policy. Section 17.4 presents the resulting dynamic market penetration and cumulative savings for the policy case of early replacement for electric motors.

Table 17.3.9 Market Penetrations Attributable to Early Replacements

	Year of Replacement				
	2016	**2017**	**2018**	**2019**	**2020**
Industry					
1-5 hp					
Base case market share	36.6%	37.1%	37.6%	38.1%	38.5%
Market share increase	1.2%	0.7%	0.4%	0.1%	0.0%
Policy case market share	37.8%	37.8%	38.0%	38.2%	38.5%
6-20 hp					
Base case market share	31.0%	31.5%	32.0%	32.5%	33.0%
Market share increase	0.0%	0.0%	0.0%	0.0%	0.0%
Policy case market share	31.0%	31.5%	32.0%	32.5%	33.0%
21-50 hp					
Base case market share	44.0%	44.5%	45.0%	45.5%	45.9%
Market share increase	8.8%	6.1%	4.0%	2.2%	0.1%
Policy case market share	52.8%	50.6%	49.0%	47.7%	46.0%
51-100 hp					
Base case market share	41.7%	42.3%	42.7%	43.2%	43.7%
Market share increase	4.6%	2.8%	1.6%	0.7%	0.0%
Policy case market share	46.3%	45.1%	44.4%	44.0%	43.7%
101-200 hp					
Base case market share	28.6%	29.2%	29.6%	30.1%	30.6%
Market share increase	15.0%	11.0%	6.8%	1.4%	0.0%
Policy case market share	43.6%	40.1%	36.5%	31.5%	30.6%
201-500 hp					
Base case market share	23.8%	24.3%	24.8%	25.3%	25.7%
Market share increase	1.6%	0.6%	0.0%	0.0%	0.0%
Policy case market share	25.3%	24.9%	24.8%	25.3%	25.7%
Commercial					
1-5 hp					
Base case market share	36.6%	37.1%	37.6%	38.1%	38.5%
Market share increase	0.0%	0.0%	0.0%	0.0%	0.0%
Policy case market share	36.6%	37.1%	37.6%	38.1%	38.5%
6-20 hp					
Base case market share	31.0%	31.5%	32.0%	32.5%	33.0%
Market share increase	0.0%	0.0%	0.0%	0.0%	0.0%
Policy case market share	31.0%	31.5%	32.0%	32.5%	33.0%
21-50 hp					
Base case market share	44.0%	44.5%	45.0%	45.5%	45.9%
Market share increase	0.2%	0.1%	0.0%	0.0%	0.0%
Policy case market share	44.2%	44.6%	45.1%	45.5%	45.9%
51-100 hp					
Base case market share	41.7%	42.3%	42.7%	43.2%	43.7%
Market share increase	0.0%	0.0%	0.0%	0.0%	0.0%

	Year of Replacement				
	2016	**2017**	**2018**	**2019**	**2020**
Policy case market share	41.8%	42.3%	42.8%	43.2%	43.7%
101-200 hp					
Base case market share	28.6%	29.2%	29.6%	30.1%	30.6%
Market share increase	0.0%	0.0%	0.0%	0.0%	0.0%
Policy case market share	28.6%	29.2%	29.6%	30.1%	30.6%
201-500 hp					
Base case market share	23.8%	24.3%	24.8%	25.3%	25.7%
Market share increase	0.0%	0.0%	0.0%	0.0%	0.0%
Policy case market share	23.8%	24.3%	24.8%	25.3%	25.7%

17.3.5 Bulk Government Purchases

Bulk government purchases can lead to Federal, State, and local governments purchasing large quantities of NEMA Premium motors. Combining the market demands of multiple public sectors also can provide a market signal to manufacturers and vendors that some of their largest customers seek motors that meet the NEMA Premium efficiency at favorable prices. Such a program also can induce “market pull,” whereby manufacturers and vendors would achieve economies of scale for producing and marketing NEMA Premium motors.

Most of the previous bulk government purchase (procurement) initiatives at the Federal, State, and municipal levels have not tracked data on numbers of purchases or degree of compliance with procurement specifications. In many cases, procurement programs are decentralized, being part of larger State or regional initiatives. DOE based its assumptions regarding the effects of this policy on studies the Federal Energy Management Program (FEMP) performed regarding the savings potential of its procurement specifications for appliances and other equipment. FEMP, however, does not track purchasing data, because of the complex range of purchasing systems, large number of vendors, and so on. States, counties, and municipalities have demonstrated increasing interest and activity in “green purchasing." Although many of the programs target office equipment, the growing infrastructure for developing and applying efficient purchasing specifications indicates that bulk government purchase programs are feasible.[22, 23]

DOE assumed that government agencies would administer bulk purchasing programs for NEMA Premium motors. FEMP had performance requirements for general-purpose, single-speed, polyphase induction motors of 1 to 500 horsepower, but suspended the purchasing specification for these motors as a result of the mandatory minimum standards established by the Energy Independence and Security Act (EISA) of 2007, effective since December 2010. Nevertheless, FEMP recommends Federal costumers to consider replacing a failed standard motor with a Premium one. Further, FEMP emphasizes that “In many cases, it may be cost effective to replace a standard motor prior to failure with a NEMA premium motor.” The scope of this regulation is much broader than the scope of the mandatory standards established in

EISA. Therefore, for the purpose of this analysis, DOE assumed that the policy would be incorporated into the FEMP program, as well as into all other government procurement programs.

DOE reviewed its own previous research on the potential for market transformation through bulk government purchases. Its major study analyzed several scenarios based on the assumption that 20 percent of Federal equipment purchases in 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy efficient purchasing ramping up during 10 years from 20 percent to 80 percent of all Federal purchases.[24] Based on this study, DOE estimated that a bulk government purchase program instituted within a 10-year period would result in at least 80 percent of government-purchased NEMA Premium motors.

DOE assumed that bulk government purchases would affect the purchase of electric motors to be installed in government-owned buildings. The 2003 Commercial Buildings Energy Consumption Survey (CBECS 2003) reported that 13.1 percent of all commercial buildings are publicly owned .[26] CBECS 2003 also estimated that government-owned buildings comprise 21.4 percent of the floor space of all commercial buildings in the United States. The activities in these buildings include education, public assembly, public offices, public order and safety, inpatient and outpatient health care, warehousing, lodging and other services. DOE assumed that medium electric motors are used in all these buildings – for instance, as part of HVAC (heating, ventilating and air conditioning) systems – and, consequently, that this constitutes the market affected by this policy.

DOE estimated that, starting in 2016, each year of a bulk government purchase policy would result in an increasing percent of shipments of government-purchased NEMA Premium motors. DOE estimated that within 10 years (by the end of 2025), bulk government purchasing programs would result in 80 percent of the market for medium electric motors in publicly-owned commercial building to meet the NEMA Premium efficiency level. DOE modeled the bulk government purchase program assuming that the market share of NEMA Premium motors achieved in 2025 would be maintained throughout the rest of the 30-year analysis period. Table 17.3.10 shows the market penetration of NEMA Premium motors attributable to bulk government purchases. The resulting increased market shares attributable to bulk government purchases shown in Table 17.3.10 were used as inputs in the NIA-RIA model. Appendix 17-Ashows the annual market share increases due to this policy. Section 17.4 below presents the resulting dynamic market penetration and cumulative savings for the policy case of bulk government purchases of NEMA Premium motors.

Table 17.3.10 Market Penetrations Attributable to Bulk Government Purchases

Commercial	**2016**	**2020**	**2025**
1-5 hp			
Base case market share	36.6%	38.5%	40.5%
Market share increase	0.9%	4.2%	8.5%
Policy case market share	37.5%	42.8%	48.9%

6-20 hp			
Base case market share	31.0%	33.0%	34.9%
Market share increase	1.1%	4.8%	9.7%
Policy case market share	32.1%	37.8%	44.6%
21-50 hp			
Base case market share	44.0%	45.9%	47.9%
Market share increase	0.8%	3.4%	6.9%
Policy case market share	44.8%	49.4%	54.8%
51-100 hp			
Base case market share	41.7%	43.7%	45.6%
Market share increase	0.8%	3.7%	7.4%
Policy case market share	42.5%	47.4%	53.0%
101-200 hp			
Base case market share	28.6%	30.6%	32.5%
Market share increase	1.1%	5.1%	10.2%
Policy case market share	29.7%	35.7%	42.7%
201-500 hp			
Base case market share	23.8%	25.7%	27.7%
Market share increase	1.2%	5.6%	11.2%
Policy case market share	25.0%	31.3%	38.9%

17.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figure 17.4.1 to Figure 17.4.3 show the effects of each non-regulatory policy on market penetration of NEMA Design A and B Premium motors. The graphs show the shipments weighted average impacts in each sector. Relative to the base case, the alternative policy cases increase the market shares of NEMA Premium motors. Recall that mandatory minimum standards result in 100-percent compliance of the market, which leads to higher market penetration of NEMA Premium motors in comparison to the alternative non-regulatory policies discussed in this RIA. The graphs in Figure 17.4.1 to Figure 17.4.3 however do not include the market penetration of motors with efficiency levels above NEMA Premium. Therefore, the lines corresponding to the market penetration of standards in those graphs do not reach 100 percent.

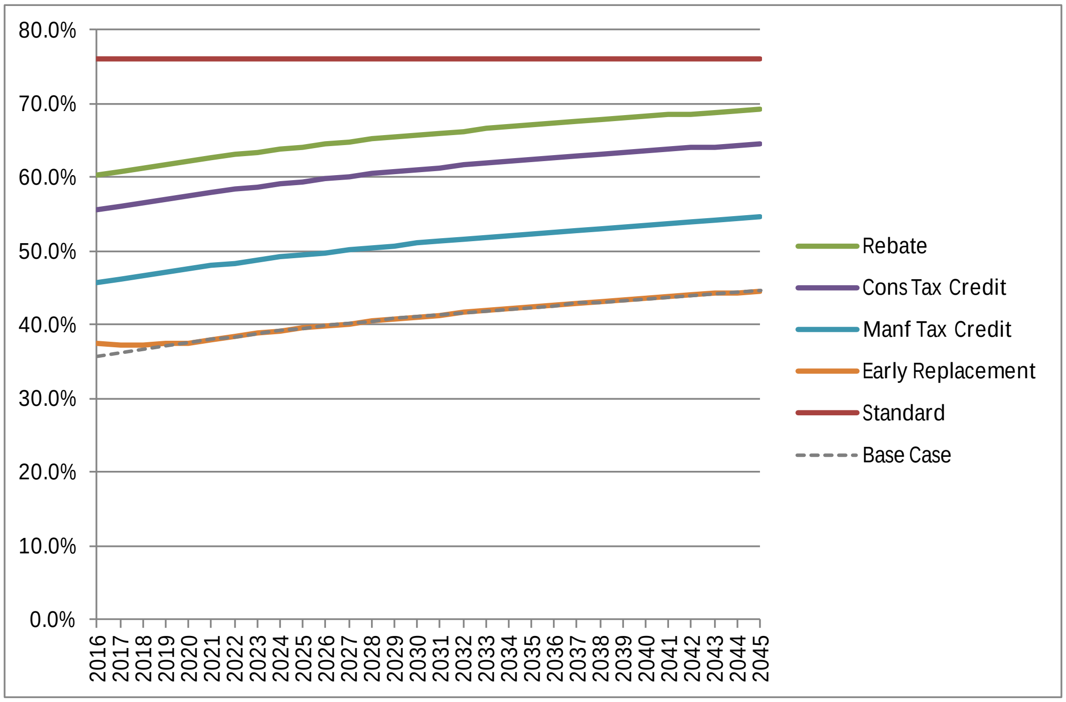

Figure 17.4.1 Market Penetration of NEMA Design A and B Premium Motors in Industry

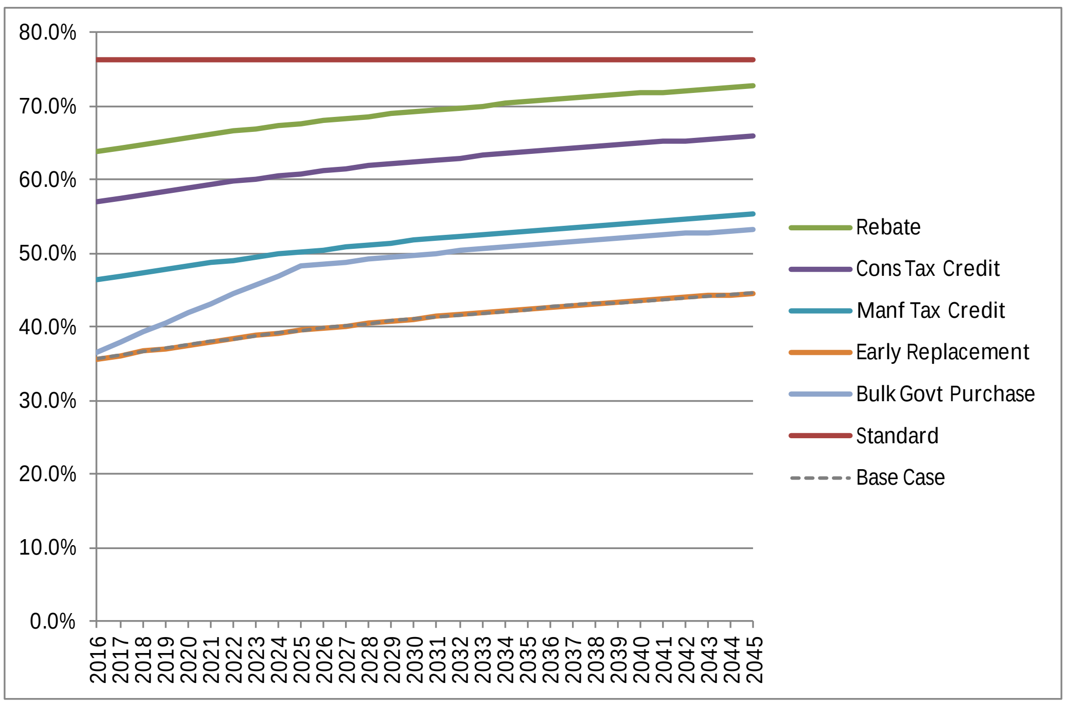

Figure 17.4.2 Market Penetration of NEMA Design A and B Premium Motors in Commercial Sector

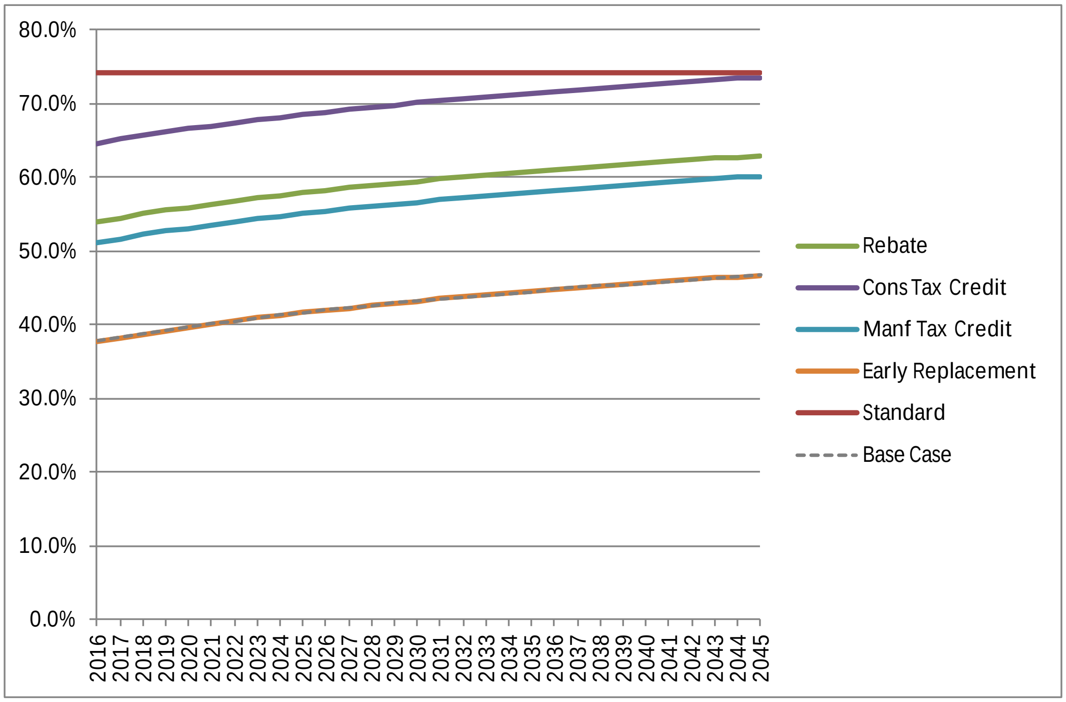

Figure 17.4.3 Market Penetration of NEMA Design A and B Premium Motors in Agriculture

Table 17.4.1 shows the NES and NPV for the five non-regulatory policies analyzed in detail in this RIA. For comparison, the table includes the impacts that new or amended efficiency standards set at TSL 2 – the NEMA Premium efficiency level – have on NEMA Design A and B motors. Because the analyses of all alternative policies – except Bulk Government Purchases – assessed in this RIA rely on consumers' energy cost savings to estimate the market penetration of NEMA Premium motors under the influence of the policy, the resulting primary energy savings and net present value are sensitive to the discount rate used in the calculations. Table 17.4.1 includes results for 7 percent and 3 percent discount rates.

The non-regulatory policy with the highest national benefits is Consumer Tax Credits, followed by Consumer Rebates and Manufacturer Tax Credits. Bulk Government Purchases and Early Replacements have smaller effects on market transformation and, consequently, much lower results. Bulk Government Purchases, despite presenting market effects close to the effects from Manufacturer Tax Credits in commercial sector for two thirds of the analysis period, affects only the commercial sector.

Table 17.4.1 Impacts of Non-Regulatory Alternative Policies for NEMA Design A and B Premium Motors*

Policy Alternatives	Primary Energy Savings (*quads*)		Net Present Value (*billion 2012$*)	
	7% DR**	3% DR	7% DR	3% DR
Consumer Rebates	2.483	2.349	4.176	9.981
Consumer Tax Credits	3.064	2.939	4.779	11.731
Manufacturer Tax Credits	1.532	1.469	2.390	5.866
Early Replacements	0.022	0.353	0.062	1.782
Bulk Government Purchases	0.531		0.781	2.247
Standards	6.273		7.681	20.704

* For motors shipped 2016-2045.
** DR: Discount rate.

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APPENDIX 5-A ENGINEERING DATA

5-A.1 INTRODUCTION

This appendix presents baseline specifications and detailed cost-efficiency results for each of the electric motor representative units analyzed in the engineering analysis (chapter 5 of the TSD).

5-A.2 BASELINE AND MAXIMUM TECHNOLOGY DESIGN SUMMARIES

Table 2.1 and Table 2.2 show the baseline and maximum technology designs for each equipment class analyzed, respectively. In the engineering analysis, all changes to cost and efficiency are measured relative the levels in Table 2.1. The representative motors chosen from each equipment class are all 4-pole, totally enclosed, fan-cooled, continuous duty, 60 hertz, and operate on less than 600 volts.

Table 2.1 Baseline Design Data

Parameter (Units)	Unit	5 hp (Design B)	30 hp (Design B)	75 hp (Design B)	5 hp (Design C)	50 hp (Design C)
Efficiency	%	82.5	89.5	93.0	87.5	93.0
Power Factor	%	82.7	86.2	86.8	75	85
Cycles	Hz	60	60	60	60	60
Tested Voltage	V	460	460	460	460	460
Speed	RPM	1,745	1,755	1,775	1,750	1,770
Full Load Torque	Nm	20.3	121.6	300.6	20.3	200.7
Current	A	6.9	37	88	7.1	59
Core Steel	-	M56	M56	M56	M47	M47
Stack Length	in	2.8	7.88	8.15	4.75	8.67
Rotor Material	-	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Main Wire	AWG	19	18	17	18	17
Breakdown Torque	% of Full Load	300	250	205	355	257
Locked-Rotor Torque	% of Full Load	240	200	170	326	211
Locked-Rotor Current	A	45.9	212	505.9	44.7	344
Pull-Up Torque	% of Full Load	187	142	165	248	159

Table 2.2 Maximum-Technology Design Data

Parameter (Units)	Unit	5 hp (Design B)	30 hp * (Design B)	75 hp * (Design B)	5 hp * (Design C)	50 hp * (Design C)
Efficiency	%	91.0	94.5	96.2	91.0	95.0
Power Factor	%	78.5	79.4	81.3	79.3	80.3
Hertz	Hz	60	60	60	60	60
Tested Voltage	V	460	460	460	460	460
Speed	RPM	1,770	1,784	1,788	1,776	1,782
Torque	Nm	20.1	119.6	299.6	20.1	199.8
Current	A	6.5	37.3	89.8	6.5	61.3
Core Steel	-	M15	M36	M36	M36	M19
Stack Length	in	5.02	7.0	12.0	5.32	9.55
Rotor Material	-	Copper	Copper	Copper	Copper	Copper
Main Wire	AWG	20.5	18	14	18	17
Breakdown Torque	% of Full Load	305	202	218.2	260.8	233.5
Locked-Rotor Torque	% of Full Load	214	154	163.8	260.8	202.9
Locked-Rotor Current	A	43.9	208	530.7	41.7	359.6
Pull-Up Torque	% of Full Load	214	139	135	260.8	202.9

* Software modeled designs

5-A.3 DESIGN SPECIFICATIONS AND LOAD PERFORMANCE OF BASELINE MOTORS

Nameplate data and results of the IEEE Standard 112 (Test Method B) (IEEE 112B) testing for the baseline representative motors are displayed in sections 5A.3.1 through 5A.3.5.

5A.3.1 5-Horsepower, NEMA Design B, Baseline Data and IEEE 112B Test Results

Table 3.1 5-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	230/460
Rated Horsepower	5.0
Rated Current	13.7/6.9
Frame	184TP
NEMA Nameplate Nominal Efficiency	82.5%
Hertz	60
RPM	1745
Enclosure	TEFC

Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	J

Table 3.2 5-Horsepower, NEMA Design B, IEEE 112B Test Results (460 Volts)

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
24.7	71.3	44	3.7
49.6	81.7	64	4.5
74.5	83.9	75	5.6
99.6	84.4	80	6.9
114.7	84.1	82	7.8

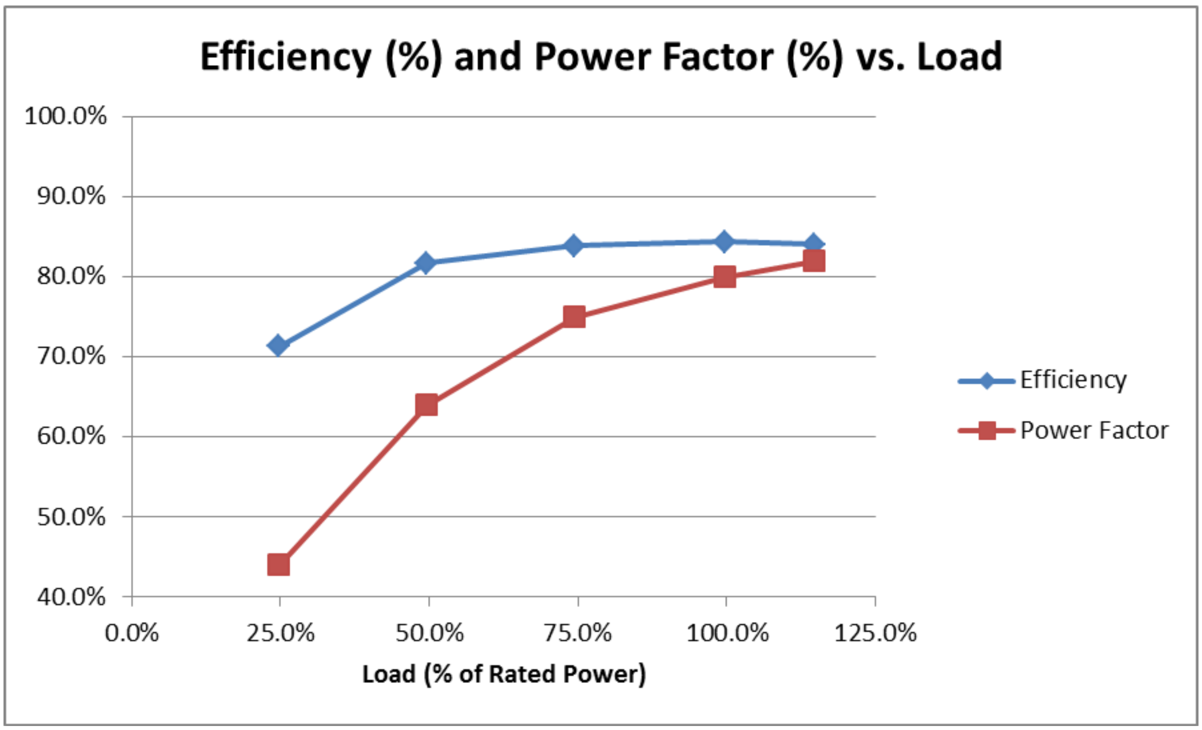

Figure 3.1 5-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.3.2 30-Horsepower, NEMA Design B, Baseline Data and IEEE 112B Test Results

Table 3.3 30-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	230/460

Rated Horsepower	30.0
Rated Current	74/37
Frame	286TPA
NEMA Nameplate Nominal Efficiency	89.5%
Hertz	60
RPM	1755
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	G

Table 3.4 30-Horsepower, NEMA Design B, IEEE 112B Test Results (460 Volts)

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25.1	84.3	57	14.6
49.6	89.2	77	20.4
75.0	90.0	84	27.8
99.9	89.4	87	36.2
115.1	88.8	87	41.8

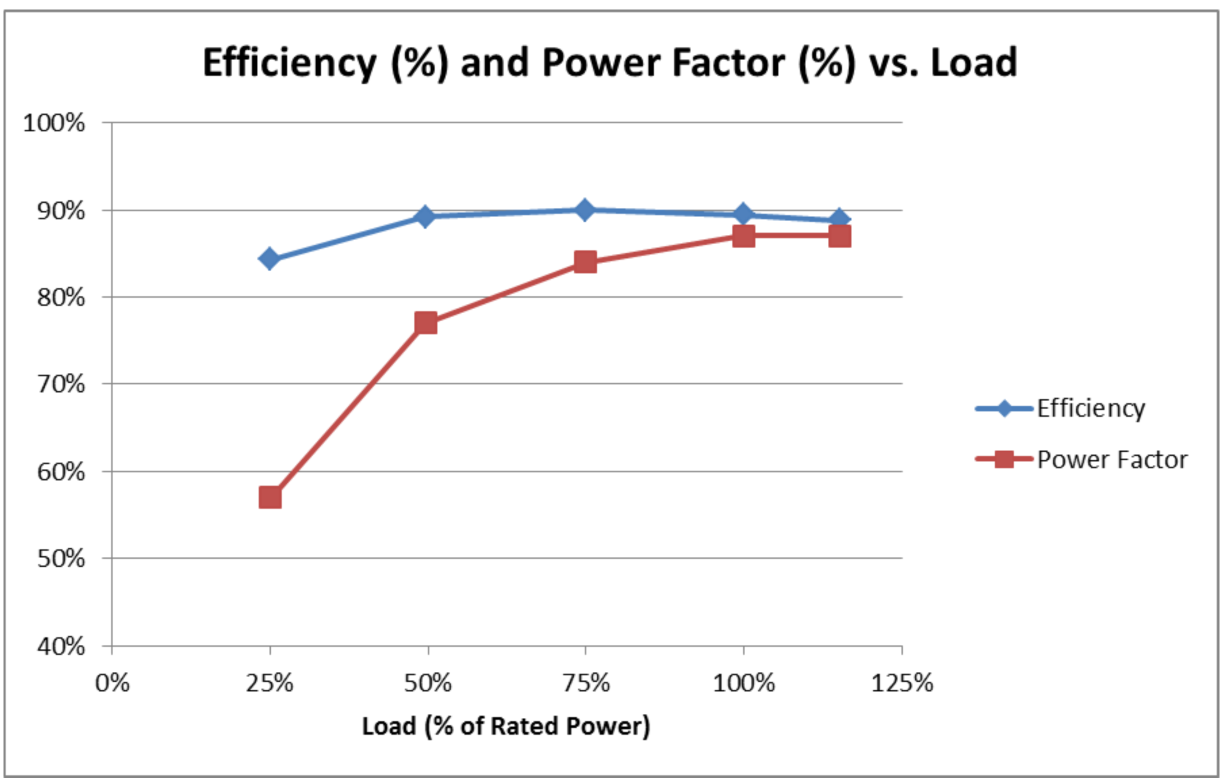

Figure 3.2 30-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.3.3 75-Horsepower, NEMA Design B, Baseline Data and IEEE 112B Test Results

Table 3.5 75-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	460
Rated Horsepower	75.0
Rated Current	88.0
Frame	365TP
NEMA Nameplate Nominal Efficiency	93.0%
Hertz	60
RPM	1775
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	F

Table 3.6 75-Horsepower, NEMA Design B, IEEE 112B Test Results (460 Volts)

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25.4	90.2	67	29.5
50.2	93.4	83	45.3
75.0	93.9	88	63.8
100.2	93.6	89	84.5
115.1	93.3	89	97.5

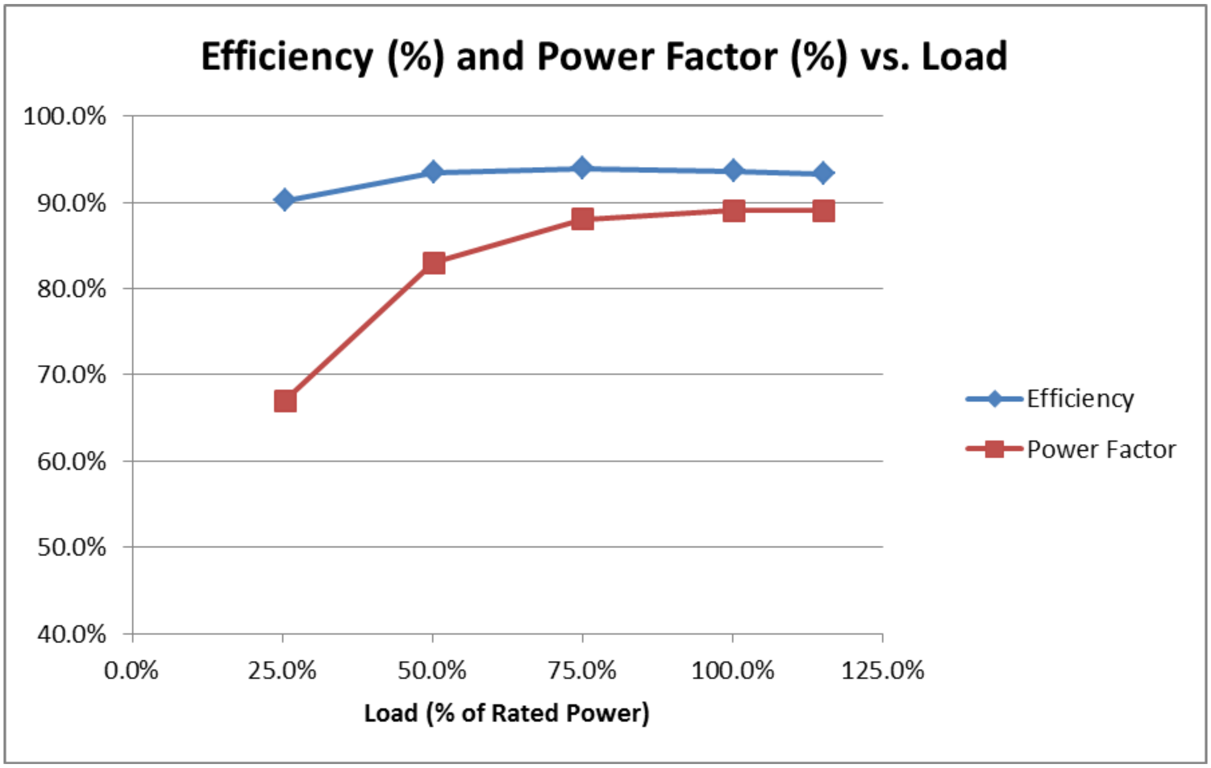

Figure 3.3 75-Horsepower NEMA Design B Efficiency and Power Factor versus Load

5A.3.4 5 Horsepower, NEMA Design C, Baseline Data and IEEE 112B Test Results

Table 3.7 5 Horsepower NEMA Design C Nameplate Data

Parameter	Value
Phases	3
Voltage	208-230/460
Rated Horsepower	5.0
Rated Current	15.3-14.16/7.08
Frame	184T
NEMA Nameplate Nominal Efficiency	87.5%
Hertz	60
RPM	1750
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	J

Table 3.8 5-Horsepower, NEMA Design C, IEEE 112B Test Results

Load	Efficiency	Power Factor	Current
%	%	%	Amperes

25.8	79.4	37	4.1
51.1	86.2	57	4.9
76.1	87.7	68	5.9
100.9	87.5	75	7.2
116.0	87.0	77	8.1

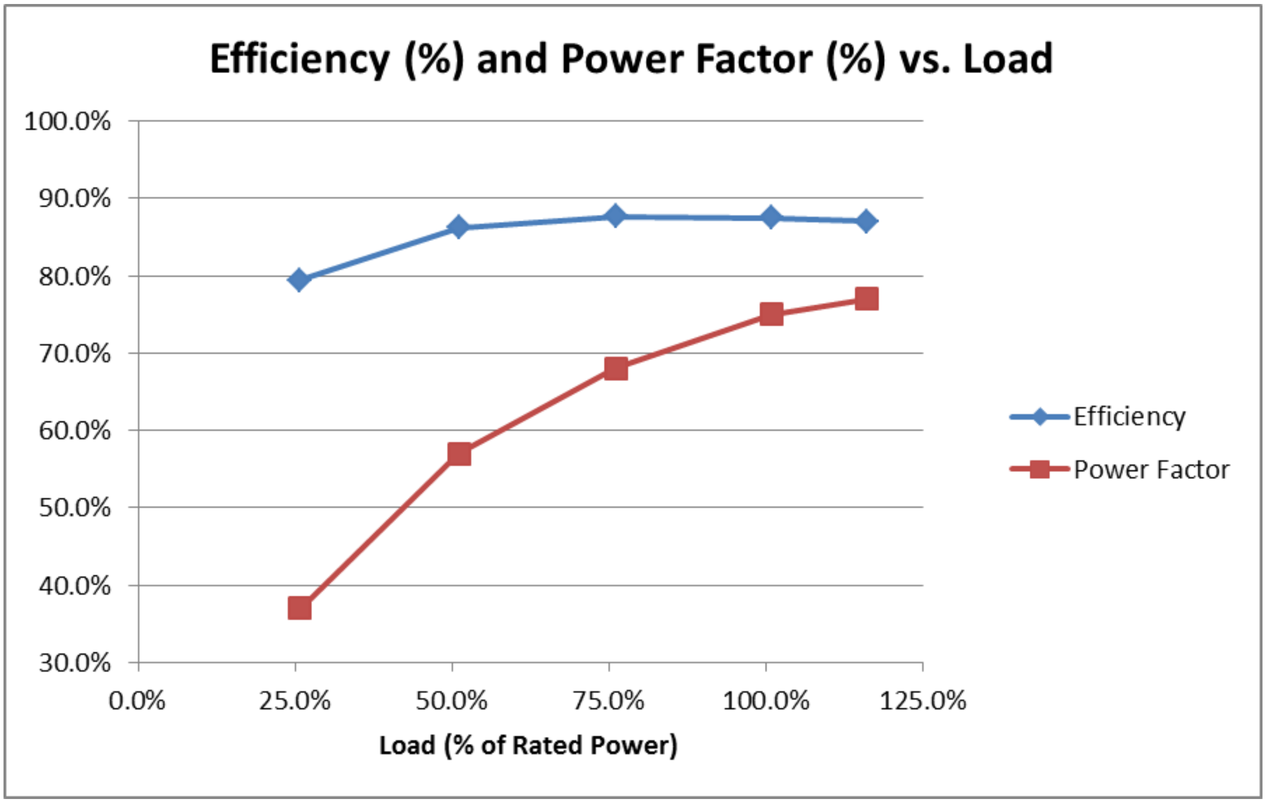

Figure 3.4 5-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load

5A.3.5 50-Horsepower, NEMA Design C, Baseline Data and IEEE 112B Test Results

Table 3.9 50-Horsepower, NEMA Design C, Nameplate Data

Parameter	Value
Phases	3
Voltage	208-230/460
Rated Horsepower	50.0
Rated Current	130-118/59
Frame	236T
NEMA Nameplate Nominal Efficiency	93.0%
Hertz	60
RPM	1770

Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	F

Table 3.10 50-Horsepower, NEMA Design C, IEEE 112B Test Results

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25.1	88.0	55	24.5
50.1	92.3	75	34.0
75.2	93.2	82	45.9
100.2	93.1	85	59.2
115.2	92.8	86	67.8

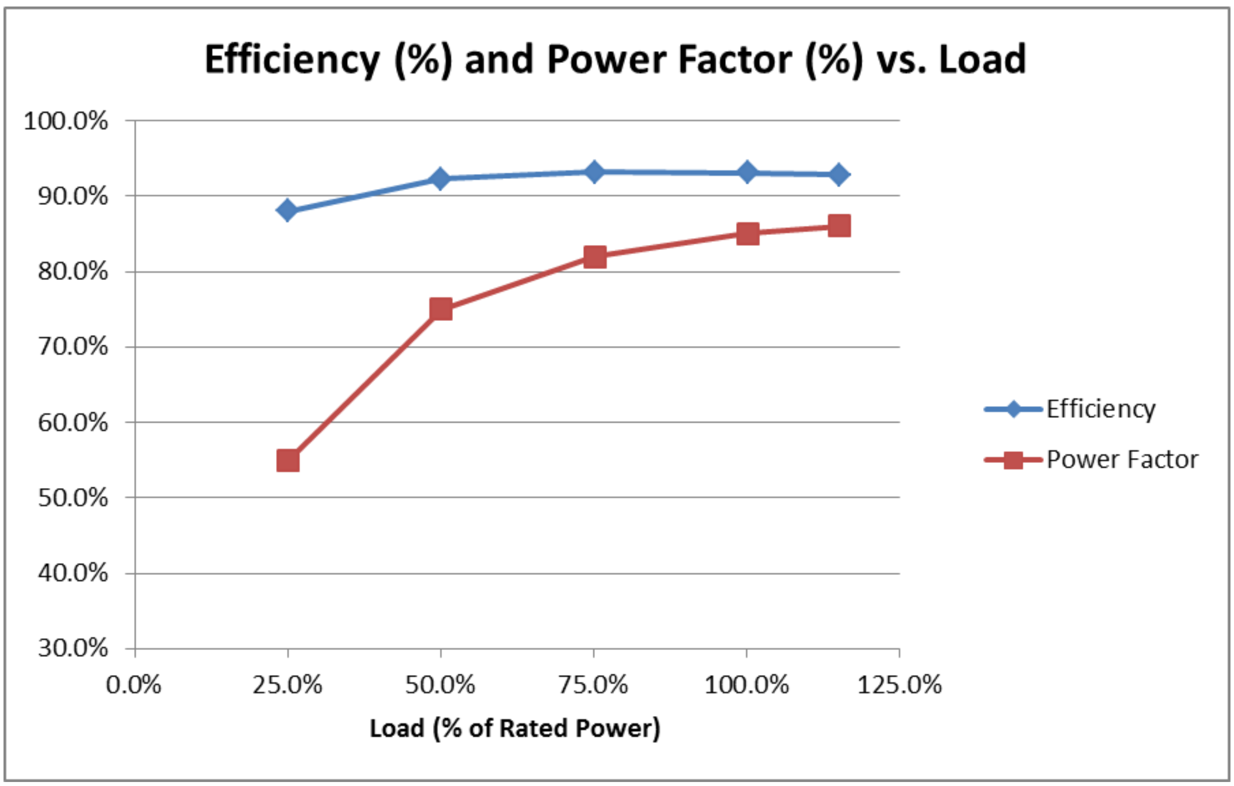

Figure 3.5 50-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load

5-A.4 DESIGN SPECIFICATIONS AND LOAD PERFORMANCE OF MAXIMUM TECHNOLOGY MOTORS

Performance data and speed versus torque curves for the maximum-technology, physical motor and computer-modeled motors are displayed in sections 5A.4.1 through 5A.4.5.

5A.4.1 5-Horsepower, NEMA Design B, Maximum-Technology Data

Table 4.1 5-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	460
Rated Horsepower	5.0
Rated Current	6.5
Frame	184T
NEMA Nameplate Nominal Efficiency	91.0%
Hertz	60
RPM	1770
Enclosure	TEFC
Insulation Class	F
NEMA Design Letter	B

Table 4.2 5-Horsepower, NEMA Design B, IEEE 112B Test Results

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25.9	88.1	41	3.4
501	91.7	62	4.2
76.1	92.0	72	5.3
101.1	91.4	78	6.7
116.1	90.9	80	7.5
125.8	90.4	80	8.1

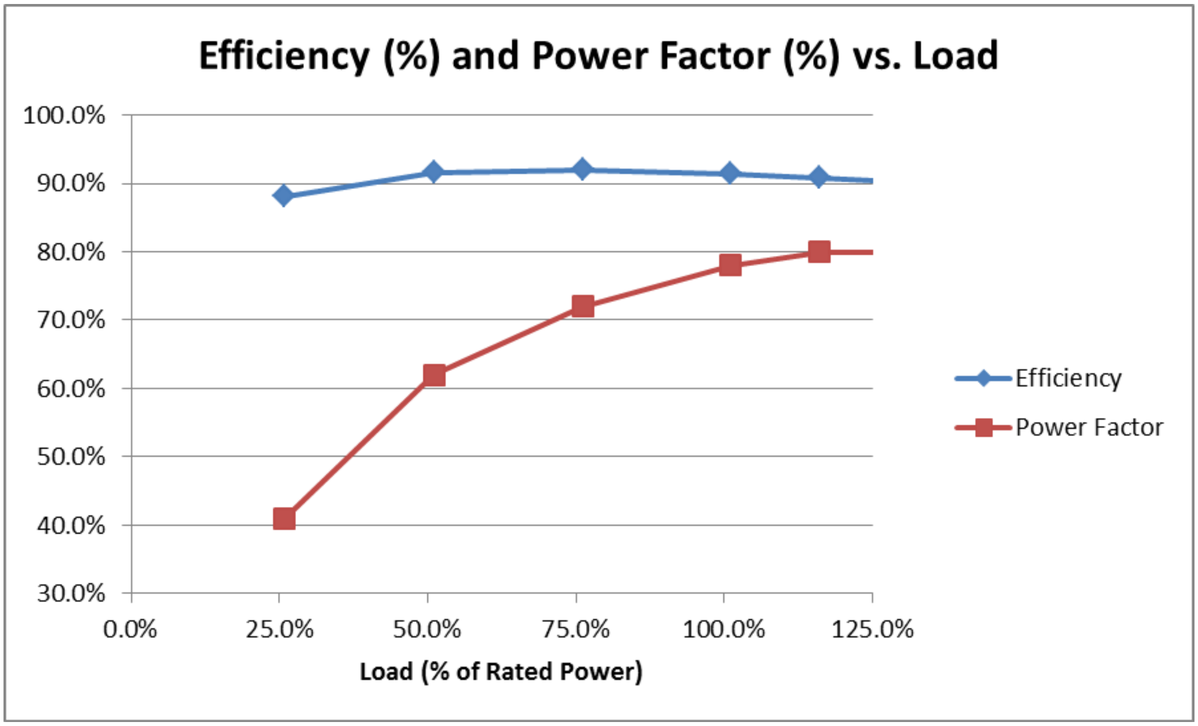

Figure 4.1 5-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.4.2 30-Horsepower, NEMA Design B, Maximum Technology Data and Modeling Results

Table 4.3 30-Horsepower, NEMA Design B, Computer Modeling Data

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	91.7	50.5	15.16
50	94.4	70.9	20.95
75	94.9	77.9	28.46
100	94.7	79.4	37.30
115	94.4	78.7	43.45
125	94.1	77.5	48.10
150	92.5	70.3	64.50

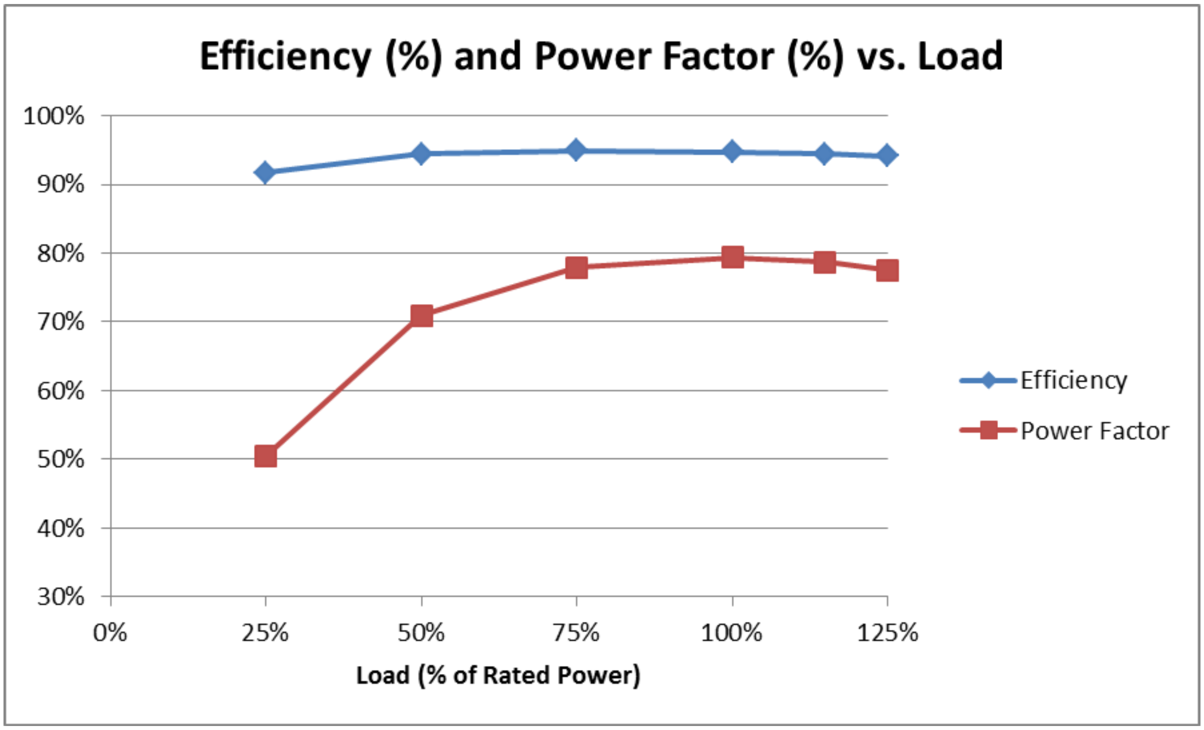

Figure 4.2 30-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.4.3 75-Horsepower, NEMA Design B, Maximum Technology Data and Modeling Results

Table 4.4 75-Horsepower, NEMA Design B, Computer Modeling Data

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	94.3	60	31.20
50	96.0	78	47.15
75	96.3	82	66.76
100	96.2	81	89.82
115	95.9	79	106.27
125	95.6	77	119.46

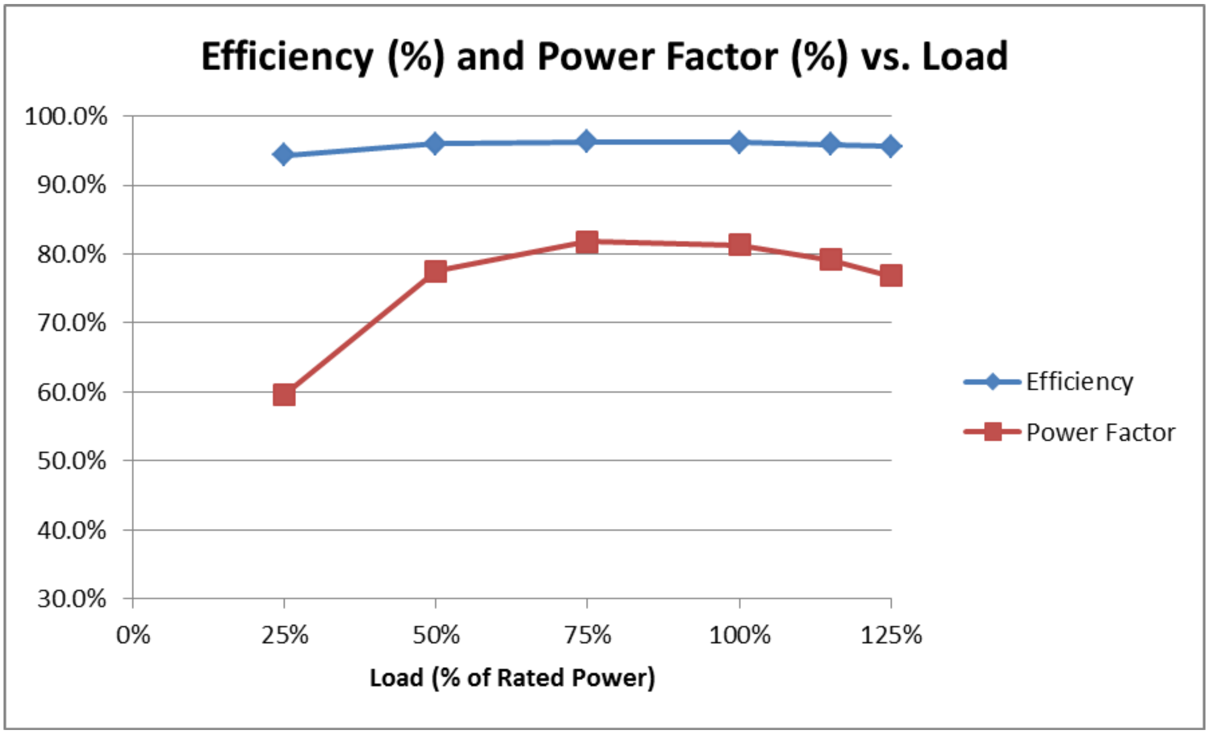

Figure 4.3 75-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.4.4 5-Horsepower, NEMA Design C, Maximum Technology Data and Modeling Results

Table 4.5 5-Horsepower, NEMA Design C, Computer Modeling Data

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	82.6	43	3.29
50	88.9	64	4.10
75	90.7	75	5.20
100	91.0	79	6.49
115	90.9	81	7.35
125	90.7	81	7.96

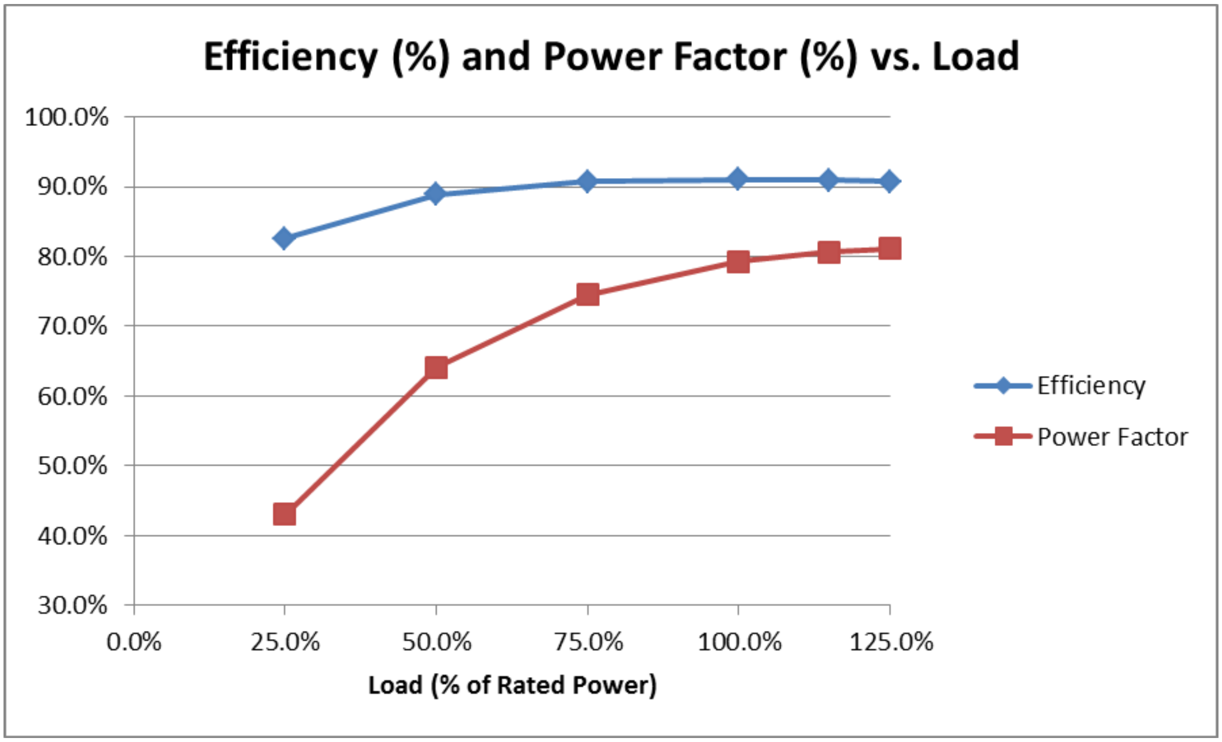

Figure 4.4 5-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load

5A.4.5 50-Horsepower, NEMA Design C, Maximum Technology Data and Modeling Results

Table 4.6 50-Horsepower, NEMA Design C, Computer Modeling Data

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	91.70	52	24.51
50	94.50	72	34.25
75	95.10	79	46.75
100	95.00	80	61.35
115	94.70	80	71.42
125	94.40	79	78.96

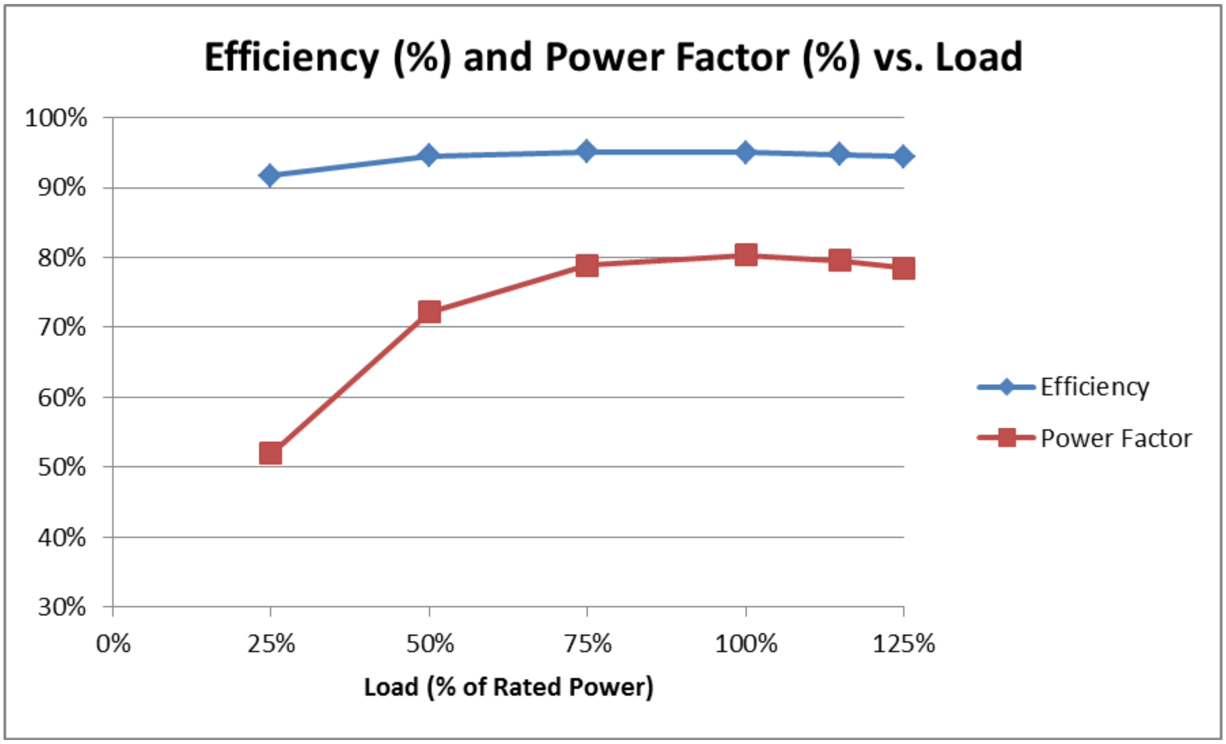

Figure 4.5 50-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load

5-A.5 EFFICIENCY LEVELS

As part of the scaling process, DOE developed efficiency levels (ELs) for each equipment class group using NEMA efficiency tables and incremental improvements of motor losses. Table 5.1–Table 5.17 show the ELs that were developed for the various NEMA design letters, pole configurations, and enclosure types.

Table 5.1 Equipment Class Group 1 at Efficiency Level 0

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	75.5	75.5	75.5	77.0	75.5	80.0	66.0	72.0
1.5	74.0	80.0	77.0	80.0	75.5	75.5	72.0	75.5
2	77.0	82.5	80.0	78.5	78.5	80.0	78.5	80.0
3	80.0	84.0	78.5	80.0	81.5	82.5	80.0	78.5
5	80.0	81.5	82.5	82.5	84.0	85.5	84.0	82.5
7.5	81.5	84.0	84.0	84.0	82.5	81.5	85.5	84.0
10	82.5	85.5	86.5	87.5	84.0	87.5	84.0	85.5
15	85.5	86.5	86.5	87.5	88.5	85.5	88.5	86.5
20	88.5	88.5	87.5	88.5	87.5	87.5	89.5	86.5
25	91.0	89.5	89.5	85.5	91.7	87.5	88.5	87.5
30	89.5	88.5	89.5	87.5	89.5	87.5	91.0	89.5
40	91.0	88.5	91.0	89.5	89.5	88.5	91.0	89.5
50	92.4	88.5	91.0	89.5	90.2	90.2	91.0	91.0
60	92.4	89.5	91.7	90.2	92.4	89.5	91.0	92.4
75	93.0	89.5	93.0	91.0	92.4	89.5	91.7	93.6
100	93.6	91.0	92.4	92.4	93.0	93.0	91.7	93.6
125	94.5	93.6	92.4	93.0	93.6	93.6	92.4	93.6
150	93.6	92.4	93.6	92.4	95.0	93.0	93.6	93.6
200	95.0	93.6	94.5	93.0	94.5	94.1	93.6	93.6
250	94.5	93.6	94.5	93.6	94.1	94.5	94.1	94.5
300	95.4	95.0	94.1	94.5	94.5	95.4	94.5	94.5
350	95.4	95.0	95.0	94.5	94.5	95.0	94.5	94.5
400	95.4	95.4	95.4	95.4	94.5	95.4	94.5	94.5
450	95.4	95.8	95.4	95.4	95.0	95.4	94.5	94.5
500	95.4	95.8	95.4	95.8	95.0	95.4	94.5	94.5

Table 5.2 Equipment Class Group 1 at Efficiency Level 1

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	75.5	75.5	82.5	82.5	80.0	80.0	74.0	74.0
1.5	82.5	82.5	84.0	84.0	85.5	84.0	77.0	75.5
2	84.0	84.0	84.0	84.0	86.5	85.5	82.5	85.5
3	85.5	84.0	87.5	86.5	87.5	86.5	84.0	86.5
5	87.5	85.5	87.5	87.5	87.5	87.5	85.5	87.5
7.5	88.5	87.5	89.5	88.5	89.5	88.5	85.5	88.5
10	89.5	88.5	89.5	89.5	89.5	90.2	88.5	89.5
15	90.2	89.5	91.0	91.0	90.2	90.2	88.5	89.5
20	90.2	90.2	91.0	91.0	90.2	91.0	89.5	90.2
25	91.0	91.0	92.4	91.7	91.7	91.7	89.5	90.2
30	91.0	91.0	92.4	92.4	91.7	92.4	91.0	91.0
40	91.7	91.7	93.0	93.0	93.0	93.0	91.0	91.0
50	92.4	92.4	93.0	93.0	93.0	93.0	91.7	91.7
60	93.0	93.0	93.6	93.6	93.6	93.6	91.7	92.4
75	93.0	93.0	94.1	94.1	93.6	93.6	93.0	93.6
100	93.6	93.0	94.5	94.1	94.1	94.1	93.0	93.6
125	94.5	93.6	94.5	94.5	94.1	94.1	93.6	93.6
150	94.5	93.6	95.0	95.0	95.0	94.5	93.6	93.6
200	95.0	94.5	95.0	95.0	95.0	94.5	94.1	93.6
250	95.4	94.5	95.0	95.4	95.0	95.4	94.5	94.5
300	95.4	95.0	95.4	95.4	95.0	95.4	94.5	94.5
350	95.4	95.0	95.4	95.4	95.0	95.4	94.5	94.5
400	95.4	95.4	95.4	95.4	95.0	95.4	94.5	94.5
450	95.4	95.8	95.4	95.8	95.0	95.4	94.5	94.5
500	95.4	95.8	95.8	95.8	95.0	95.4	94.5	94.5

Table 5.3 Equipment Class Group 1 at Efficiency Level 2

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3	86.5	85.5	89.5	89.5	89.5	88.5	85.5	87.5
5	88.5	86.5	89.5	89.5	89.5	89.5	86.5	88.5
7.5	89.5	88.5	91.7	91.0	91.0	90.2	86.5	89.5
10	90.2	89.5	91.7	91.7	91.0	91.7	89.5	90.2
15	91.0	90.2	92.4	93.0	91.7	91.7	89.5	90.2
20	91.0	91.0	93.0	93.0	91.7	92.4	90.2	91.0
25	91.7	91.7	93.6	93.6	93.0	93.0	90.2	91.0
30	91.7	91.7	93.6	94.1	93.0	93.6	91.7	91.7
40	92.4	92.4	94.1	94.1	94.1	94.1	91.7	91.7
50	93.0	93.0	94.5	94.5	94.1	94.1	92.4	92.4
60	93.6	93.6	95.0	95.0	94.5	94.5	92.4	93.0
75	93.6	93.6	95.4	95.0	94.5	94.5	93.6	94.1
100	94.1	93.6	95.4	95.4	95.0	95.0	93.6	94.1
125	95.0	94.1	95.4	95.4	95.0	95.0	94.1	94.1
150	95.0	94.1	95.8	95.8	95.8	95.4	94.1	94.1
200	95.4	95.0	96.2	95.8	95.8	95.4	94.5	94.1
250	95.8	95.0	96.2	95.8	95.8	95.8	95.0	95.0
300	95.8	95.4	96.2	95.8	95.8	95.8	95.0	95.0
350	95.8	95.4	96.2	95.8	95.8	95.8	95.0	95.0
400	95.8	95.8	96.2	95.8	95.8	95.8	95.0	95.0
450	95.8	96.2	96.2	96.2	95.8	96.2	95.0	95.0
500	95.8	96.2	96.2	96.2	95.8	96.2	95.0	95.0

Table 5.4 Equipment Class Group 1 at Efficiency Level 3

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	78.5	78.5	86.5	86.5	84.0	84.0	77.0	77.0
1.5	85.5	85.5	87.5	87.5	88.5	87.5	80.0	78.5
2	86.5	86.5	87.5	87.5	89.5	88.5	85.5	87.5
3	87.5	86.5	90.2	90.2	90.2	89.5	86.5	88.5
5	89.5	87.5	90.2	90.2	90.2	90.2	87.5	89.5
7.5	90.2	89.5	92.4	91.7	91.7	91.0	87.5	90.2
10	91.0	90.2	92.4	92.4	91.7	92.4	90.2	91.0
15	91.7	91.0	93.0	93.6	92.4	92.4	90.2	91.0
20	91.7	91.7	93.6	93.6	92.4	93.0	91.0	91.7
25	92.4	92.4	94.1	94.1	93.6	93.6	91.0	91.7
30	92.4	92.4	94.1	94.5	93.6	94.1	92.4	92.4
40	93.0	93.0	94.5	94.5	94.5	94.5	92.4	92.4
50	93.6	93.6	95.0	95.0	94.5	94.5	93.0	93.0
60	94.1	94.1	95.4	95.4	95.0	95.0	93.0	93.6
75	94.1	94.1	95.8	95.4	95.0	95.0	94.1	94.5
100	94.5	94.1	95.8	95.8	95.4	95.4	94.1	94.5
125	95.4	94.5	95.8	95.8	95.4	95.4	94.5	94.5
150	95.4	94.5	96.2	96.2	96.2	95.8	94.5	94.5
200	95.8	95.4	96.5	96.2	96.2	95.8	95.0	94.5
250	96.2	95.4	96.5	96.2	96.2	96.2	95.4	95.4
300	96.2	95.8	96.5	96.2	96.2	96.2	95.4	95.4
350	96.2	95.8	96.5	96.2	96.2	96.2	95.4	95.4
400	96.2	96.2	96.5	96.2	96.2	96.2	95.4	95.4
450	96.2	96.5	96.5	96.5	96.2	96.5	95.4	95.4
500	96.2	96.5	96.5	96.5	96.2	96.5	95.4	95.4

Table 5.5 Equipment Class Group 1 at Efficiency Level 4

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	80.0	80.0	87.5	87.5	85.5	85.5	78.5	78.5
1.5	86.5	86.5	88.5	88.5	89.5	88.5	81.5	80.0
2	87.5	87.5	88.5	88.5	90.2	89.5	86.5	88.5
3	88.5	87.5	91.0	91.0	91.0	90.2	87.5	89.5
5	90.2	88.5	91.0	91.0	91.0	91.0	88.5	90.2
7.5	91.0	90.2	93.0	92.4	92.4	91.7	88.5	91.0
10	91.7	91.0	93.0	93.0	92.4	93.0	91.0	91.7
15	92.4	91.7	94.1	94.1	93.0	93.0	91.0	91.7
20	92.4	92.4	94.1	94.1	93.0	93.6	91.7	92.4
25	93.0	93.0	94.5	94.5	94.1	94.1	91.7	92.4
30	93.0	93.0	94.5	95.0	94.1	94.5	93.0	93.0
40	93.6	93.6	95.0	95.0	95.0	95.0	93.0	93.0
50	94.1	94.1	95.4	95.4	95.0	95.0	93.6	93.6
60	94.5	94.5	95.8	95.8	95.4	95.4	93.6	94.1
75	94.5	94.5	96.2	95.8	95.4	95.4	94.5	95.0
100	95.0	94.5	96.2	96.2	95.8	95.8	94.5	95.0
125	95.8	95.0	96.2	96.2	95.8	95.8	95.0	95.0
150	95.8	95.0	96.5	96.5	96.5	96.2	95.0	95.0
200	96.2	95.8	96.8	96.5	96.5	96.2	95.4	95.0
250	96.5	95.8	96.8	96.5	96.5	96.5	95.8	95.8
300	96.5	96.2	96.8	96.5	96.5	96.5	95.8	95.8
350	96.5	96.2	96.8	96.5	96.5	96.5	95.8	95.8
400	96.5	96.5	96.8	96.5	96.5	96.5	95.8	95.8
450	96.5	96.8	96.8	96.8	96.5	96.8	95.8	95.8
500	96.5	96.8	96.8	96.8	96.5	96.8	95.8	95.8

Table 5.6 Equipment Class Group 2 at Efficiency Level 0

	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	82.5	82.5	80.0	80.0	74.0	74.0
1.5	84.0	84.0	85.5	84.0	77.0	75.5
2	84.0	84.0	86.5	85.5	82.5	85.5
3	87.5	86.5	87.5	86.5	84.0	86.5
5	87.5	87.5	87.5	87.5	85.5	87.5
7.5	89.5	88.5	89.5	88.5	85.5	88.5
10	89.5	89.5	89.5	90.2	88.5	89.5
15	91.0	91.0	90.2	90.2	88.5	89.5
20	91.0	91.0	90.2	91.0	89.5	90.2
25	92.4	91.7	91.7	91.7	89.5	90.2
30	92.4	92.4	91.7	92.4	91.0	91.0
40	93.0	93.0	93.0	93.0	91.0	91.0
50	93.0	93.0	93.0	93.0	91.7	91.7
60	93.6	93.6	93.6	93.6	91.7	92.4
75	94.1	94.1	93.6	93.6	93.0	93.6
100	94.5	94.1	94.1	94.1	93.0	93.6
125	94.5	94.5	94.1	94.1	93.6	93.6
150	95.0	95.0	95.0	94.5	93.6	93.6
200	95.0	95.0	95.0	94.5	94.1	93.6

Table 5.7 Equipment Class Group 2 at Efficiency Level 1

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	85.5	85.5	82.5	82.5	75.5	75.5
1.5	86.5	86.5	87.5	86.5	78.5	77.0
2	86.5	86.5	88.5	87.5	84.0	86.5
3	89.5	89.5	89.5	88.5	85.5	87.5
5	89.5	89.5	89.5	89.5	86.5	88.5
7.5	91.7	91.0	91.0	90.2	86.5	89.5
10	91.7	91.7	91.0	91.7	89.5	90.2
15	92.4	93.0	91.7	91.7	89.5	90.2
20	93.0	93.0	91.7	92.4	90.2	91.0
25	93.6	93.6	93.0	93.0	90.2	91.0
30	93.6	94.1	93.0	93.6	91.7	91.7
40	94.1	94.1	94.1	94.1	91.7	91.7
50	94.5	94.5	94.1	94.1	92.4	92.4
60	95.0	95.0	94.5	94.5	92.4	93.0
75	95.4	95.0	94.5	94.5	93.6	94.1
100	95.4	95.4	95.0	95.0	93.6	94.1
125	95.4	95.4	95.0	95.0	94.1	94.1
150	95.8	95.8	95.8	95.4	94.1	94.1
200	96.2	95.8	95.8	95.4	94.5	94.1

Table 5.8 Equipment Class Group 2 at Efficiency Level 2

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	87.5	87.5	85.5	85.5	78.5	78.5
1.5	88.5	88.5	89.5	88.5	81.5	80.0
2	88.5	88.5	90.2	89.5	86.5	88.5
3	91.0	91.0	91.0	90.2	87.5	89.5
5	91.0	91.0	91.0	91.0	88.5	90.2
7.5	93.0	92.4	92.4	91.7	88.5	91.0
10	93.0	93.0	92.4	93.0	91.0	91.7
15	93.6	94.1	93.0	93.0	91.0	91.7
20	94.1	94.1	93.0	93.6	91.7	92.4
25	94.1	94.1	93.6	93.6	91.0	91.7
30	94.1	94.5	93.6	94.1	92.4	92.4
40	94.5	94.5	94.5	94.5	92.4	92.4
50	95.0	95.0	94.5	94.5	93.0	93.0
60	95.4	95.4	95.0	95.0	93.0	93.6
75	95.8	95.4	95.0	95.0	94.1	94.5
100	95.8	95.8	95.4	95.4	94.1	94.5
125	95.8	95.8	95.4	95.4	94.5	94.5
150	96.2	96.2	96.2	95.8	94.5	94.5
200	96.5	96.2	96.2	95.8	95.0	94.5

Table 5.9 Equipment Class Group 3 at Efficiency Level 0

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	75.5	75.5	82.5	82.5	80.0	80.0	74.0	74.0
1.5	82.5	82.5	84.0	84.0	85.5	84.0	77.0	75.5
2	84.0	84.0	84.0	84.0	86.5	85.5	82.5	85.5
3	85.5	84.0	87.5	86.5	87.5	86.5	84.0	86.5
5	87.5	85.5	87.5	87.5	87.5	87.5	85.5	87.5
7.5	88.5	87.5	89.5	88.5	89.5	88.5	85.5	88.5
10	89.5	88.5	89.5	89.5	89.5	90.2	88.5	89.5
15	90.2	89.5	91.0	91.0	90.2	90.2	88.5	89.5
20	90.2	90.2	91.0	91.0	90.2	91.0	89.5	90.2
25	91.0	91.0	92.4	91.7	91.7	91.7	89.5	90.2
30	91.0	91.0	92.4	92.4	91.7	92.4	91.0	91.0
40	91.7	91.7	93.0	93.0	93.0	93.0	91.0	91.0
50	92.4	92.4	93.0	93.0	93.0	93.0	91.7	91.7
60	93.0	93.0	93.6	93.6	93.6	93.6	91.7	92.4
75	93.0	93.0	94.1	94.1	93.6	93.6	93.0	93.6
100	93.6	93.0	94.5	94.1	94.1	94.1	93.0	93.6
125	94.5	93.6	94.5	94.5	94.1	94.1	93.6	93.6
150	94.5	93.6	95.0	95.0	95.0	94.5	93.6	93.6
200	95.0	94.5	95.0	95.0	95.0	94.5	94.1	93.6
250	95.4	94.5	95.0	95.4	95.0	95.4	94.5	94.5
300	95.4	95.0	95.4	95.4	95.0	95.4	94.5	94.5
350	95.4	95.0	95.4	95.4	95.0	95.4	94.5	94.5
400	95.4	95.4	95.4	95.4	95.0	95.4	94.5	94.5
450	95.4	95.8	95.4	95.8	95.0	95.4	94.5	94.5
500	95.4	95.8	95.8	95.8	95.0	95.4	94.5	94.5

Table 5.10 Equipment Class Group 3 at Efficiency Level 1

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3	86.5	85.5	89.5	89.5	89.5	88.5	85.5	87.5
5	88.5	86.5	89.5	89.5	89.5	89.5	86.5	88.5
7.5	89.5	88.5	91.7	91.0	91.0	90.2	86.5	89.5
10	90.2	89.5	91.7	91.7	91.0	91.7	89.5	90.2
15	91.0	90.2	92.4	93.0	91.7	91.7	89.5	90.2
20	91.0	91.0	93.0	93.0	91.7	92.4	90.2	91.0
25	91.7	91.7	93.6	93.6	93.0	93.0	90.2	91.0
30	91.7	91.7	93.6	94.1	93.0	93.6	91.7	91.7
40	92.4	92.4	94.1	94.1	94.1	94.1	91.7	91.7
50	93.0	93.0	94.5	94.5	94.1	94.1	92.4	92.4
60	93.6	93.6	95.0	95.0	94.5	94.5	92.4	93.0
75	93.6	93.6	95.4	95.0	94.5	94.5	93.6	94.1
100	94.1	93.6	95.4	95.4	95.0	95.0	93.6	94.1
125	95.0	94.1	95.4	95.4	95.0	95.0	94.1	94.1
150	95.0	94.1	95.8	95.8	95.8	95.4	94.1	94.1
200	95.4	95.0	96.2	95.8	95.8	95.4	94.5	94.1
250	95.8	95.0	96.2	95.8	95.8	95.8	95.0	95.0
300	95.8	95.4	96.2	95.8	95.8	95.8	95.0	95.0
350	95.8	95.4	96.2	95.8	95.8	95.8	95.0	95.0
400	95.8	95.8	96.2	95.8	95.8	95.8	95.0	95.0
450	95.8	96.2	96.2	96.2	95.8	96.2	95.0	95.0
500	95.8	96.2	96.2	96.2	95.8	96.2	95.0	95.0

Table 5.11 Equipment Class Group 3 at Efficiency Level 2

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	78.5	78.5	86.5	86.5	84.0	84.0	77.0	77.0
1.5	85.5	85.5	87.5	87.5	88.5	87.5	80.0	78.5
2	86.5	86.5	87.5	87.5	89.5	88.5	85.5	87.5
3	87.5	86.5	90.2	90.2	90.2	89.5	86.5	88.5
5	89.5	87.5	90.2	90.2	90.2	90.2	87.5	89.5
7.5	90.2	89.5	92.4	91.7	91.7	91.0	87.5	90.2
10	91.0	90.2	92.4	92.4	91.7	92.4	90.2	91.0
15	91.7	91.0	93.0	93.6	92.4	92.4	90.2	91.0
20	91.7	91.7	93.6	93.6	92.4	93.0	91.0	91.7
25	92.4	92.4	94.1	94.1	93.6	93.6	91.0	91.7
30	92.4	92.4	94.1	94.5	93.6	94.1	92.4	92.4
40	93.0	93.0	94.5	94.5	94.5	94.5	92.4	92.4
50	93.6	93.6	95.0	95.0	94.5	94.5	93.0	93.0
60	94.1	94.1	95.4	95.4	95.0	95.0	93.0	93.6
75	94.1	94.1	95.8	95.4	95.0	95.0	94.1	94.5
100	94.5	94.1	95.8	95.8	95.4	95.4	94.1	94.5
125	95.4	94.5	95.8	95.8	95.4	95.4	94.5	94.5
150	95.4	94.5	96.2	96.2	96.2	95.8	94.5	94.5
200	95.8	95.4	96.5	96.2	96.2	95.8	95.0	94.5
250	96.2	95.4	96.5	96.2	96.2	96.2	95.4	95.4
300	96.2	95.8	96.5	96.2	96.2	96.2	95.4	95.4
350	96.2	95.8	96.5	96.2	96.2	96.2	95.4	95.4
400	96.2	96.2	96.5	96.2	96.2	96.2	95.4	95.4
450	96.2	96.5	96.5	96.5	96.2	96.5	95.4	95.4
500	96.2	96.5	96.5	96.5	96.2	96.5	95.4	95.4

Table 5.12 Equipment Class Group 3 at Efficiency Level 3

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	80.0	80.0	87.5	87.5	85.5	85.5	78.5	78.5
1.5	86.5	86.5	88.5	88.5	89.5	88.5	81.5	80.0
2	87.5	87.5	88.5	88.5	90.2	89.5	86.5	88.5
3	88.5	87.5	91.0	91.0	91.0	90.2	87.5	89.5
5	90.2	88.5	91.0	91.0	91.0	91.0	88.5	90.2
7.5	91.0	90.2	93.0	92.4	92.4	91.7	88.5	91.0
10	91.7	91.0	93.0	93.0	92.4	93.0	91.0	91.7
15	92.4	91.7	94.1	94.1	93.0	93.0	91.0	91.7
20	92.4	92.4	94.1	94.1	93.0	93.6	91.7	92.4
25	93.0	93.0	94.5	94.5	94.1	94.1	91.7	92.4
30	93.0	93.0	94.5	95.0	94.1	94.5	93.0	93.0
40	93.6	93.6	95.0	95.0	95.0	95.0	93.0	93.0
50	94.1	94.1	95.4	95.4	95.0	95.0	93.6	93.6
60	94.5	94.5	95.8	95.8	95.4	95.4	93.6	94.1
75	94.5	94.5	96.2	95.8	95.4	95.4	94.5	95.0
100	95.0	94.5	96.2	96.2	95.8	95.8	94.5	95.0
125	95.8	95.0	96.2	96.2	95.8	95.8	95.0	95.0
150	95.8	95.0	96.5	96.5	96.5	96.2	95.0	95.0
200	96.2	95.8	96.8	96.5	96.5	96.2	95.4	95.0
250	96.5	95.8	96.8	96.5	96.5	96.5	95.8	95.8
300	96.5	96.2	96.8	96.5	96.5	96.5	95.8	95.8
350	96.5	96.2	96.8	96.5	96.5	96.5	95.8	95.8
400	96.5	96.5	96.8	96.5	96.5	96.5	95.8	95.8
450	96.5	96.8	96.8	96.8	96.5	96.8	95.8	95.8
500	96.5	96.8	96.8	96.8	96.5	96.8	95.8	95.8

Table 5.13 Equipment Class Group 4 at Efficiency Level 0

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	75.5	77.0	75.5	80.0	66.0	72.0
1.5	77.0	80.0	75.5	75.5	72.0	75.5
2	80.0	78.5	78.5	80.0	78.5	80.0
3	78.5	80.0	81.5	82.5	80.0	78.5
5	82.5	82.5	84.0	85.5	84.0	82.5
7.5	84.0	84.0	82.5	81.5	85.5	84.0
10	86.5	87.5	84.0	87.5	84.0	85.5
15	86.5	87.5	88.5	85.5	88.5	86.5
20	87.5	88.5	87.5	87.5	89.5	86.5
25	89.5	85.5	91.7	87.5	88.5	87.5
30	89.5	87.5	89.5	87.5	91.0	89.5

Table 5.14 Equipment Class Group 4 at Efficiency Level 1

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	82.5	82.5	80.0	80.0	74.0	74.0
1.5	84.0	84.0	85.5	84.0	77.0	75.5
2	84.0	84.0	86.5	85.5	82.5	85.5
3	87.5	86.5	87.5	86.5	84.0	86.5
5	87.5	87.5	87.5	87.5	85.5	87.5
7.5	89.5	88.5	89.5	88.5	85.5	88.5
10	89.5	89.5	89.5	90.2	88.5	89.5
15	91.0	91.0	90.2	90.2	88.5	89.5
20	91.0	91.0	90.2	91.0	89.5	90.2
25	92.4	91.7	91.7	91.7	89.5	90.2
30	92.4	92.4	91.7	92.4	91.0	91.0

Table 5.15 Equipment Class Group 4 at Efficiency Level 2

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	85.5	85.5	82.5	82.5	75.5	75.5
1.5	86.5	86.5	87.5	86.5	78.5	77.0
2	86.5	86.5	88.5	87.5	84.0	86.5
3	89.5	89.5	89.5	88.5	85.5	87.5
5	89.5	89.5	89.5	89.5	86.5	88.5
7.5	91.7	91.0	91.0	90.2	86.5	89.5
10	91.7	91.7	91.0	91.7	89.5	90.2
15	92.4	93.0	91.7	91.7	89.5	90.2
20	93.0	93.0	91.7	92.4	90.2	91.0
25	93.6	93.6	93.0	93.0	90.2	91.0
30	93.6	94.1	93.0	93.6	91.7	91.7

Table 5.16 Equipment Class Group 4 at Efficiency Level 3

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	86.5	86.5	84.0	84.0	77.0	77.0
1.5	87.5	87.5	88.5	87.5	80.0	78.5
2	87.5	87.5	89.5	88.5	85.5	87.5
3	90.2	90.2	90.2	89.5	86.5	88.5
5	90.2	90.2	90.2	90.2	87.5	89.5
7.5	92.4	91.7	91.7	91.0	87.5	90.2
10	92.4	92.4	91.7	92.4	90.2	91.0
15	93.0	93.6	92.4	92.4	90.2	91.0
20	93.6	93.6	92.4	93.0	91.0	91.7
25	94.1	94.1	93.6	93.6	91.0	91.7
30	94.1	94.5	93.6	94.1	92.4	92.4

Table 5.17 Equipment Class Group 4 at Efficiency Level 4

	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	87.5	87.5	85.5	85.5	78.5	78.5
1.5	88.5	88.5	89.5	88.5	81.5	80.0
2	88.5	88.5	90.2	89.5	86.5	88.5
3	91.0	91.0	91.0	90.2	87.5	89.5
5	91.0	91.0	91.0	91.0	88.5	90.2
7.5	93.0	92.4	92.4	91.7	88.5	91.0
10	93.0	93.0	92.4	93.0	91.0	91.7
15	94.1	94.1	93.0	93.0	91.0	91.7
20	94.1	94.1	93.0	93.6	91.7	92.4
25	94.5	94.5	94.1	94.1	91.7	92.4
30	94.5	95.0	94.1	94.5	93.0	93.0

5-A.6 MATERIAL PRICING ASSUMPTIONS

DOE gathered material pricing information from numerous sources, including subject matter experts (SMEs), manufacturers, internal material pricing databases developed from research on other rulemakings, the U.S. Census Bureau's Producer Price Index, the London Metal Exchange and the Commodity Exchange, Inc. DOE used a 2012 dollar pricing for a majority of the materials, but for copper wire and cast copper prices DOE used a three-year average dating from 2010–2012.

5A.6.1 Copper Wire Pricing

DOE used a three-year average price for copper due to the large price fluctuations in copper wire and copper used for casting. The three-year average copper pricings are displayed in Table 6.1. DOE used a constant price for all wire gauges due to the small pricing differences between the different wire gauges. After averaging the three years of data, DOE marked up the copper wire prices by a constant 30% to account for processing of the raw material.

Table 6.1 Copper Material Pricing

Material Type	3 Year Average	Year		
Cu Wire ($/lb)	2012–2010	2012	2011	2010
Cu Wire, Gauge 14 & 14.5	$4.66*	$3.61	$4.00	$3.15
Cu Wire, Gauge 15 & 15.5	$4.66*	$3.61	$4.00	$3.15
Cu Wire, Gauge 16 & 16.5	$4.66*	$3.61	$4.00	$3.15
Cu Wire, Gauge 17 & 17.5	$4.66*	$3.61	$4.00	$3.15
Cu Wire, Gauge 18 & 18.5	$4.66*	$3.61	$4.00	$3.15
Cu Wire, Gauge 19 , 19.5, 20 &20.5	$4.66*	$3.61	$4.00	$3.15
Casting Materials ($/lb)				
Casting Materials - Copper	$3.59	$3.61	$4.00	$3.15

*Includes 30% markup to account for processing of raw material

5A.6.2 2011 Material Pricing

DOE used a constant 2012$ pricing for the remaining materials which include electrical steels, aluminum for casting, cast iron, and hot rolled steel. These price assumptions are displayed in Table 6.2.

Table 6.2 Material Pricing in Constant 2011$

Motor Frame/End Bell Material ($/lb)	
Frame Material - Cast Iron 20k-30k psi	$0.58
Frame Material - Steel Fabrication	$0.45
Frame Material - Aluminum (extruded or cast)	$1.15
Casting Materials ($/lb)	
Casting Materials - Aluminum	$1.15
Core Steels - ASTM #, Thickness, Processing ($/lb)	
26M12, .0185", fully/semi-processed	$1.04
26M15, .0185", fully/semi-processed	$1.00
26M19, .0185", fully/semi-processed	$0.97
26M22, .0185", fully/semi-processed	$0.90
26M27, .0185", fully/semi-processed	$0.84
26M36, .0185", fully/semi-processed	$0.76
26M47, .0185", fully/semi-processed	$0.74
26M56, .0185", fully/semi-processed	$0.69
Rotor Shaft ($/lb)	
Hot Rolled AISI #1040 Series	$0.51
Bearings ($/each)	
Front Bearing, 5-HP	$4.62
Back Bearing, 5-HP	$3.37
Front Bearing, 30-HP	$15.31

Back Bearing, 30-HP	$10.14
Front Bearing, 50-HP	$16.55
Back Bearing, 50-HP	$11.12
Front Bearing, 75-HP	$32.02
Back Bearing, 75-HP	$27.38

5-A.7 LABOR TIME AND COST ASSUMPTIONS

DOE estimated labor hours for each EL of each representative unit. DOE requested information from manufacturers concerning labor time associated with certain electric motor horsepower ratings. A summary of these labor time estimates is displayed in Table 7.1. Due to the limited manufacturer feedback, DOE relied primarily on SME input to derive the time requirements to build the representative units. For the purchased representative units (EL 0-3 for the NEMA Design B motors and EL 0 for the NEMA Design C motors) DOE relied on visual inspection by motor industry experts to determine if a motor was machine or hand wound. All software-modeled motors with a slot fill greater than 82%, including all max-tech ELs, were considered hand wound. Approximate slot fill percentages are displayed in Table 7.2. Furthermore, any software-modeled motors with a slot fill

Table 7.1 Labor Hour Assumptions by Efficiency Level (EL)

HP Rating	EL 0	EL 1	EL 2	EL 3	EL 4
5, Design B	1.50 hrs	1.58 hrs	1.65 hrs	1.74 hrs	4.50 hrs*
30, Design B	3.11 hrs	3.27 hrs	3.43 hrs	3.60 hrs	6.75 hrs*
75, Design B	5.72 hrs	6.01 hrs	6.29 hrs	6.64 hrs	11.34 hrs*
5, Design C	1.58 hrs	1.66 hrs	4.54 hrs*	-	-
50, Design C	4.00 hrs	9.00 hrs*	9.45 hrs*	-	-

* Based on slot fill calculations, DOE assumed a hand-wound labor hour amount for these motors

Table 7.2 Slot Fill Percentages by Efficiency Level (EL)

HP Rating	EL 0	EL 1	EL 2	EL 3	EL 4
5, Design B	38.7%	51.7%	70.0%	54.5%	53.3%
30, Design B	47.5%	64.8%	50.9%	70.0%	83.2%
75, Design B	50.9%	35.0%	70.0%	70.0%	85.1%
5, Design C	53.3%	79.9%	82.9%	—	—
50, Design C	62.5%	85.3%	81.3%	—	—

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APPENDIX 5-B SAMPLE TEAR-DOWN REPORT

5-B.1 FIVE-HORSEPOWER NEMA DESIGN B, 4-POLE ELECTRIC MOTOR TEAR-DOWN REPORT

The U.S. Department of Energy (DOE) derived the electric motor production and material costs for the engineering analysis by purchasing a sample of electric motors, and then having a professional motor testing laboratory disassemble each motor and inventory the component parts. DOE performed tear downs on the electric motors representing efficiency level (EL) 0, EL 1, EL 2,and EL 3 for the National Electrical Manufacturers Association (NEMA) Design B equipment-class group (ECG1). For the 5-horsepower representative unit in ECG 1, DOE also performed a tear down at EL4. Electric motors representing EL 0 were torn down for all the representative units for the NEMA Design C equipment-class group (equipment-class group 2). These tear-downs provided DOE the necessary data to construct a bill of materials that DOE could normalize, using a standard cost model and markup, to produce a projected manufacturer selling price. Table 5B.1 shows a sample tear-down report for one of the five-horsepower (5-HP) NEMA Design B, 4-pole, totally enclosed, fan cooled electric motors purchased by DOE.

Table 5-B.1 Sample Tear-Down Report of a 5-HP, NEMA Design B, Electric Motor

Stator Assembly		
Steel Laminations (M47 Grade, 0.0185" Thick)	29.40	lb
Copper Wire (3#20 AWG)	12.20	
Rotor Assembly		
Steel Laminations (M47 Grade, 0.0185" Thick)	17.00	lb
Aluminum (Cast)	3.42	lb
Shaft (Steel)	4.50	lb
Other Major Costs		
Steel Frame and Bolt on Steel Base (9.6 lb)	9.60	lb
Terminal Housing (Steel)	1.00	lb
Bearing 207	1.00	ea
Bearing 205	1.00	ea
End bell (Aluminum) (PE)	12	lb
Stator Hardware		
Slot Liner (Nomex)	6.05	sq-ft
Top Stick (Nomex)	6.05	sq-ft
Coil Extension Insulation (Phase Paper)	1.00	sq-ft
Lead Wire Thermal Insulation Sleeve	12.00	ft
Lead Wire	0.25	lb
Lace Cord	36.00	ft
Varnish	0.025	Gal
Miscellaneous Hardware		

Fan Cover (Plastic)	1.00	ea
Fan (Plastic)	1.00	ea
Wave Spring (Steel)	1.00	ea
Axial Thrust Nut Ring 2 Holes (Steel)	1.00	ea
Terminal Housing Cover (Steel)	1.00	ea
Rubber Groumet Cover (Over Thrust Bolts)	1.00	ea
Terminal Housing Base Gasket (Foam)	1.00	ea
Terminal Housing Cover Gasket (Foam)	1.00	ea
Axial Thrust Bolts (#10 x 2/75)	2.00	ea
Terminal Housing Mounting Bolts (1/4-20 x .5)	4.00	ea
Terminal Housing Cover Bolts (#10 x .375)	2.00	ea
Stator Axial Tie Bolts (6 mm x 10.5)	4.00	ea
Fan Cover Mounting Bolts (1/4 x .5)	2.00	ea
Ground Connection Screw	1.00	ea
Grease Port Screws	4.00	ea

APPENDIX 5-C EFFICIENCY MODELING VALIDATION

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APPENDIX 5-C EFFICIENCY MODELING COMPARISON

5-C.1 INTRODUCTION

DOE worked with technical experts to develop certain ELs, in particular, the max-tech efficiency levels for each representative unit analyzed. The software program that DOE used for its analysis is a proprietary software program called VICA.[1] DOE retained an electric motors subject matter expert (SME)[2] with design and software experience, who prepared a set of designs with increasing efficiency. The SME also checked his designs against tear-down data and calibrated his software using the relevant test results.

In response to the preliminary analysis, multiple stakeholders requested clarification on how DOE compared its software modeled results to the electric motors that it had tested and torn down. Table 5-C.1 details the comparisons between the torn down motors and correlated software models.

Table 5-C.1 Comparison of Tested and Softwared Calculated Efficiency

Horsepower	Rotor Construction	Rated Nominal Efficiency	IEEE 112B Tested Efficiency	Software Calculated Efficiency	Difference (Tested − Calculated)
5	Aluminum	89.5%	89.1%	88.9%	−0.2%
5	Copper	91.0%	91.5%	91.2%	−0.3%
30	Aluminum	94.1%	93.9%	93.5%	−0.4%
75	Aluminum	95.4%	95.45%	95.3%	−0.2%
75	Aluminum	95.8%	95.3%	95.4%	+0.2%

[1] VICA stands for "Veinott Interactive Computer Aid."
[2] Dr. Howard Jordan, Ph.D, an electric motor design expert with over 40 years of industry experience served as DOE's subject matter expert.

APPENDIX 7-A ENERGY USE SCENARIO FOR ELECTRIC MOTORS WITH HIGHER OPERATING SPEEDS

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APPENDIX 7-A ENERGY USE SCENARIO FOR ELECTRIC MOTORS WITH HIGHER OPERATING SPEEDS

7-A.1 BACKGROUND

The installation of a higher efficiency motor alone may increase the energy consumption for a particular application, instead of realizing energy savings. A more efficient squirrel-cage induction motor usually has less slip than an older less efficient motor because of a reduction in the resistance of the rotor. This results in higher operating speed and potential overloading of the motor. The U.S. Department of Energy (DOE) acknowledges that the cubic relationship between speed and power requirement in certain fan, pump, and centrifugal compressor applications can affect the benefits gained by efficient motors which have a lower slip. This appendix describes the methodology DOE used to estimate this effect as a sensitivity analysis in the Life-Cycle-Cost spreadsheet at http://www.eere.energy.gov/buildings/appliance_standards .

7-A.2 METHOD FOR DETERMINING ENERGY SAVING IN VARIABLE TORQUE APPLICATIONS

DOE based its methodology on a previous publication[a] which states the following:

In the case where there is a cubic relationship between the power and the speed,

$$Po_{EE}(L) = Po_{BE}(L).\frac{\omega_{EE}(L)^3}{\omega_{BE}(L)^3}$$

Where:
L is the load in percentage
$Po_{EE}(L)$ is the output power of the energy efficient motor
$Po_{BE}(L)$ is the output power of the baseline efficiency motor
$\omega_{EE}(L)$ is the operating speed of the energy efficient motor
$\omega_{BE}(L)$ is the operating speed of the baseline efficient motor

When the operating speeds are the same then:

$$Po_{EE}(L) = Po_{BE}(L)$$

If the more efficient motor has a higher speed then it produces more output power then required by the application:

$$Po_{EE}(L) > Po_{BE}(L)$$

---

[a] P. Pillay. *Practical considerations in applying energy efficient motors in the petrochemical industry*. Petroleum and Chemical Industry Conference, 1995. Record of Conference Papers., Industry Applications Society 42nd Annual.

If the only useful power is that generated by the baseline motor ($Po_{BE}(L)$), then the "effective" losses[b] of the energy efficient motor are:

$$Losses(L) = Pin_{EE}(L) - Po_{BE}(L)$$

Where:
$Pin_{EE}(L)$ is the input power of the energy efficient motor.

The efficiency of the EE motor is $\eta_{EE}(L)$ and $Pin_{EE}(L)$ is:

$$Pin_{EE}(L) = \frac{Po_{EE}(L)}{\eta_{EE}(L)}$$

And:

$$Pin_{EE}(L) = Po_{BE}(L).\frac{\omega_{EE}(L)^3}{\omega_{BE}(L)^3}.\frac{1}{\eta_{EE}(L)}$$

Then the "effective" losses of the EE motor are:

$$Losses(L) = Po_{BE}(L)(\frac{\omega_{EE}(L)^3}{\omega_{BE}(L)^3}.\frac{1}{\eta_{EE}(L)} - 1) \text{ [Equation 1]}$$

If the end-user does not adjust for the higher speed of the energy efficient motor, then the losses experienced will be greater than if the operating speeds remain constant.

DOE calculated "effective" losses vs. load tables based on Equation 1 and used these values to estimate the energy use of higher efficiency motors in variable torque applications which would not benefit from higher operating speeds.

7-A.3 ASSUMPTIONS TO DETERMINE ENERGY SAVINGS IN VARIABLE TORQUE APPLICATIONS

No sufficient solid data was found to estimate the share of motors which are negatively impacted by higher operating speeds. DOE therefore considered a scenario described by the two following main assumptions: (1) the share of motors which are negatively impacted by higher operating speeds, and (2) the actual operating speed of the motor in the field.

7-A.3.1 Share of motors negatively impacted by higher operating speeds

DOE assumed that 60 percent of pumps, fans and compressor applications are variable torque applications.

[b] The "effective" losses experienced are not losses, they include the increased load imposed by increased speeds associated with variable torque applications.

Of these 60 percent, DOE assumed that all fans and a majority (70 percent) of compressors and pumps would be negatively impacted by higher operating speeds; and that 30 percent of compressors and pumps would not be negatively impacted from higher operating speeds as their time of use would decrease as the flow increases with the speed (e.g. a pump filling a reservoir).[c] DOE assumed this revolutions per minute (RPM) effect did not impact fire pump motors.

When choosing to run the life-cycle cost (LCC) spreadsheet based on the “RPM scenario” the LCC results are based on the “effective” losses for 60 percent of all fans and 42 percent of all compressors and pumps applications. This does not account for the share of users who adjust for increased motor speed.

7-A.4 SENSITIVITY ANALYSIS

The results provided by applying this methodology do not account for motors which are positively impacted for higher operating speeds and rely on two major assumptions: (1) the share of motors which are negatively impacted by higher operating speeds, and (2) the actual operating speed of the motor in the field. DOE believes the data supporting these assumptions is not sufficiently robust to incorporate this effect in the main analysis and therefore incorporated it as a sensitivity scenario in the LCC spreadsheet.

---

[c] This corresponds to 0.6 percent of fan applications being negatively impacted and 0.6x0.7 =0.42 percent of compressor and pump applications being negatively impacted by an increase in RPM.

APPENDIX 8-A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

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APPENDIX 8-A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

To utilize the life-cycle cost (LCC) spreadsheet, it is necessary for the user to have the appropriate hardware and software tools. The U.S. Department of Energy (DOE) assumes the user has a reasonably current computer operating under the Windows operating system. The development team uses relatively new systems and has not defined the minimum system requirements. Users need Microsoft Excel to execute the spreadsheet. For full functionality, users need a copy of Oracle Crystal Ball.

8-A.1 STARTUP

The LCC spreadsheet can be found on the DOE website at http://www.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/42. Open the file. (Each computer system will have a unique setup for loading a file. Users should refer to their software manuals if they have problems loading the spreadsheet file.) For users new to Excel and/or Crystal Ball, section 8.8.2 contains basic instructions for operating the LCC spreadsheets.

8-A.2 ELECTRIC MOTORS WORKSHEET OVERVIEW

The LCC spreadsheet for electric motors contains the following worksheets:

Summary Results

This worksheet contains input selections and summary results tables.

LCC and Payback

This worksheet reports calculations for a single sample.

Definitions

This worksheet contains values used to populate the spreadsheet's form elements.

Rebuttable Payback

This worksheet calculates and presents the rebuttable payback period for each of the representative units.

Energy Use

This worksheet calculates annual electricity use.

Equipment Price

This worksheet calculates retail equipment price and total installed cost inputs.

Sectors and Applications

This worksheet calculates input data regarding sector, application, hours of operation, and motor loading.

Energy Price

This worksheet calculates electricity price input data for the industrial, commercial, and agricultural sectors.

Energy Price Trend

This worksheet contains AEO 2013 price trend information.

Discount Rate

This worksheet contains the discount rate analysis.

Lifetime

This worksheet contains lifetime distributions.

Base Case Eff Dist

This worksheet contains efficiency distributions.

8-A.3 BASIC INSTRUCTIONS FOR OPERATING THE LIFE-CYCLE COST SPREADSHEET

1. Download and open the spreadsheet.
2. Select choices from the various user-selectable options.
3. Click the "Run" button to run the simulation using DOE's parameters.

To produce sensitivity results directly using Crystal Ball, select custom inputs on the "Summary" worksheet and click the "Run" button. Once Crystal Ball has completed the simulation, it will produce a series of distributions. To view these distributions, users can either interact with Crystal Ball or utilize VBA macros stored in the spreadsheet. To generate various charts, after the simulation has completed run the macro "Clear" followed by "CopyAll." Charts will be available in the hidden worksheets "LCC/PBP Box Plots" and LCC/PBP Frequency Charts."

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APPENDIX 8B. LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

8B.1 DISTRIBUTION OF LIFE-CYCLE COST RESULTS

The distributions presented in this section each correspond to example runs of 10,000 Monte Carlo samples.

8B.1.1 Representative Unit 1, NEMA Design B, 5 Horsepower, Four Poles, Enclosed Motor

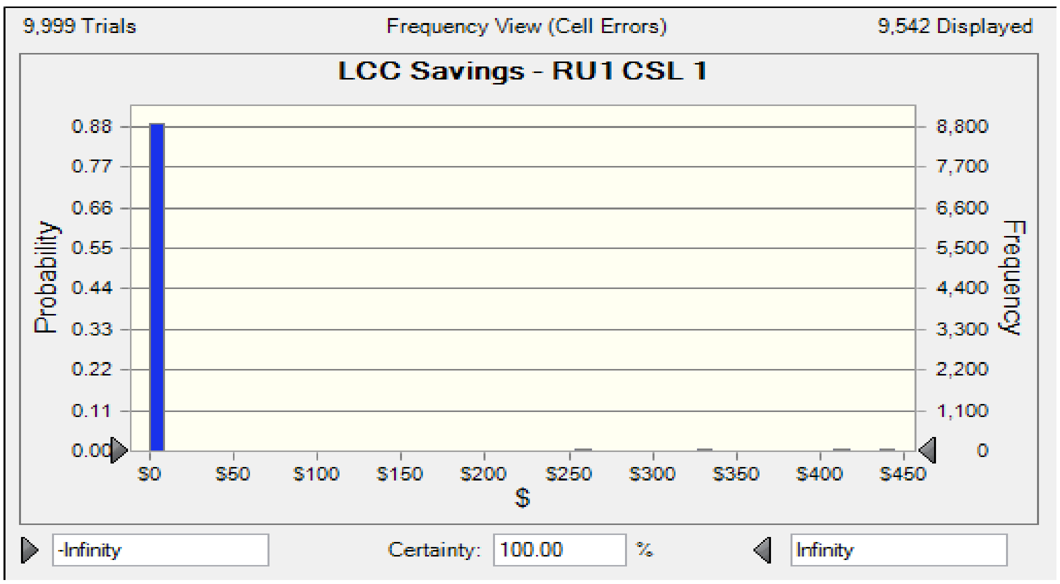


Figure 8B.1.1 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 1

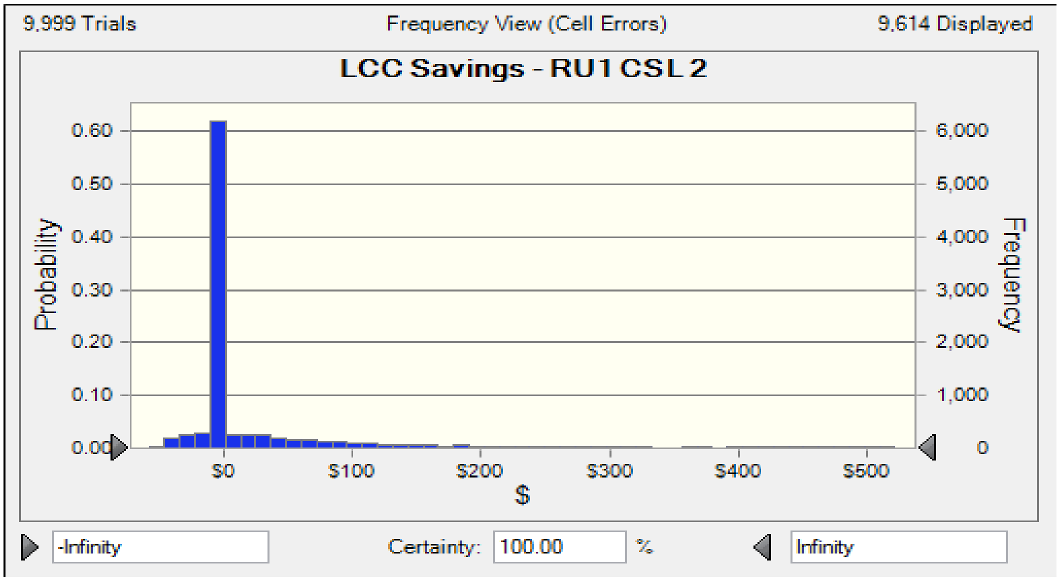


Figure 8B.1.2 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 2

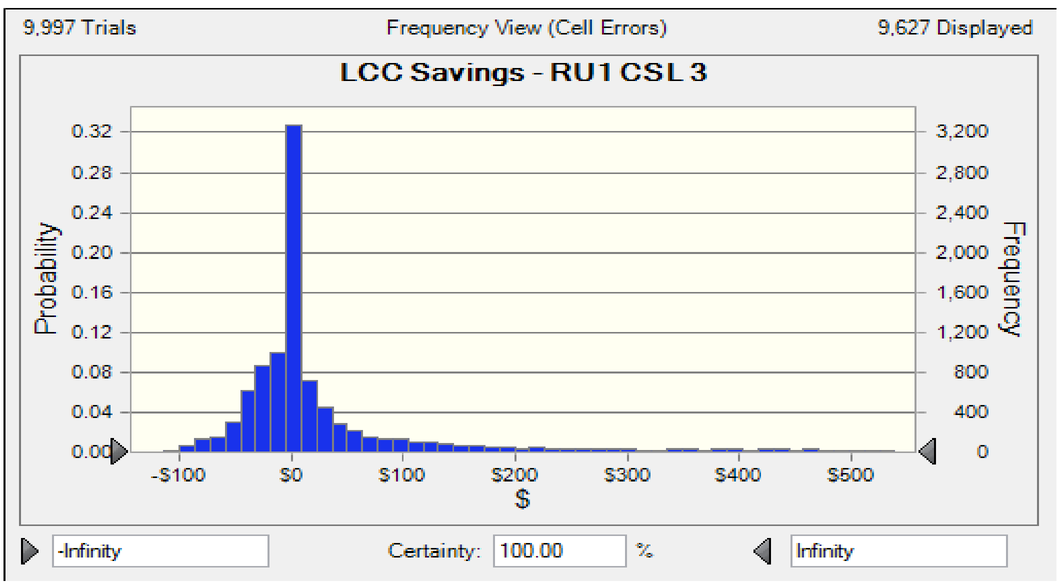


Figure 8B.1.3 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 3

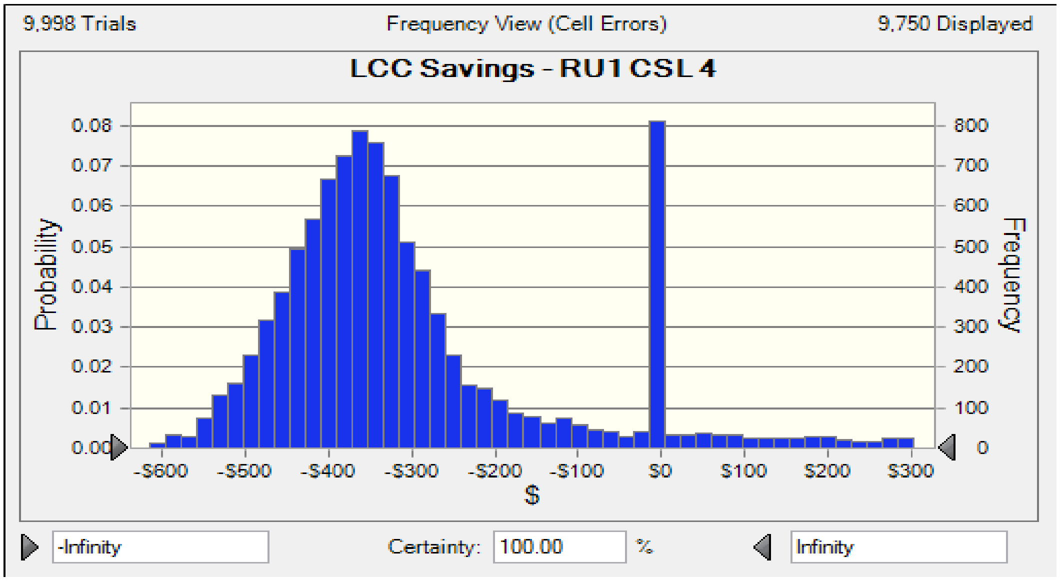


Figure 8B.1.4 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 4

8B.1.2 Representative Unit 2, NEMA Design B, 30 Horsepower, Four Poles, Enclosed Motor

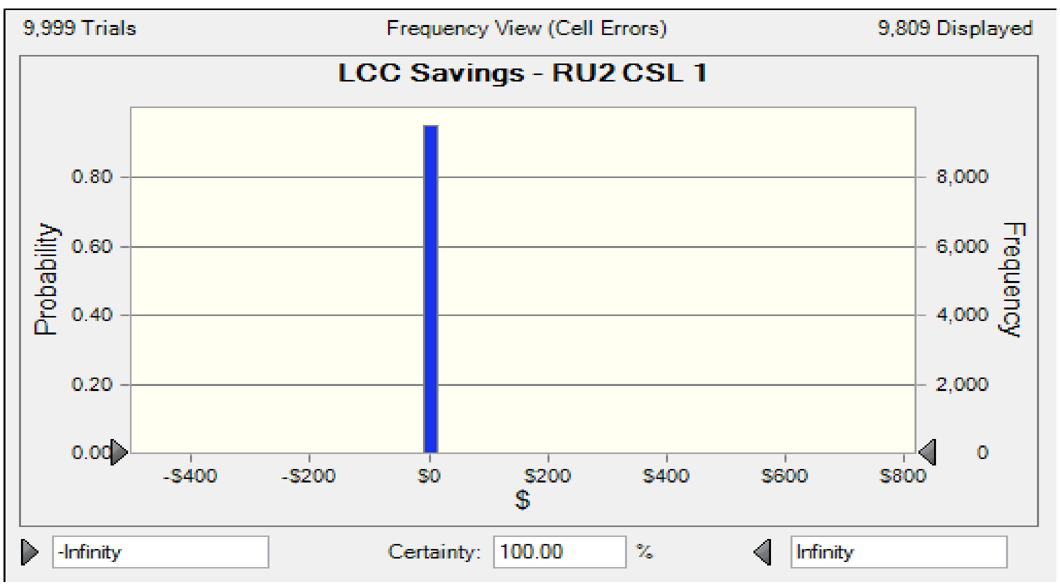


Figure 8B.1.5 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 1

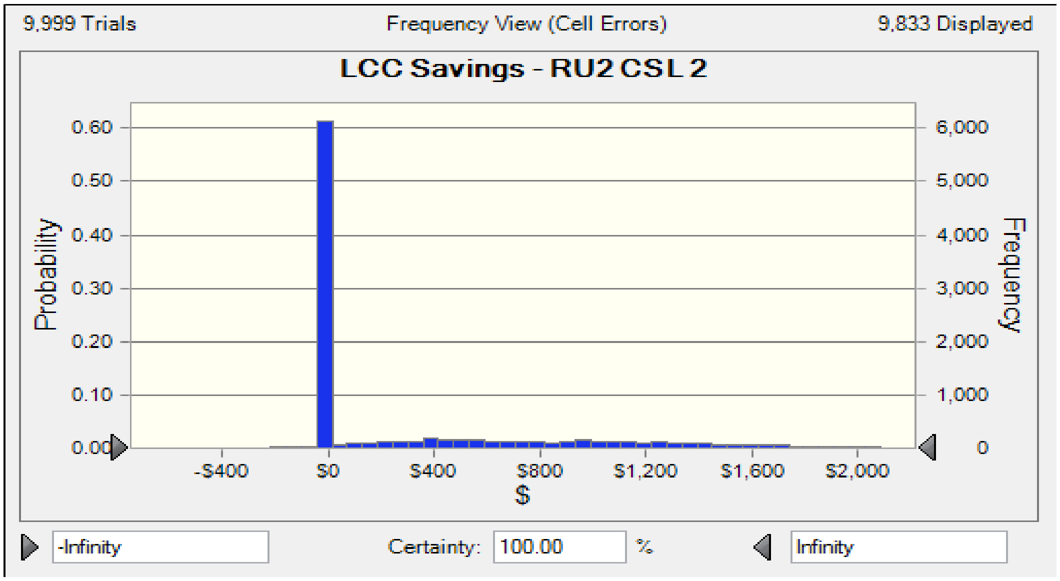


Figure 8B.1.6 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 2

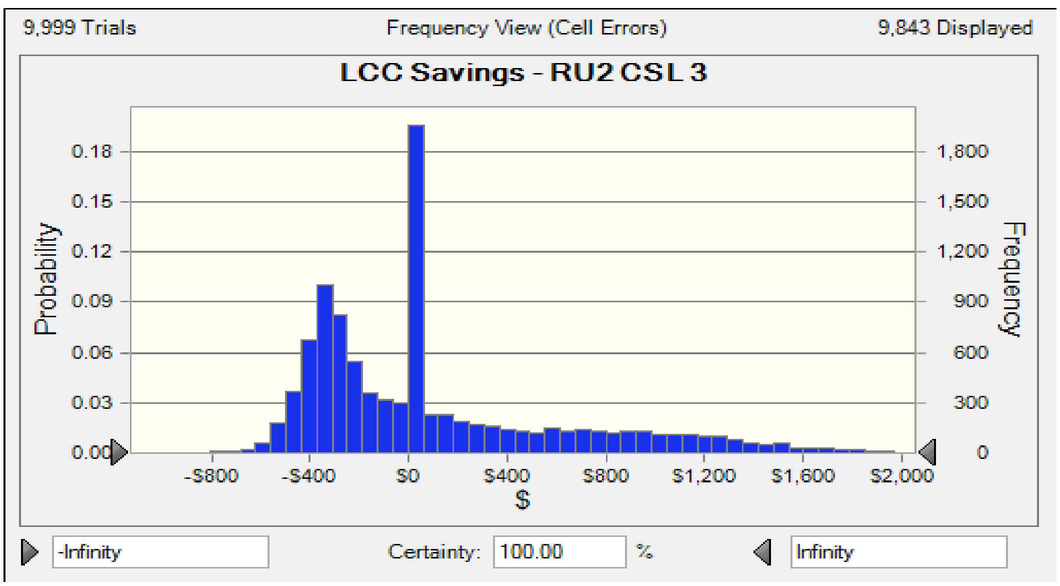


Figure 8B.1.7 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 3

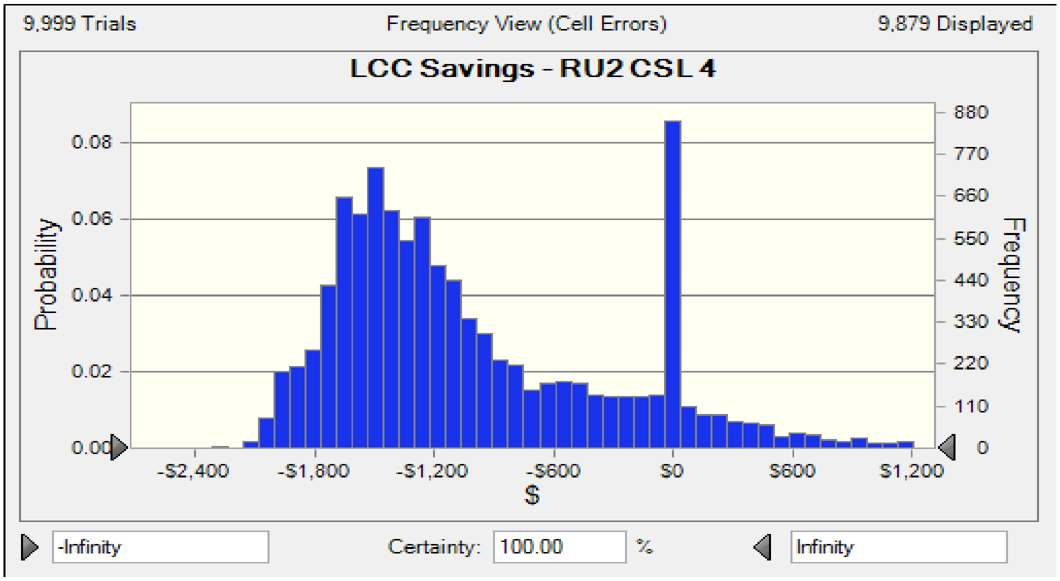


Figure 8B.1.8 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 4

8B.1.3 Representative Unit 3, NEMA Design B, 75 Horsepower, Four Poles, Enclosed Motor

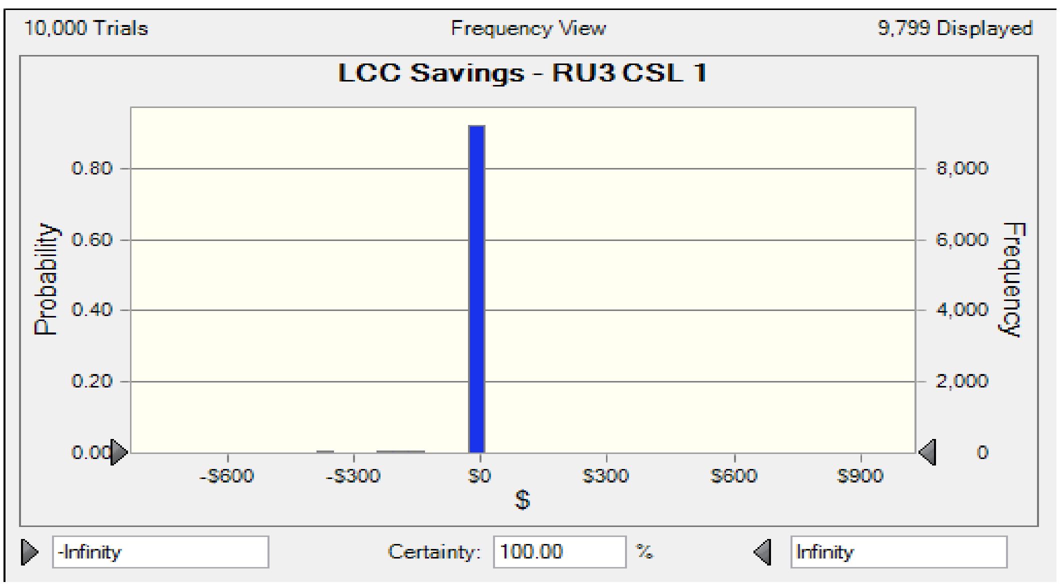


Figure 8B.1.9 Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 1

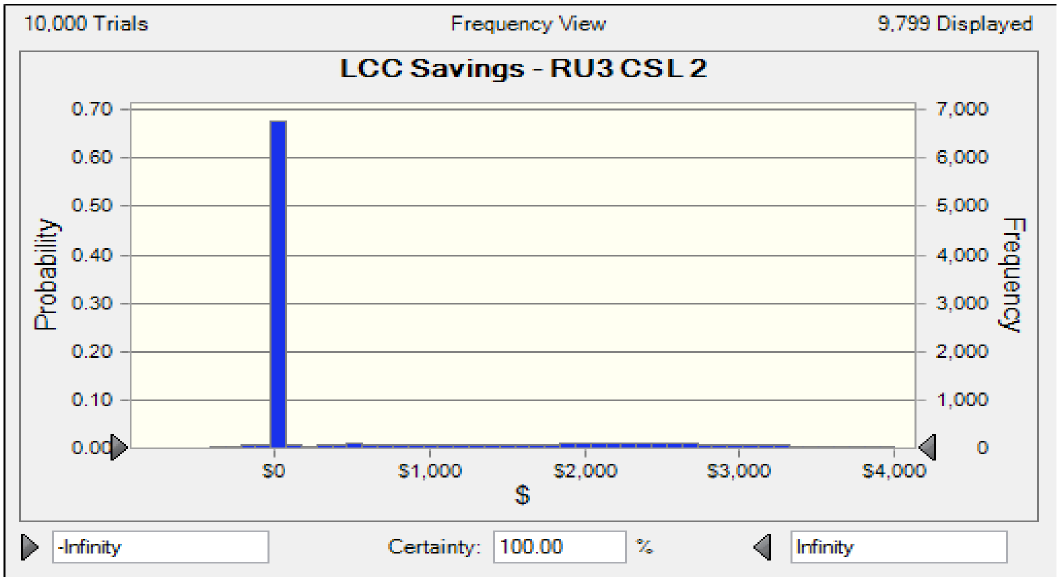


Figure 8B.1.10 Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 2

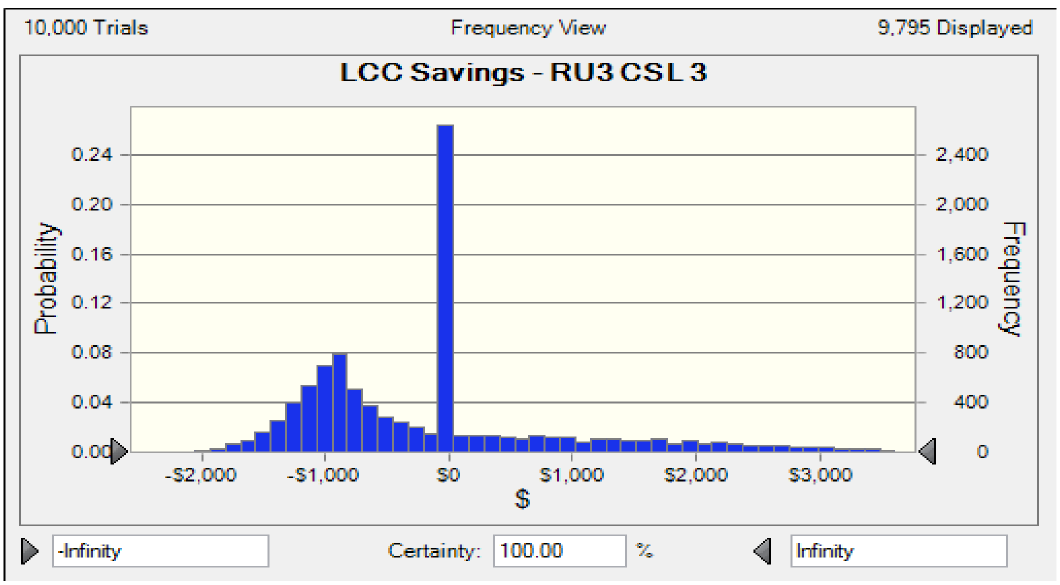


Figure 8B.1.11 Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 3

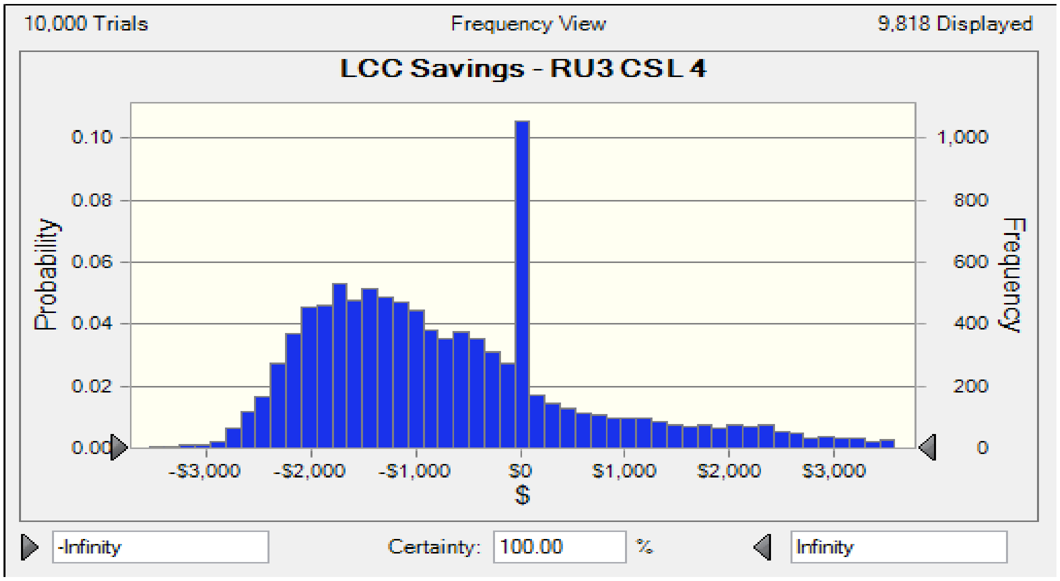


Figure 8B.1.12 Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 4

8B.1.4 Representative Unit 4, NEMA Design C, 5 Horsepower, Four Poles, Enclosed Motor

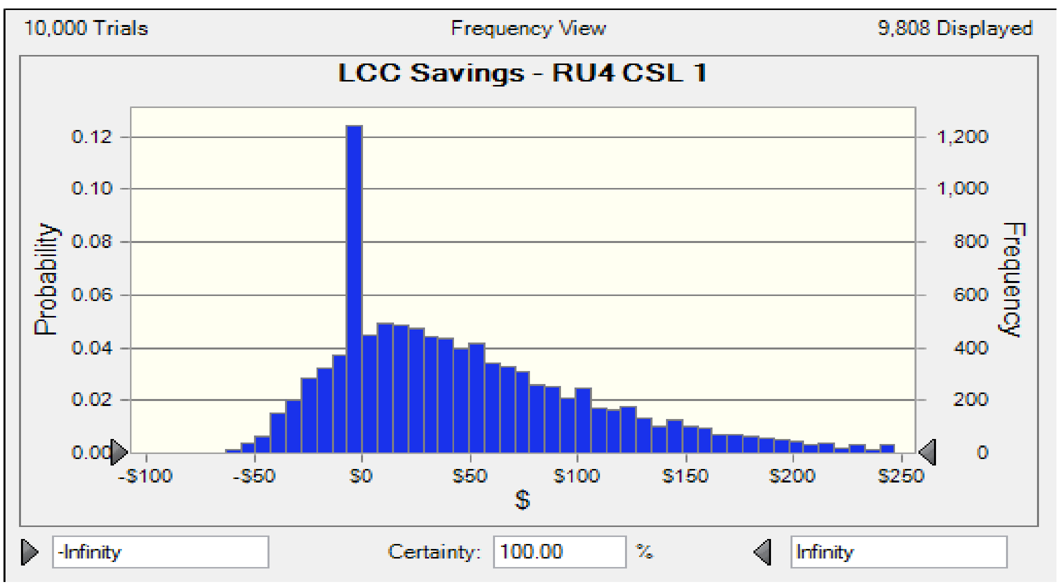


Figure 8B.1.13 Representative Unit 4: Distribution of Life-Cycle Cost Savings for CSL 1

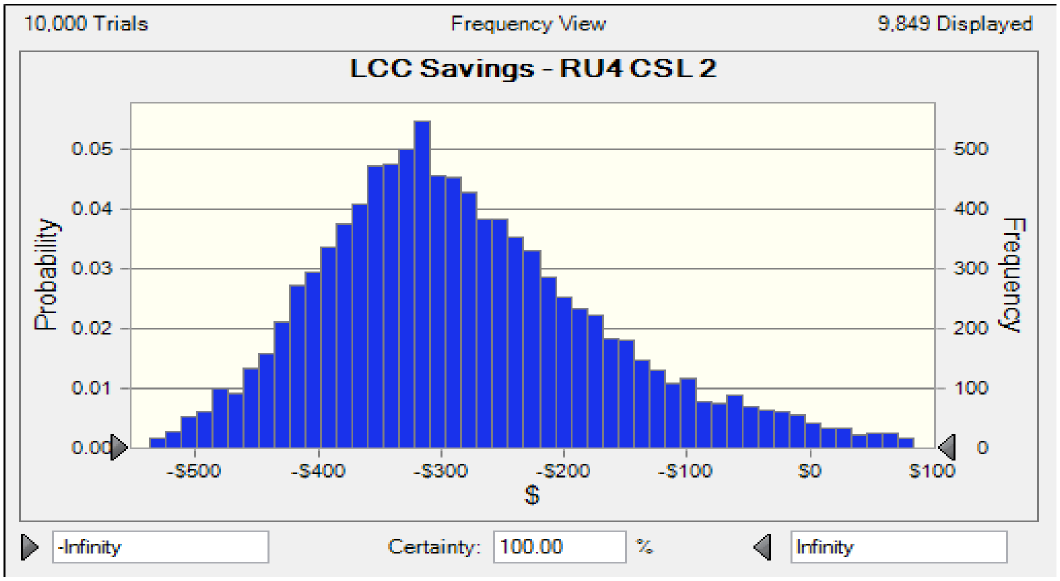


Figure 8B.1.14 Representative Unit 4: Distribution of Life-Cycle Cost Savings for CSL 2

8B.1.5 Representative Unit 5, NEMA Design C, 50 Horsepower, Four Poles, Enclosed Motor

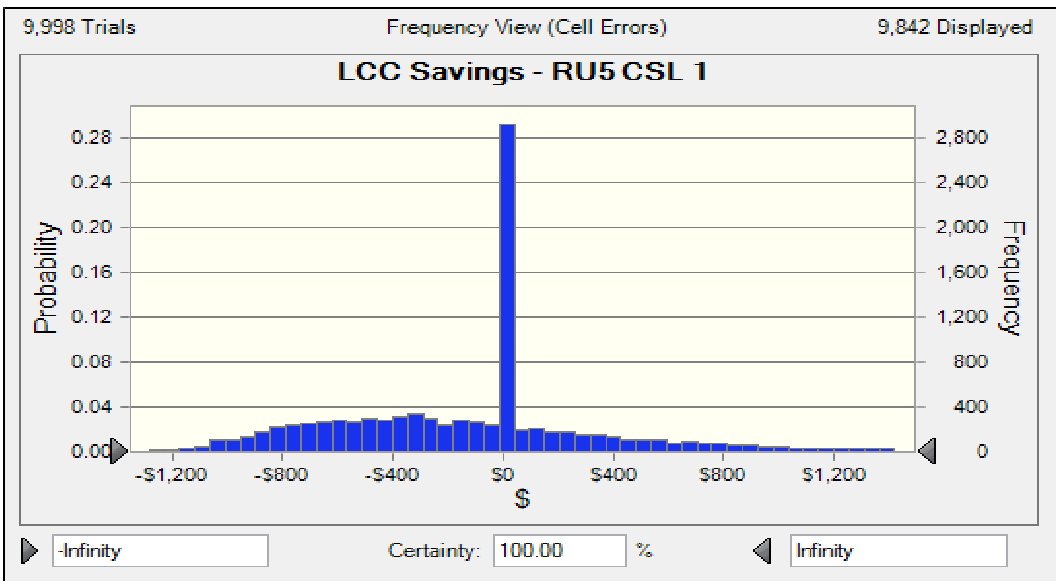


Figure 8B.1.15 Representative Unit 5: Distribution of Life-Cycle Cost Savings for CSL 1

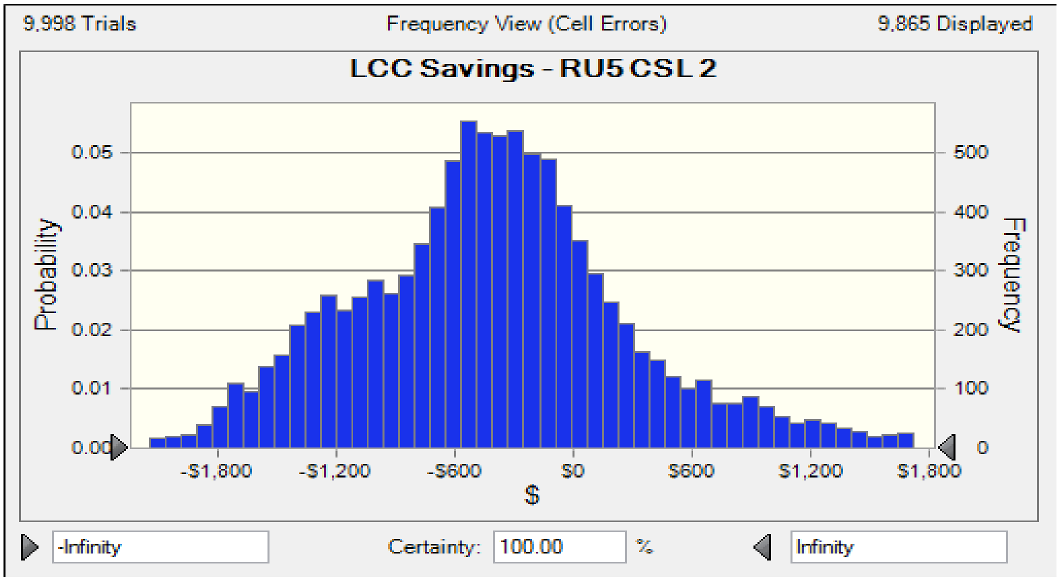


Figure 8B.1.16 Representative Unit 5: Distribution of Life-Cycle Cost Savings for CSL 2

8B.1.6 Representative Unit 6, Fire Pump, 5 Horsepower, Four Poles, Enclosed Electric Motor

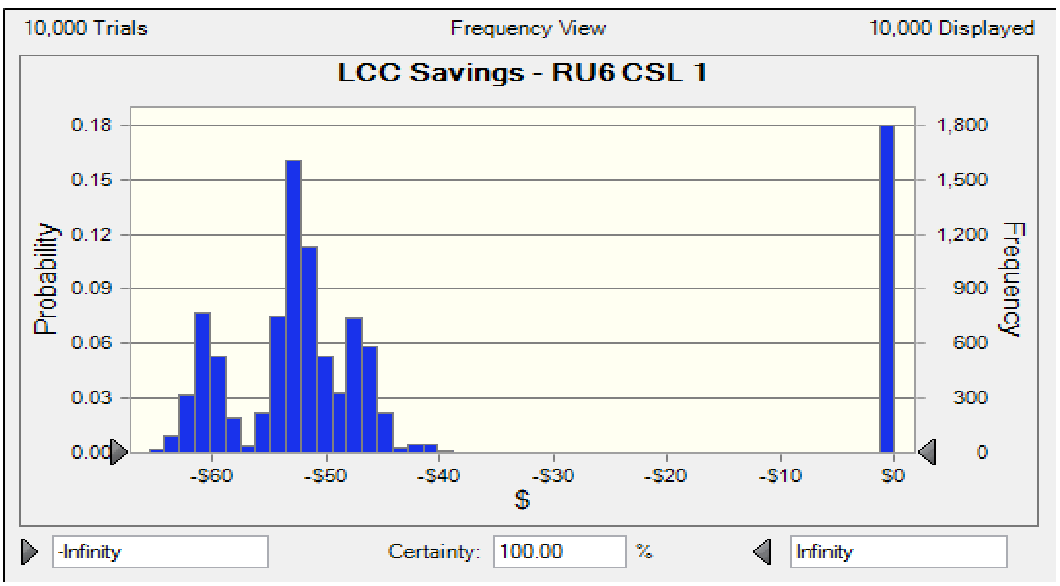


Figure 8B.1.17 Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 1

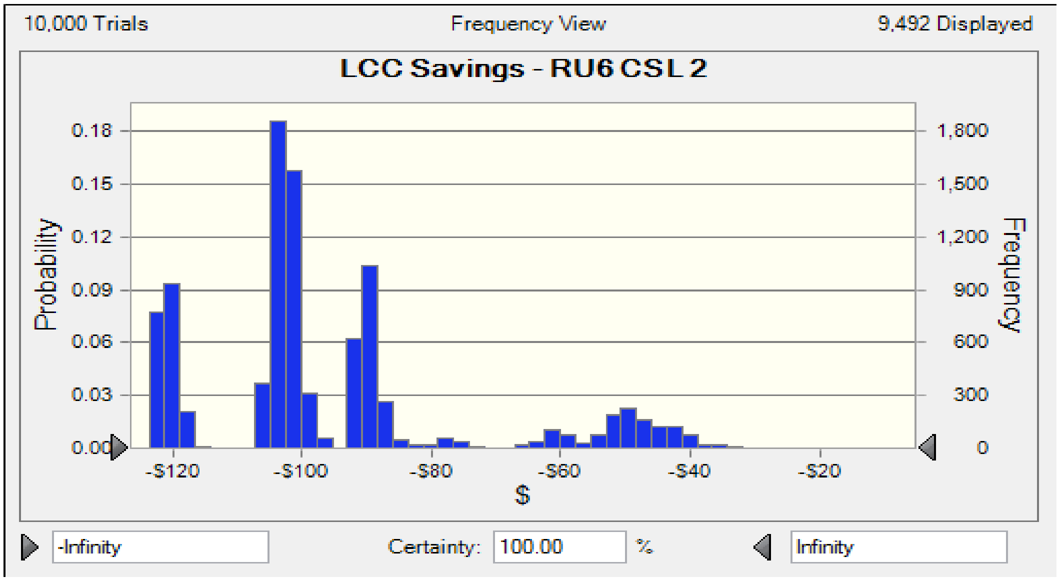


Figure 8B.1.18 Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 2

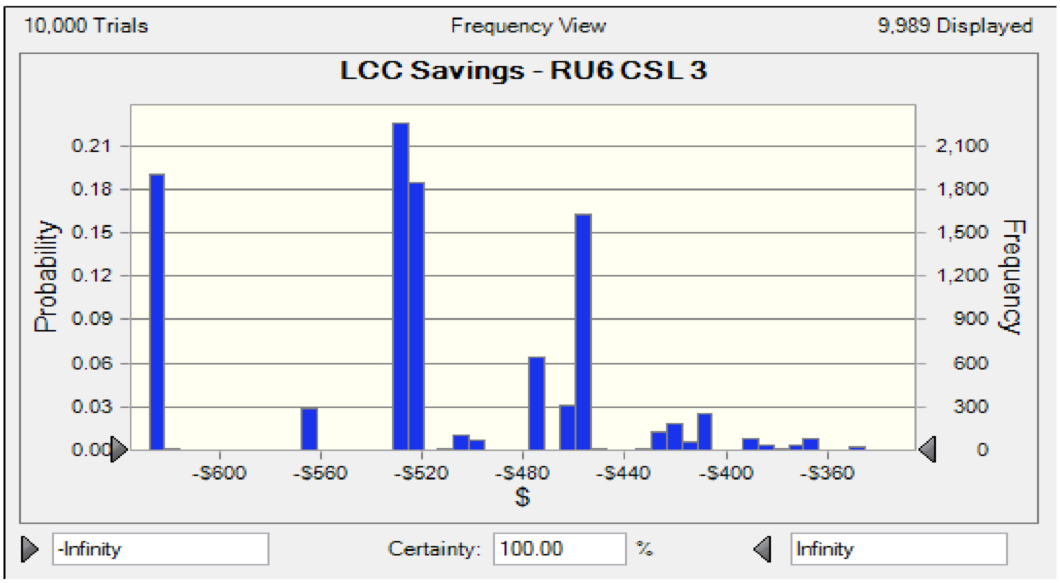


Figure 8B.1.19 Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 3

8B.1.7 Representative Unit 7, Fire Pump, 30 Horsepower, Four Poles, Enclosed Electric Motor

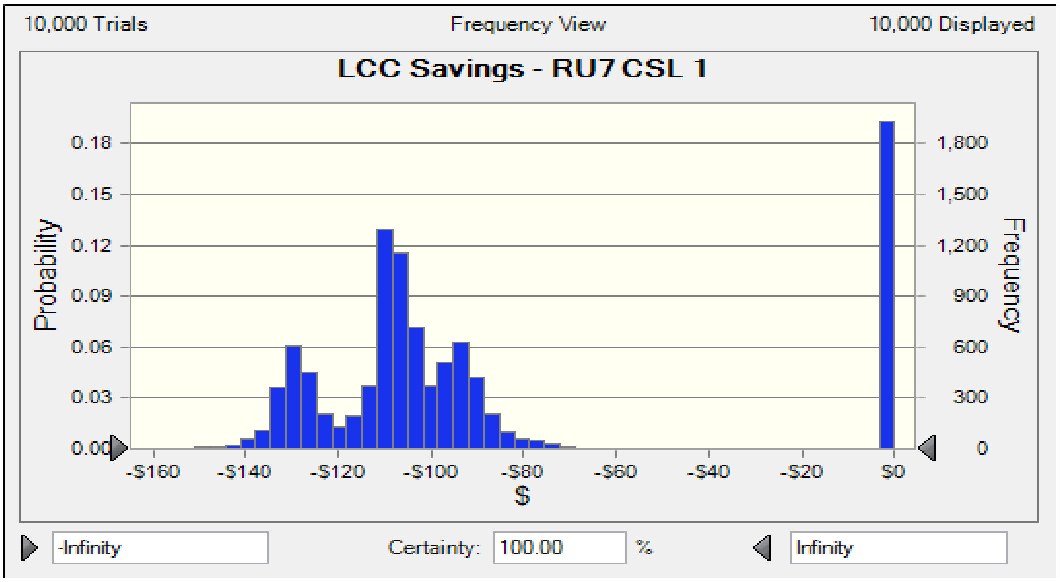


Figure 8B.1.20 Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 1

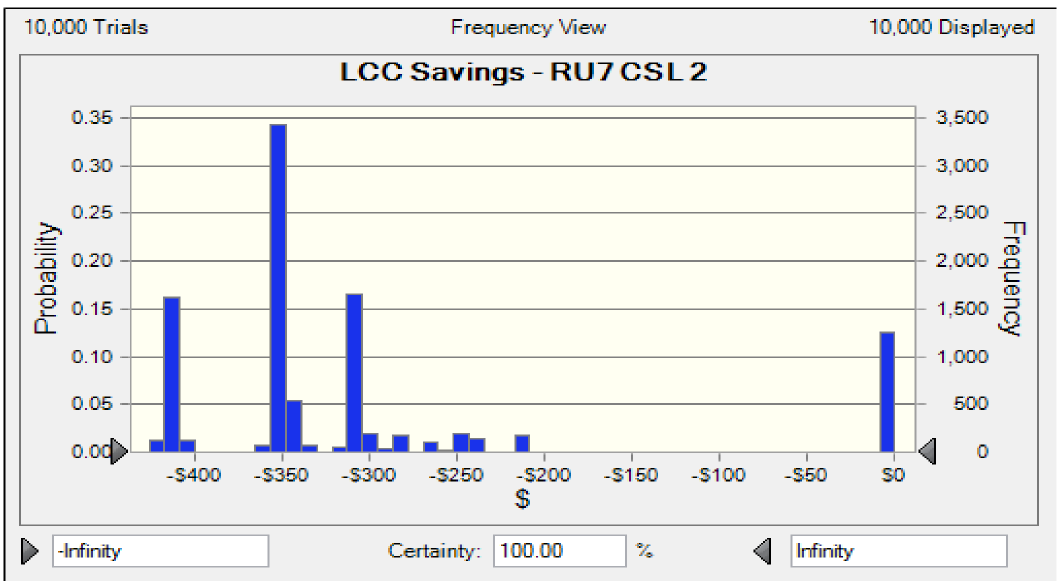


Figure 8B.1.21 Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 2

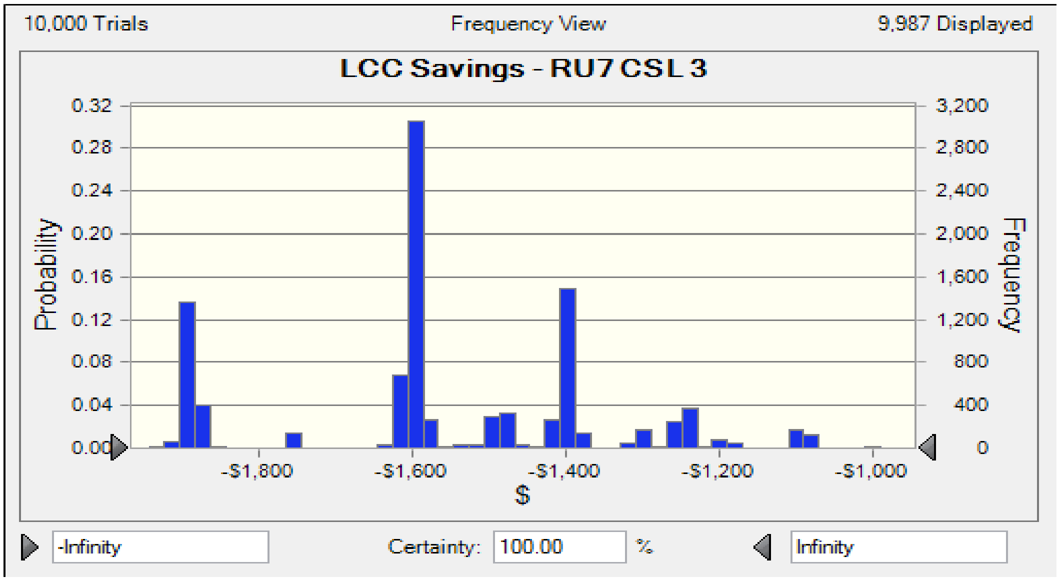


Figure 8B.1.22 Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 3

8B.1.8 Representative Unit 8, Fire Pump, 75 Horsepower, Four Poles, Enclosed Electric Motor

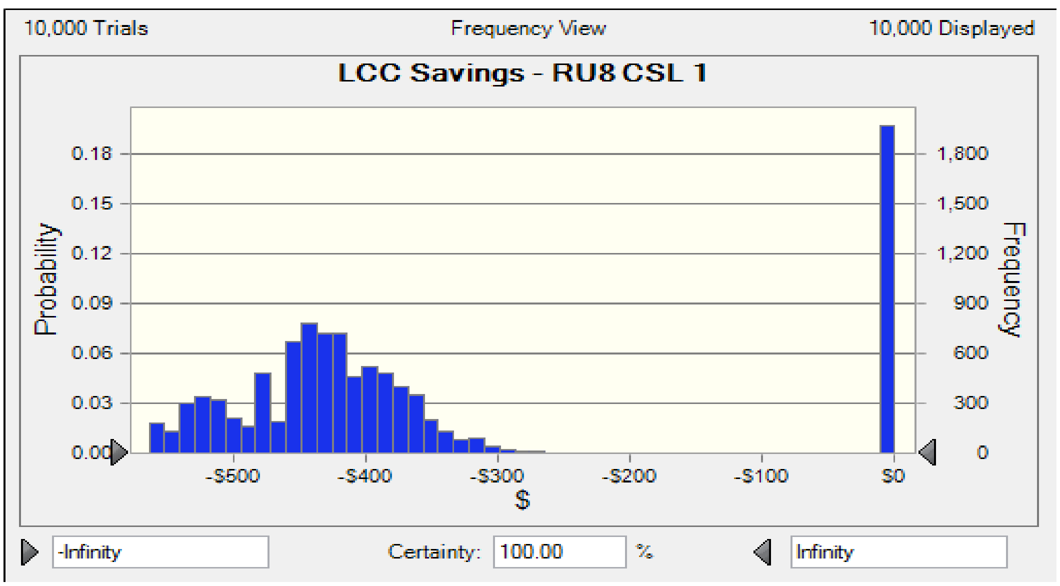


Figure 8B.1.23 Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 1

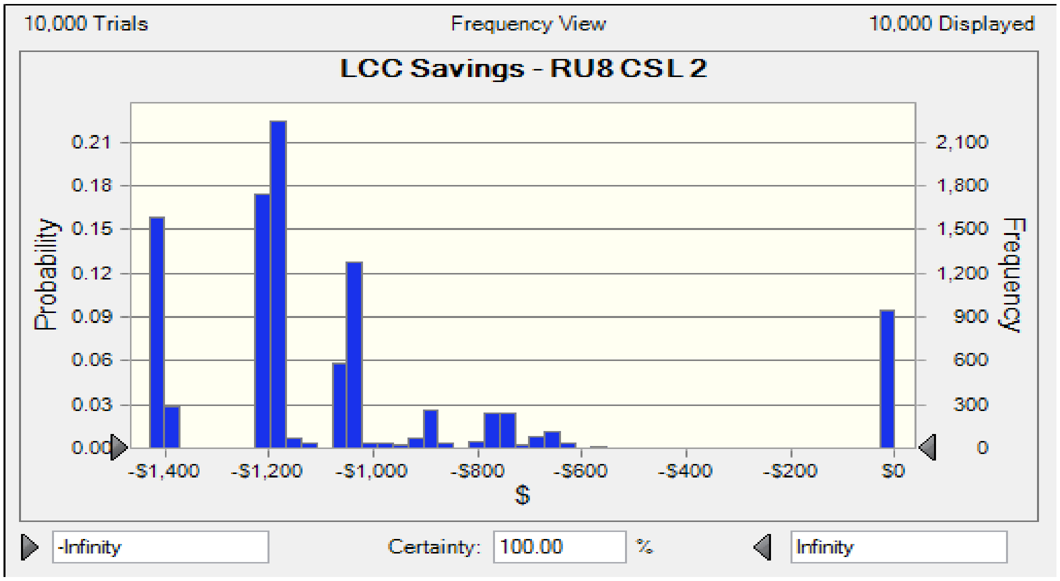


Figure 8B.1.24 Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 2

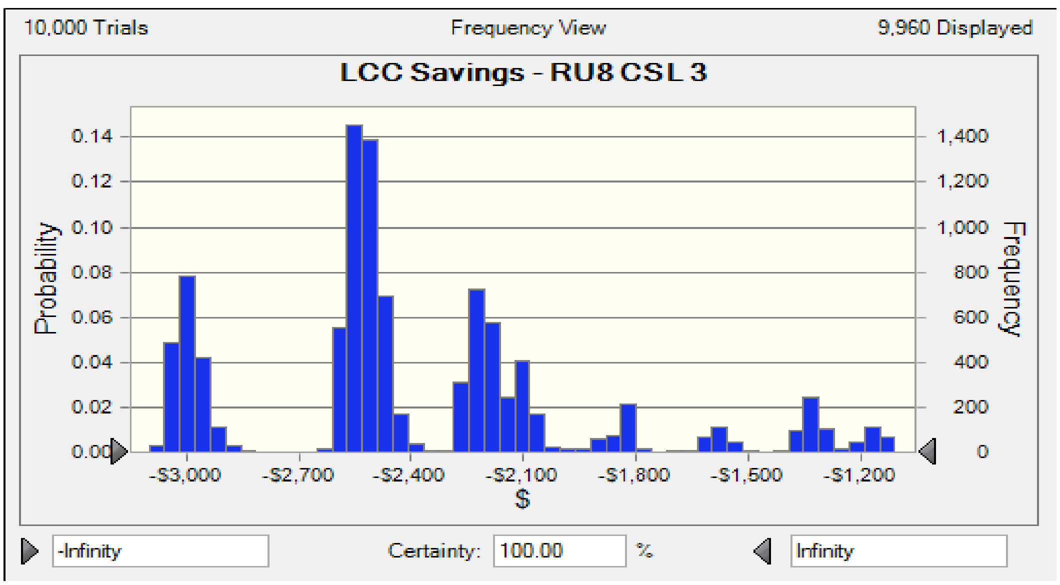


Figure 8B.1.25 Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 3

8B.1.9 Representative Unit 9, Brake Motor, NEMA Design B, T-Frame, 5 Horsepower, Four Poles, Enclosed Motor

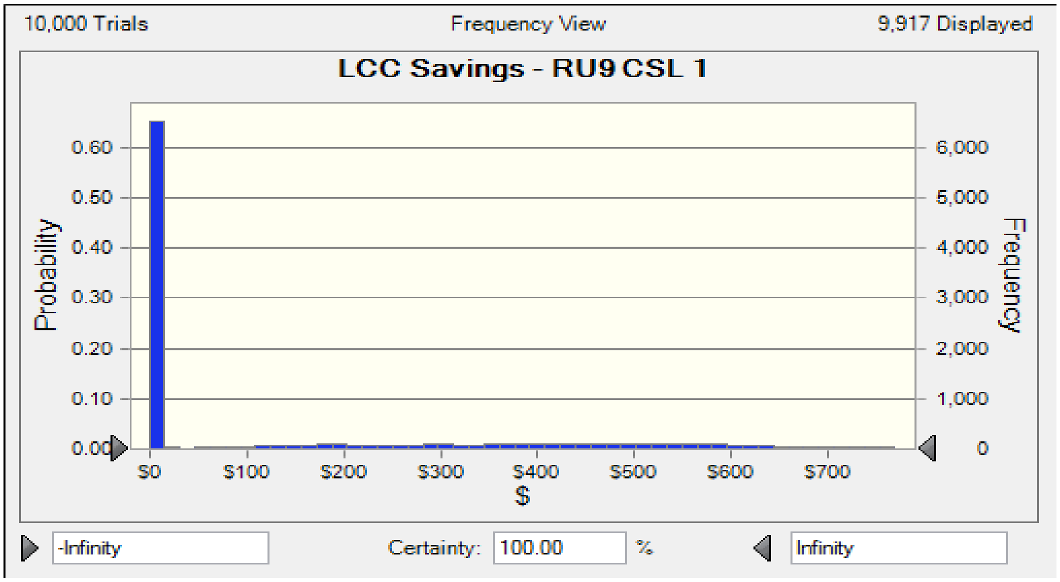


Figure 8B.1.26 Representative Unit 9: Distribution of Life-Cycle Cost Savings for CSL 1

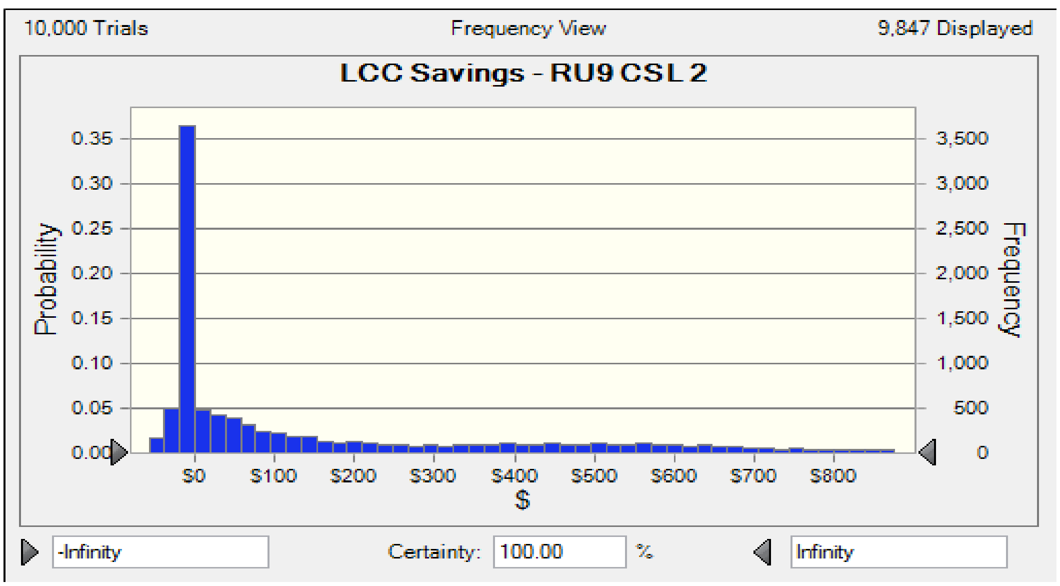


Figure 8B.1.27 Representative Unit 9: Distribution of Life-Cycle Cost Savings for CSL 2

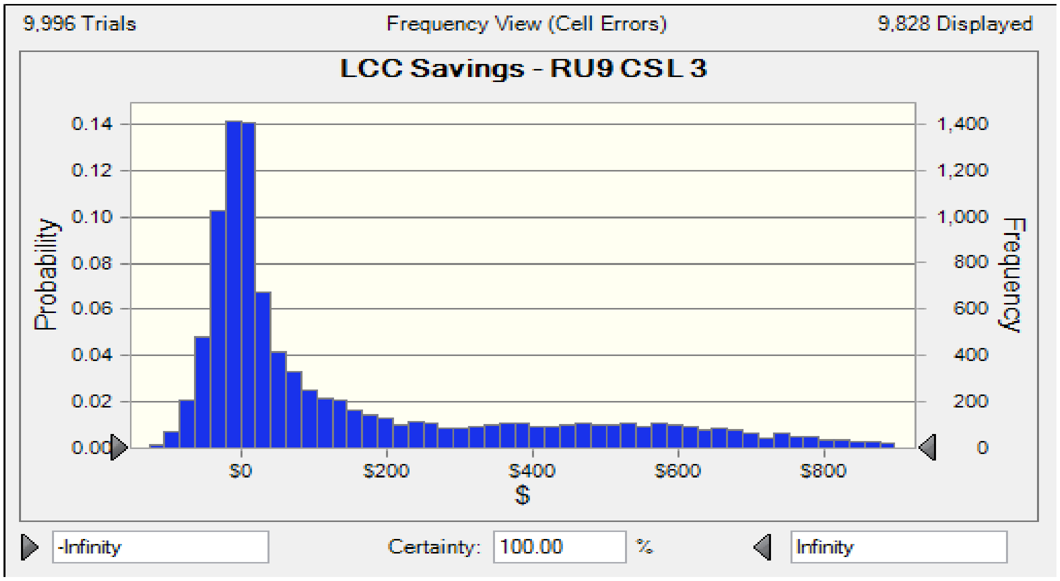


Figure 8B.1.28 Representative Unit 9: Distribution of Life-Cycle Cost Savings for CSL 3

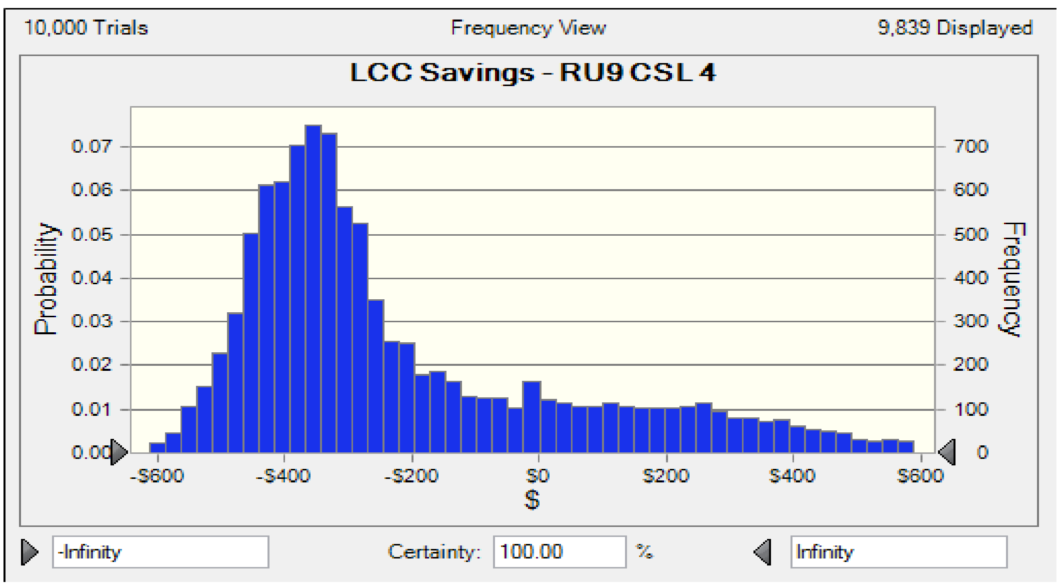


Figure 8B.1.29 Representative Unit 9: Distribution of Life-Cycle Cost Savings for CSL 4

8B.1.10 Representative Unit 10, Brake Motor, NEMA Design B, T-Frame, 30 Horsepower, Four Poles, Enclosed Motor

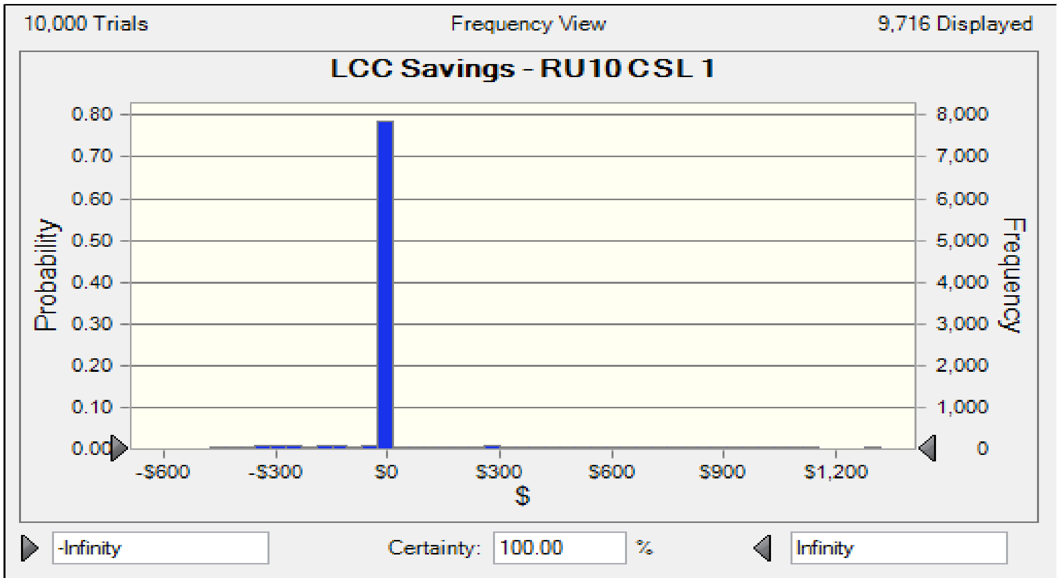


Figure 8B.1.30 Representative Unit 10: Distribution of Life-Cycle Cost Savings for CSL 1

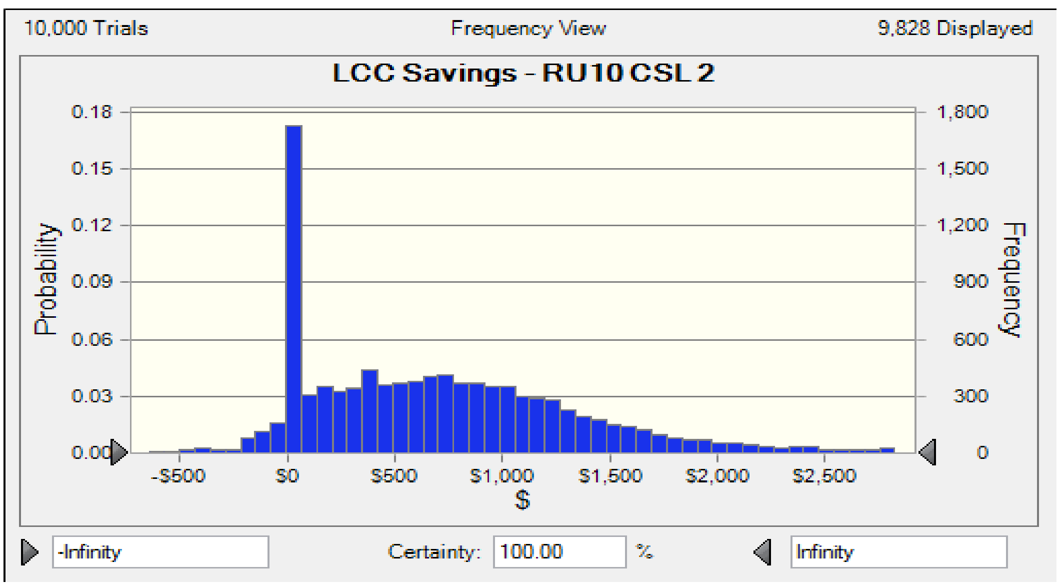


Figure 8B.1.31 Representative Unit 10: Distribution of Life-Cycle Cost Savings for CSL 2

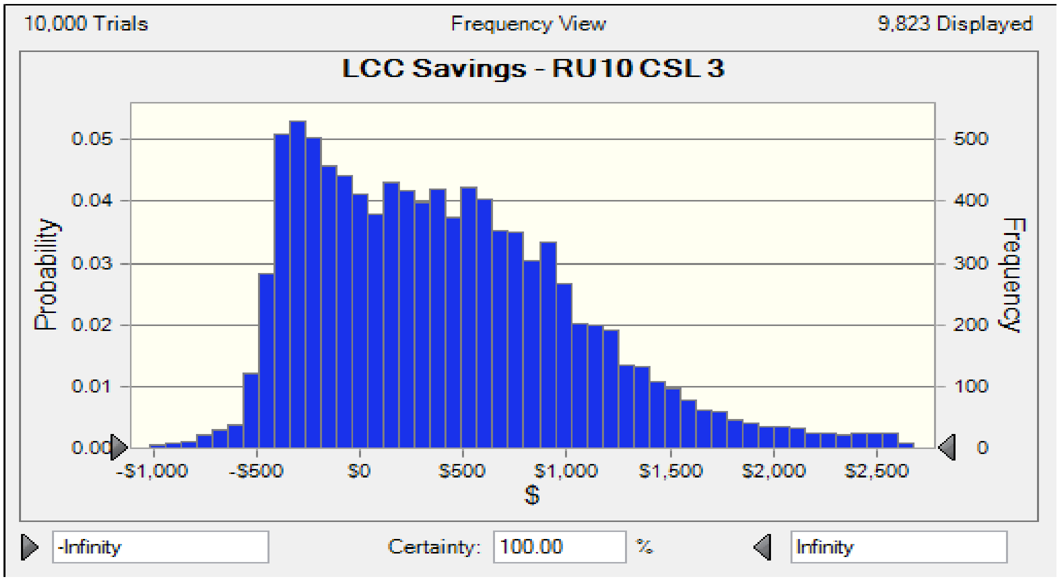


Figure 8B.1.32 Representative Unit 10: Distribution of Life-Cycle Cost Savings for CSL 3

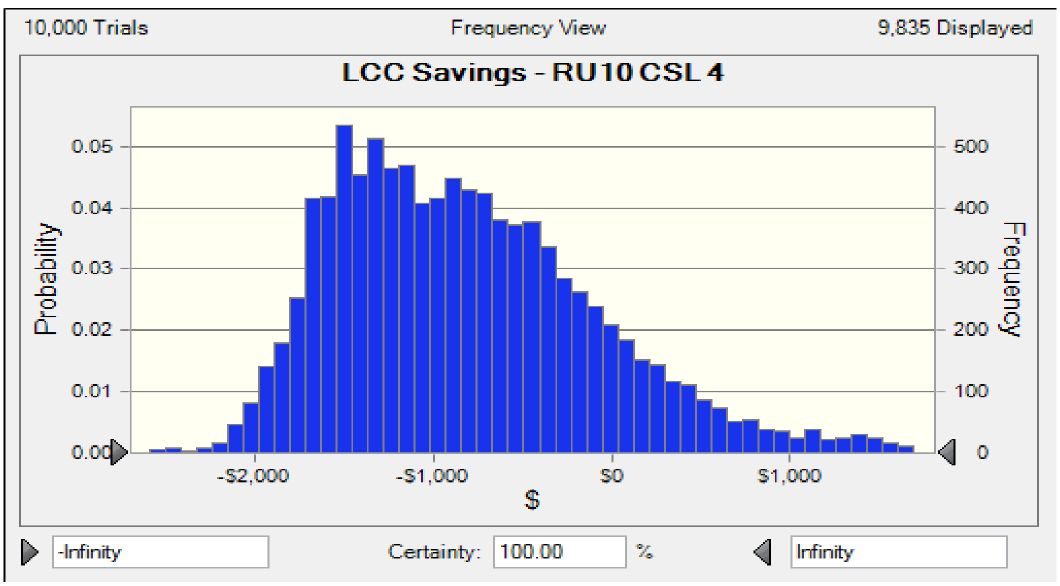


Figure 8B.1.33 Representative Unit 10: Distribution of Life-Cycle Cost Savings for CSL 4

8B.2 DISTRIBUTION OF PAYBACK PERIOD RESULTS

8B.2.1 Representative Unit 1, NEMA Design B, 5 Horsepower, Four Poles, Enclosed Motor

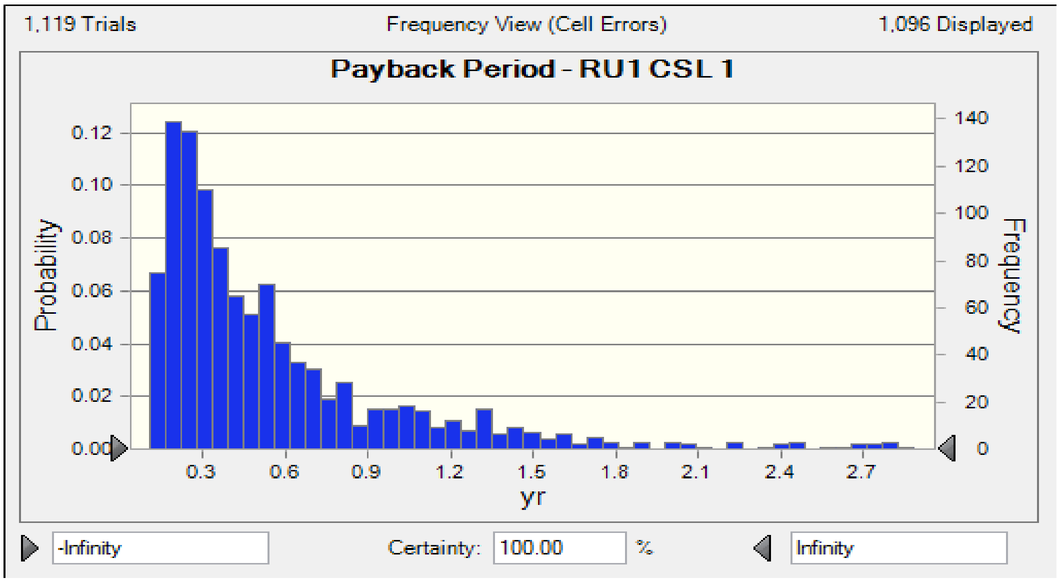


Figure 8B.2.1 Representative Unit 1: Distribution of Payback Periods for CSL 1

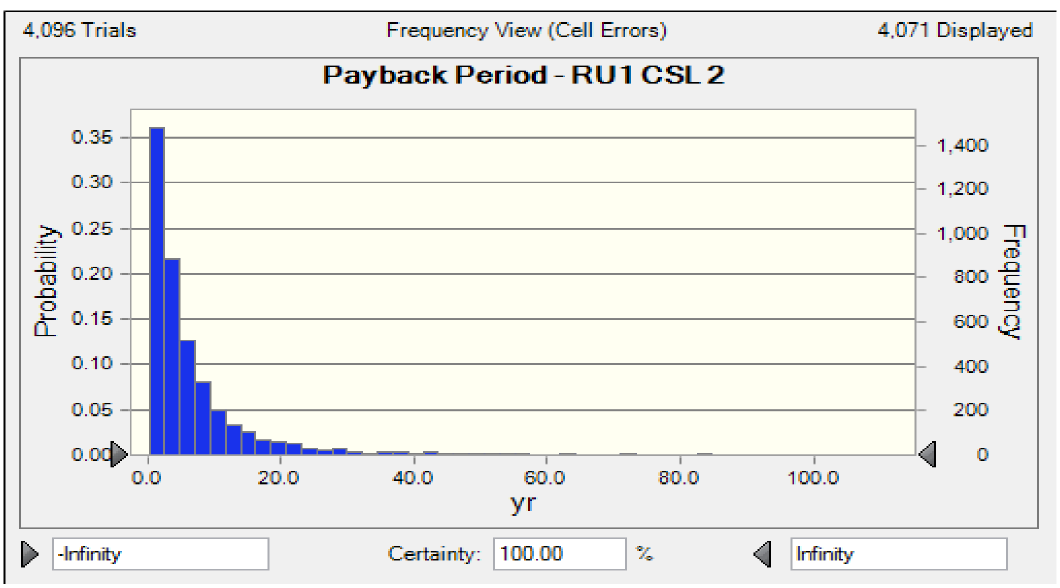


Figure 8B.2.2 Representative Unit 1: Distribution of Payback Periods for CSL 2

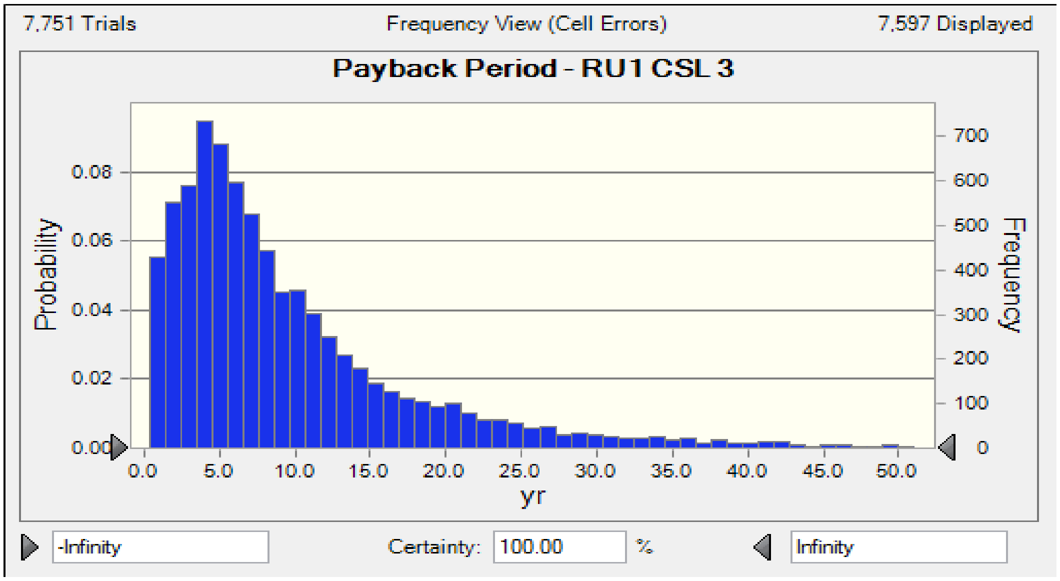


Figure 8B.2.3 Representative Unit 1: Distribution of Payback Periods for CSL 3

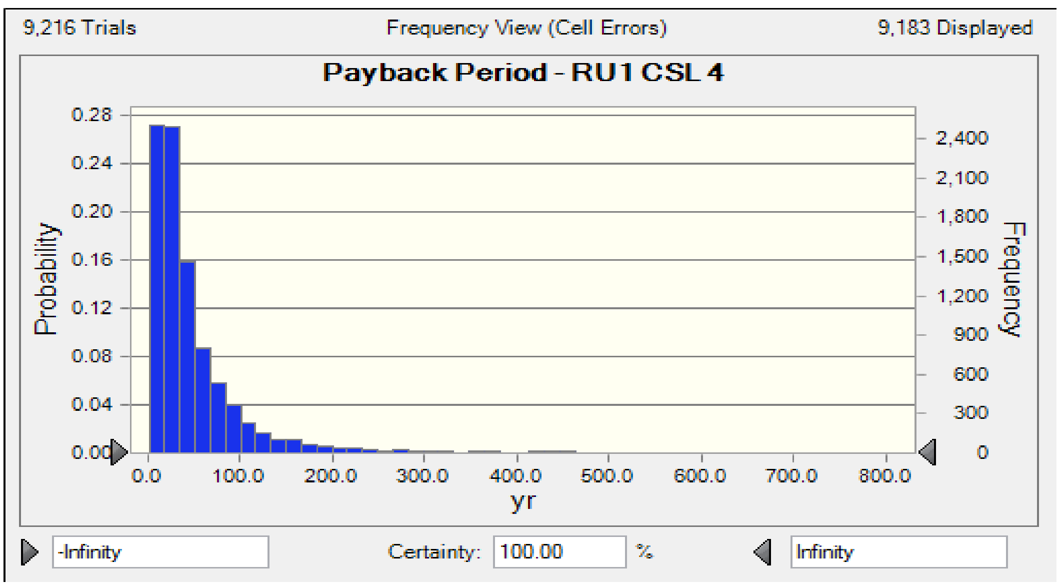


Figure 8B.2.4 Representative Unit 1: Distribution of Payback Periods for CSL 4

8B.2.2 Representative Unit 2, NEMA Design B, 30 Horsepower, Four Poles, Enclosed Motor

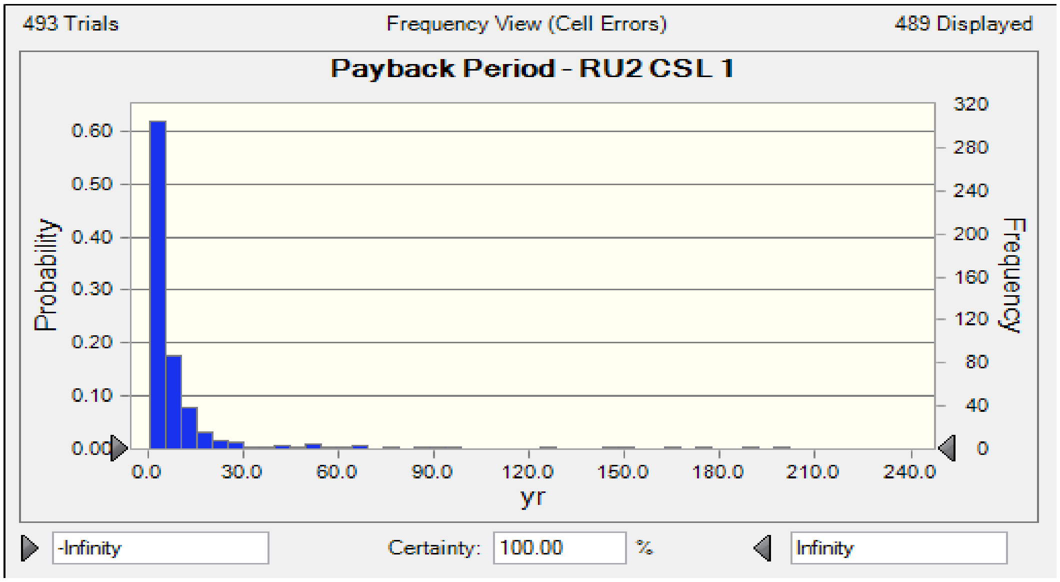


Figure 8B.2.5 Representative Unit 2: Distribution of Payback Periods for CSL 1

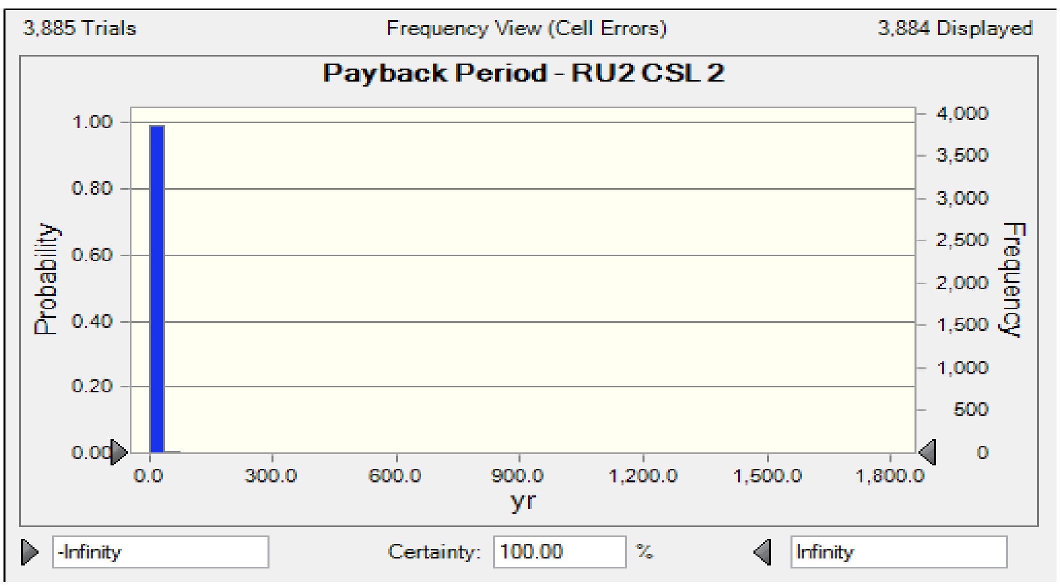


Figure 8B.2.6 Representative Unit 2: Distribution of Payback Periods for CSL 2

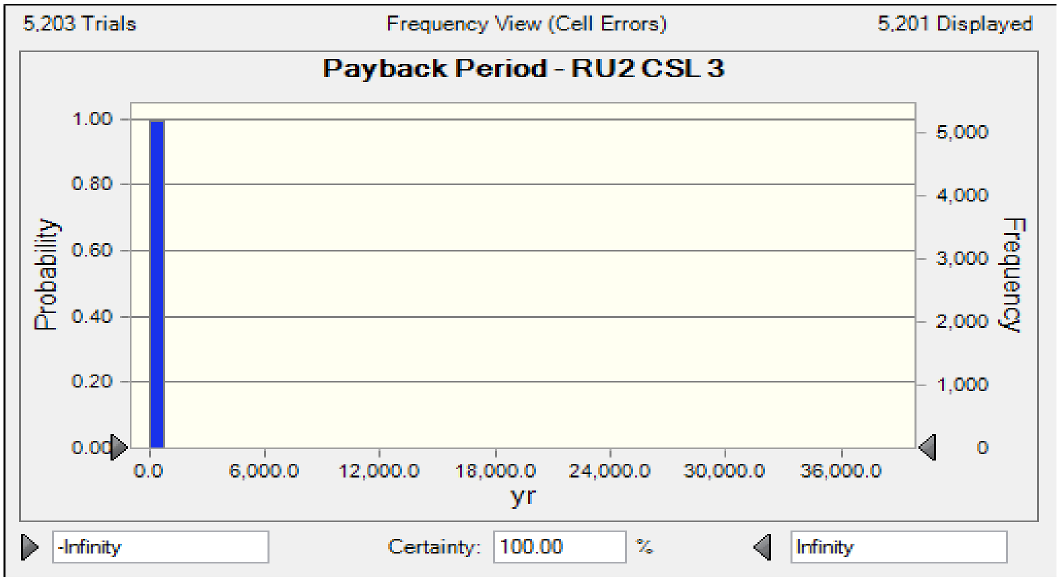


Figure 8B.2.7 Representative Unit 2: Distribution of Payback Periods for CSL 3

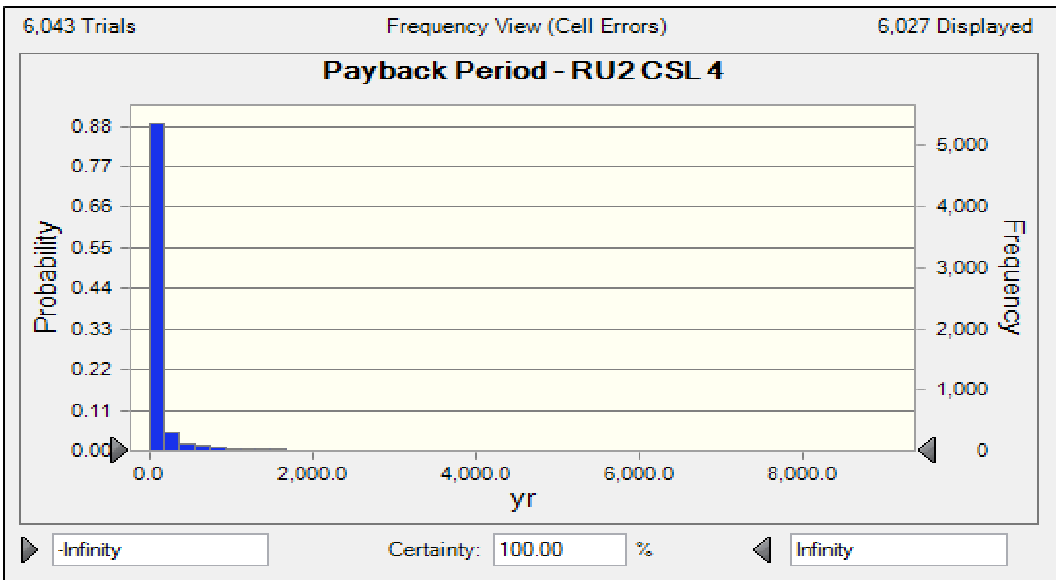


Figure 8B.2.8 Representative Unit 2: Distribution of Payback Periods for CSL 4

8B.2.3 Representative Unit 3, NEMA Design B, 75 Horsepower, Four Poles, Enclosed Motor

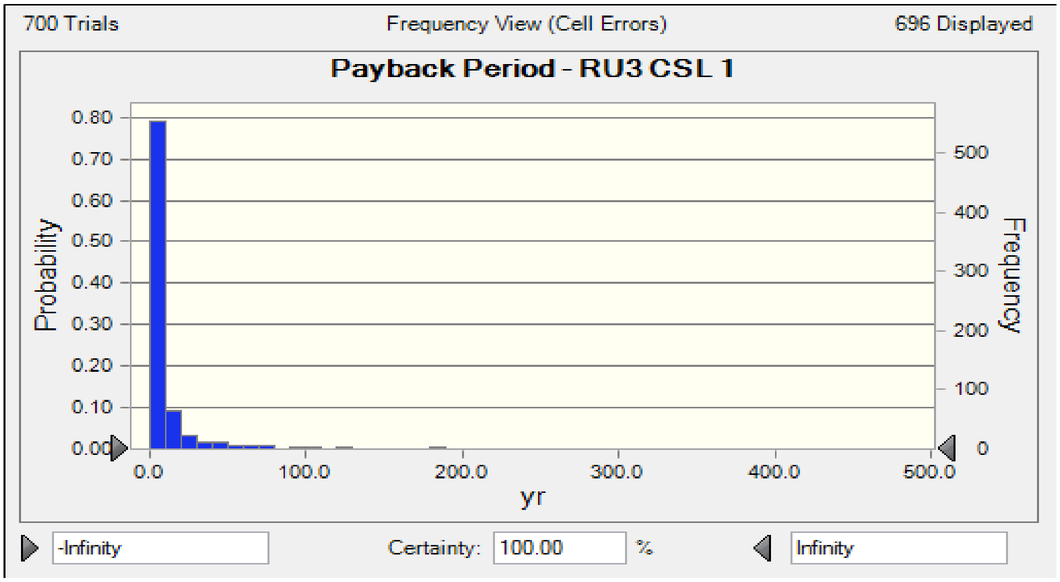


Figure 8B.2.9 Representative Unit 3: Distribution of Payback Periods for CSL 1

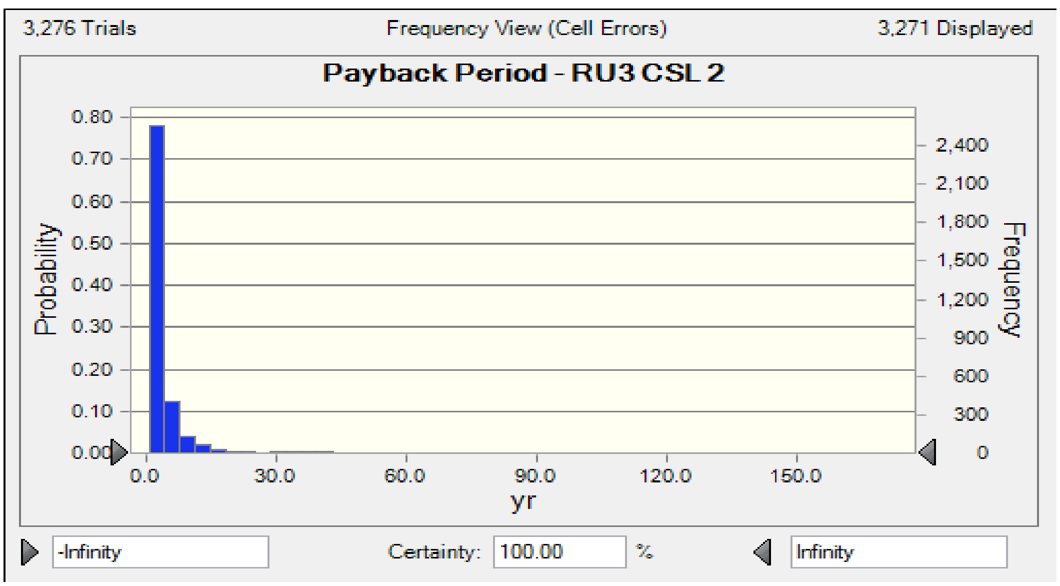


Figure 8B.2.10 Representative Unit 3: Distribution of Payback Periods for CSL 2

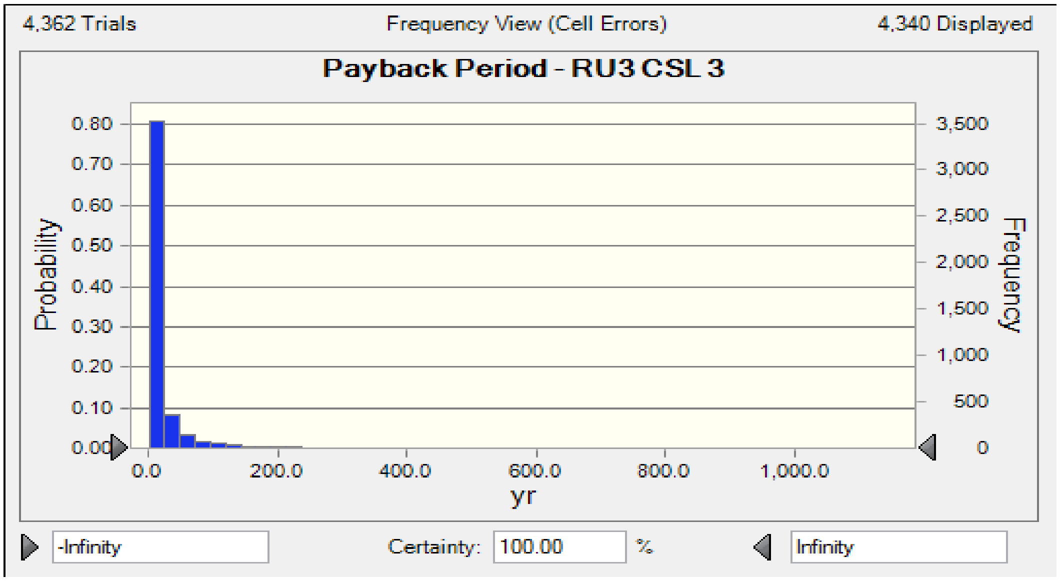


Figure 8B.2.11 Representative Unit 3: Distribution of Payback Periods for CSL 3

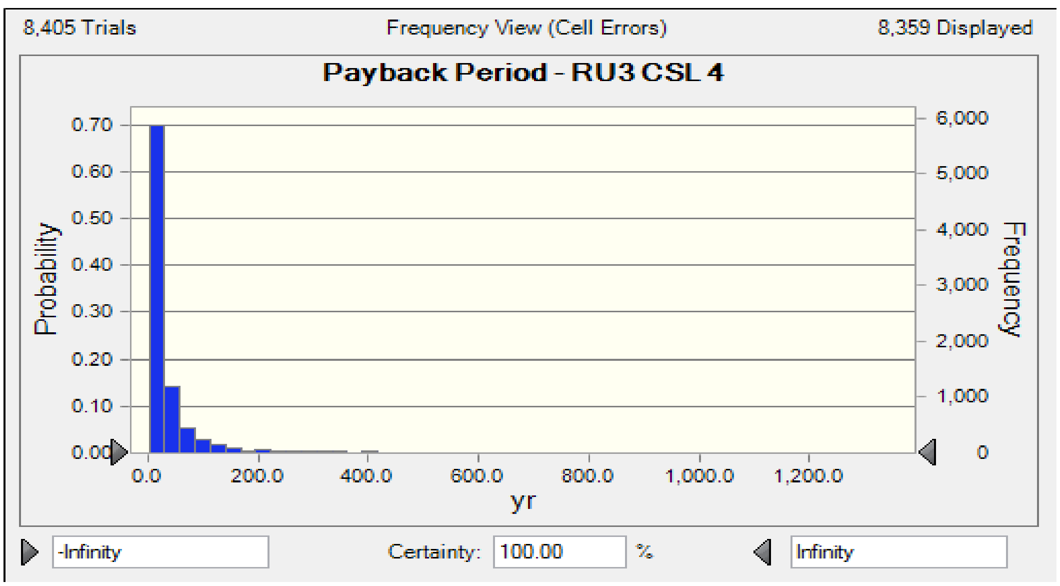


Figure 8B.2.12 Representative Unit 3: Distribution of Payback Periods for CSL 4

8B.2.4 Representative Unit 4, NEMA Design C, 5 Horsepower, Four Poles, Enclosed Motor

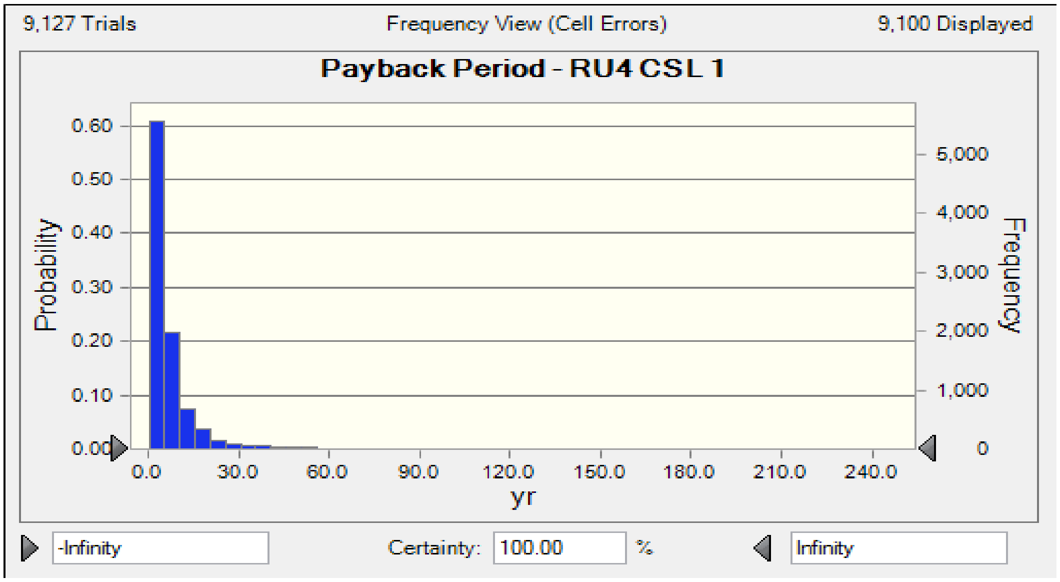


Figure 8B.2.13 Representative Unit 4: Distribution of Payback Periods for CSL 1

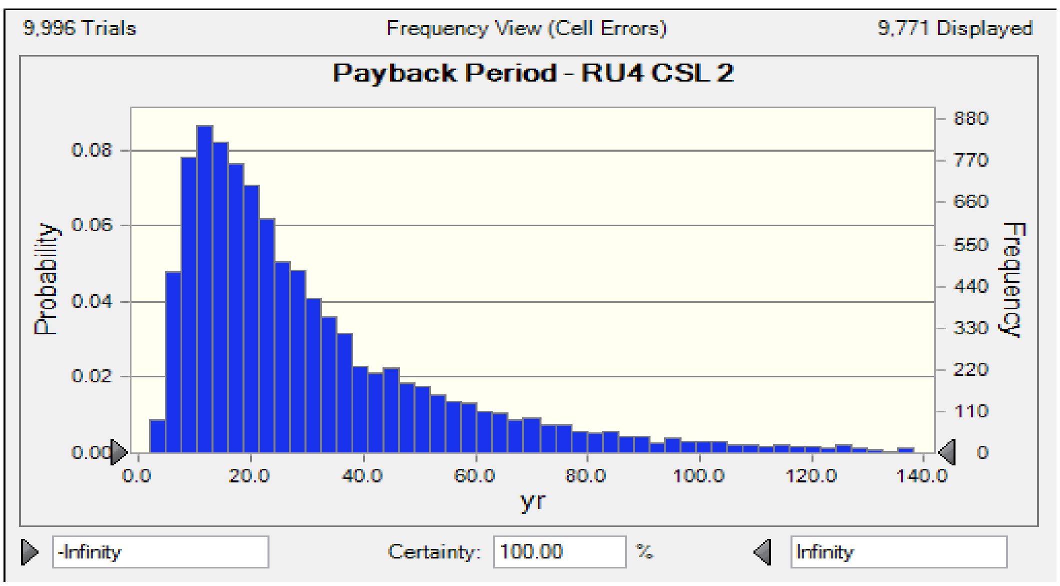


Figure 8B.2.14 Representative Unit 4: Distribution of Payback Periods for CSL 2

8B.2.5 Representative Unit 5, NEMA Design C, 50 Horsepower, Four Poles, Enclosed Motor

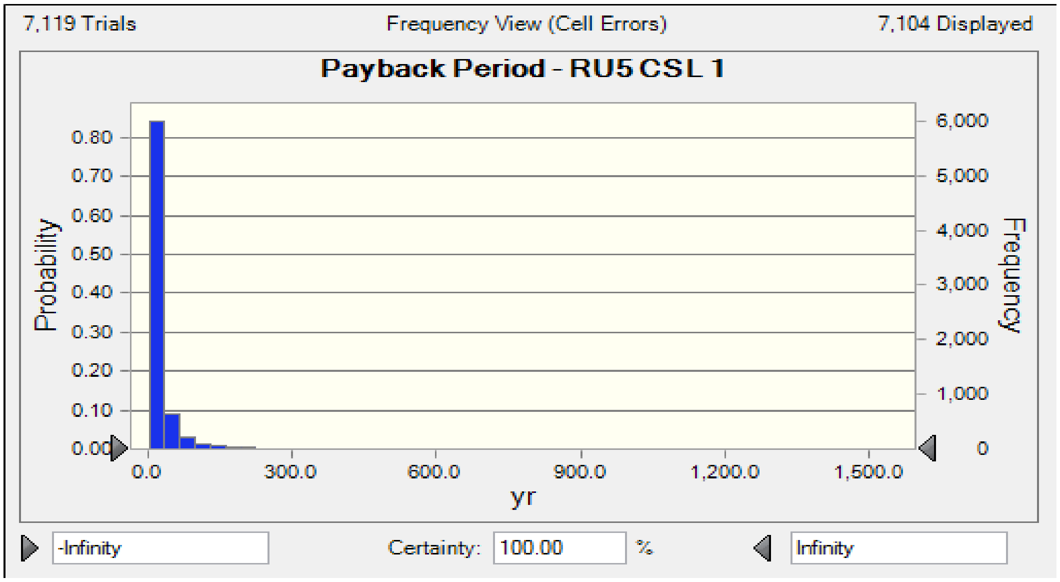


Figure 8B.2.15 Representative Unit 5: Distribution of Payback Periods for CSL 1

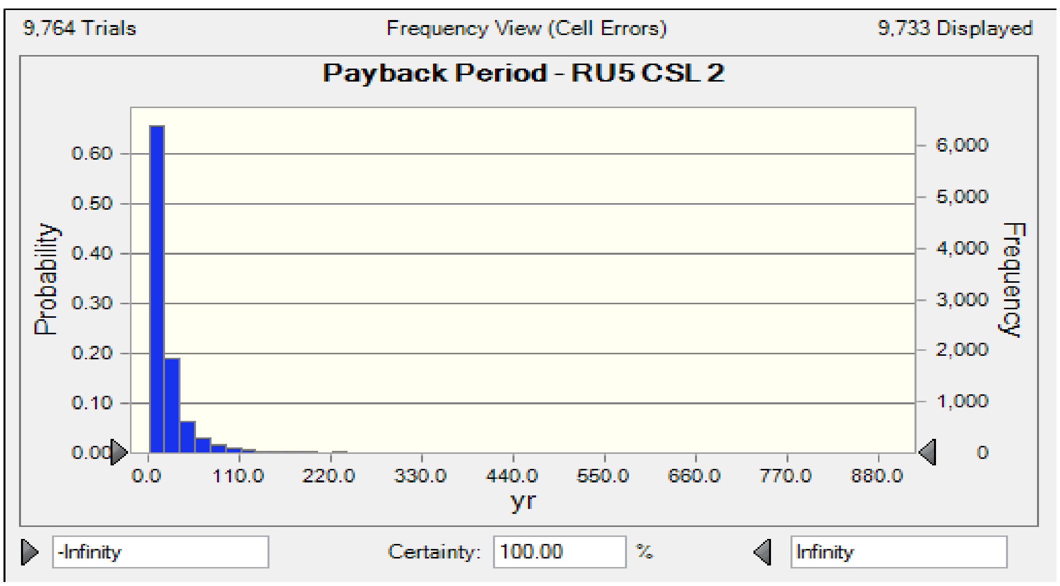


Figure 8B.2.16 Representative Unit 5: Distribution of Payback Periods for CSL 2

8B.2.6 Representative Unit 6, Fire Pump, 5 Horsepower, Four Poles, Enclosed Electric Motor

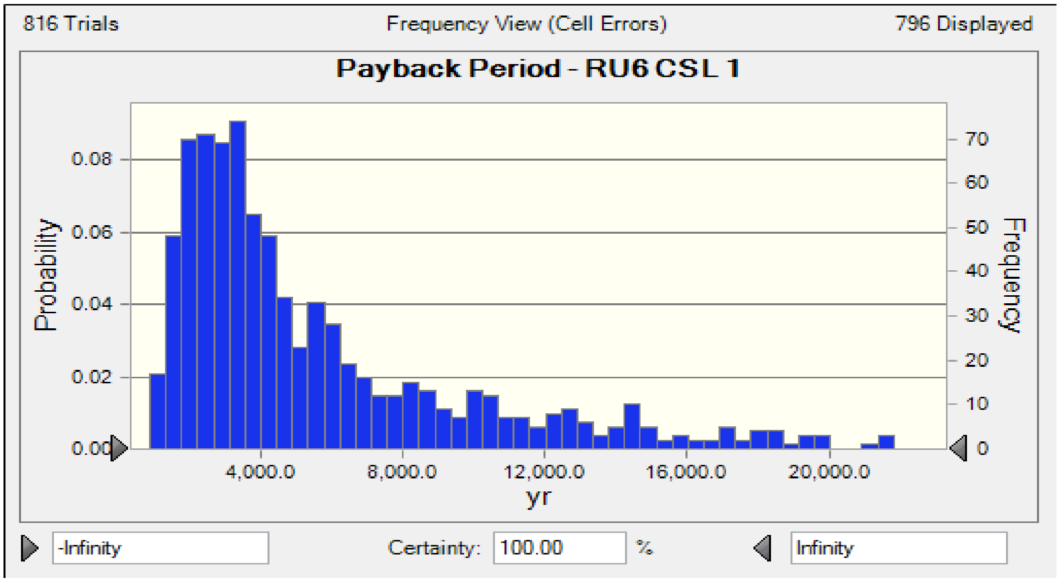


Figure 8B.2.17 Representative Unit 6: Distribution of Payback Periods for CSL 1

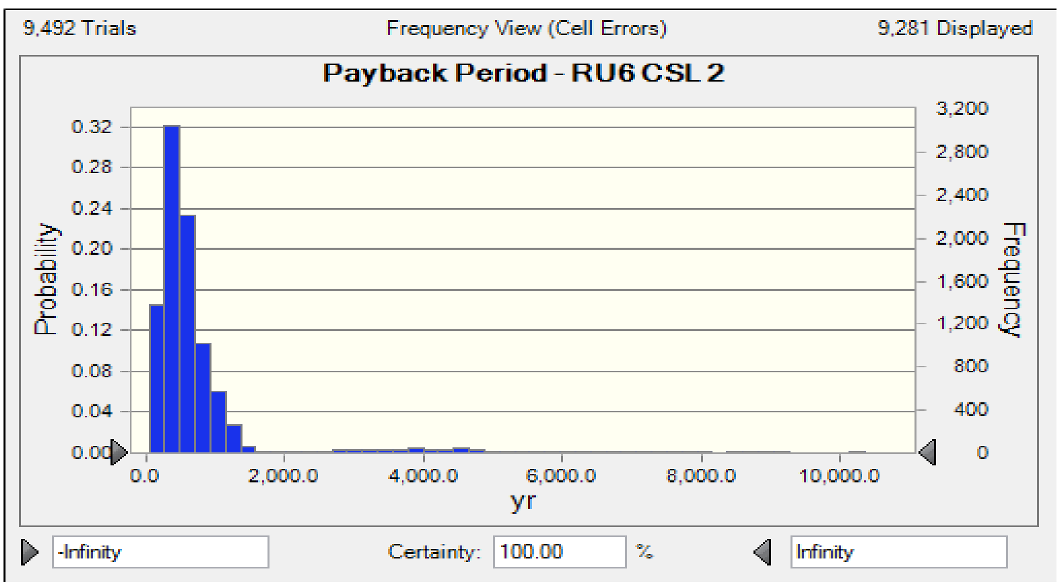


Figure 8B.2.18 Representative Unit 6: Distribution of Payback Periods for CSL 2

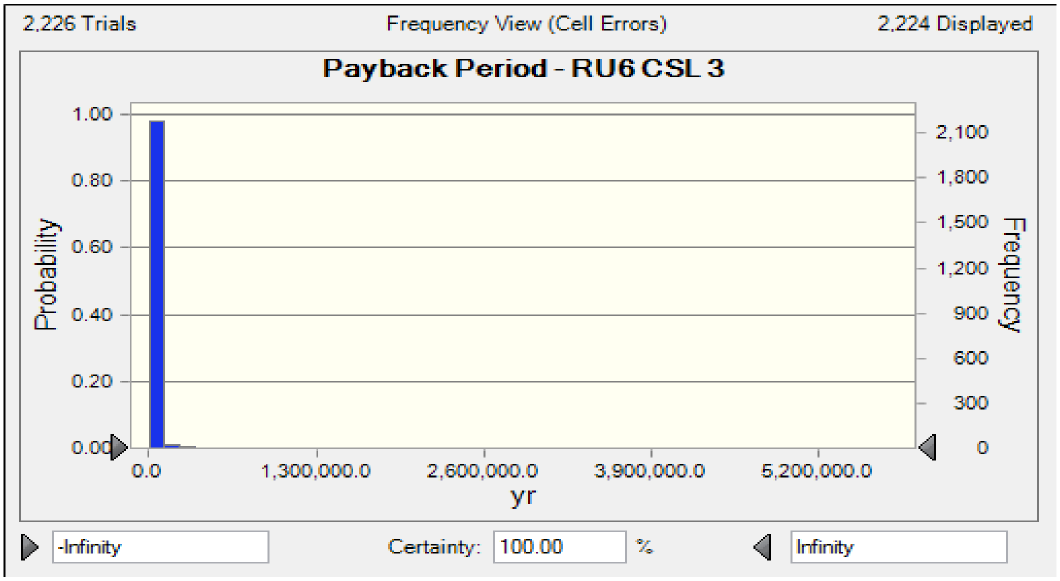


Figure 8B.2.19 Representative Unit 6: Distribution of Payback Periods for CSL 3

8B.2.7 Representative Unit 7, Fire Pump, 30 Horsepower, Four Poles, Enclosed Electric Motor

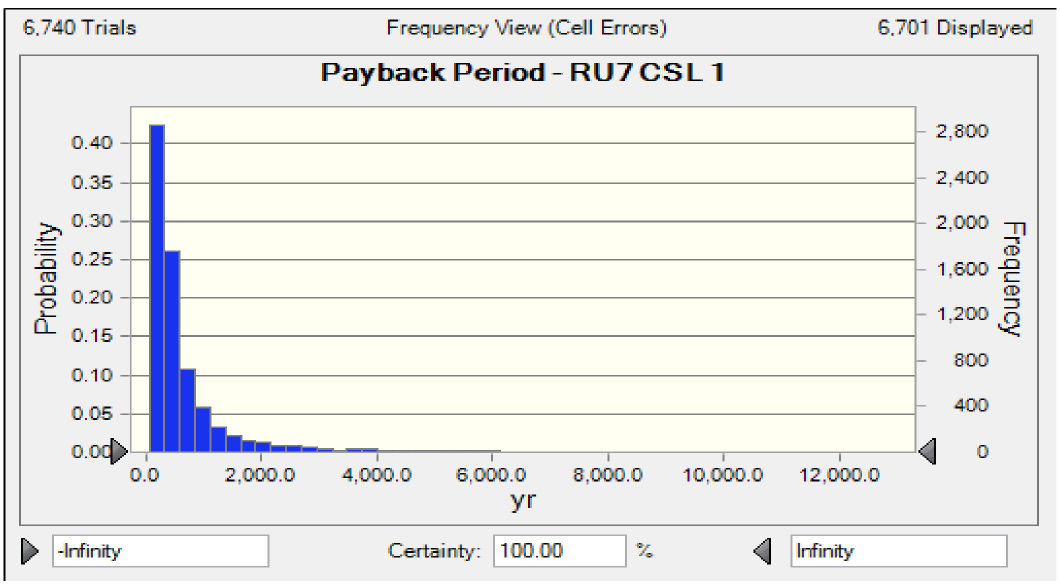
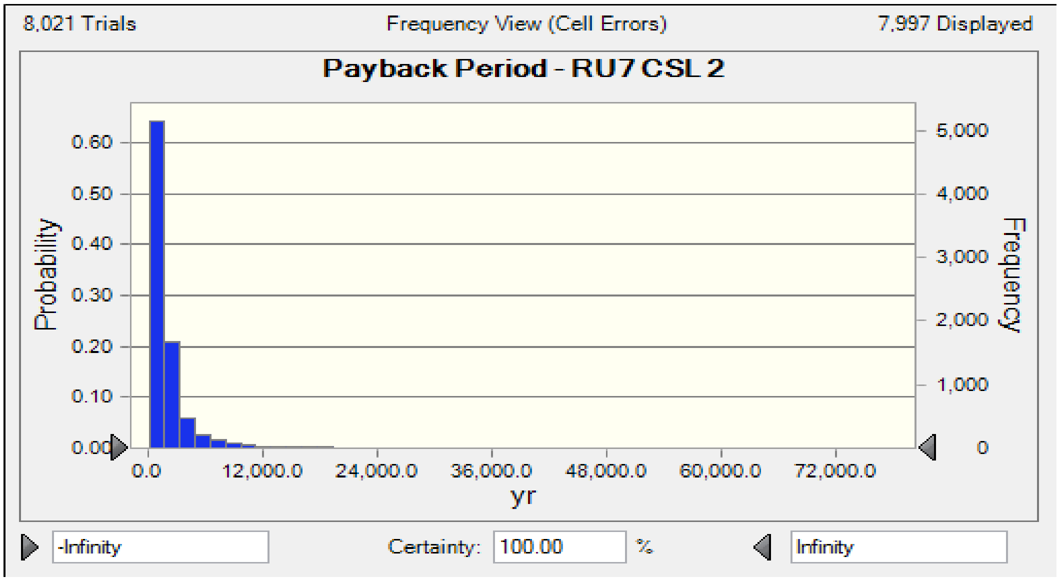


Figure 8B.2.20 Representative Unit 7: Distribution of Payback Periods for CSL 1



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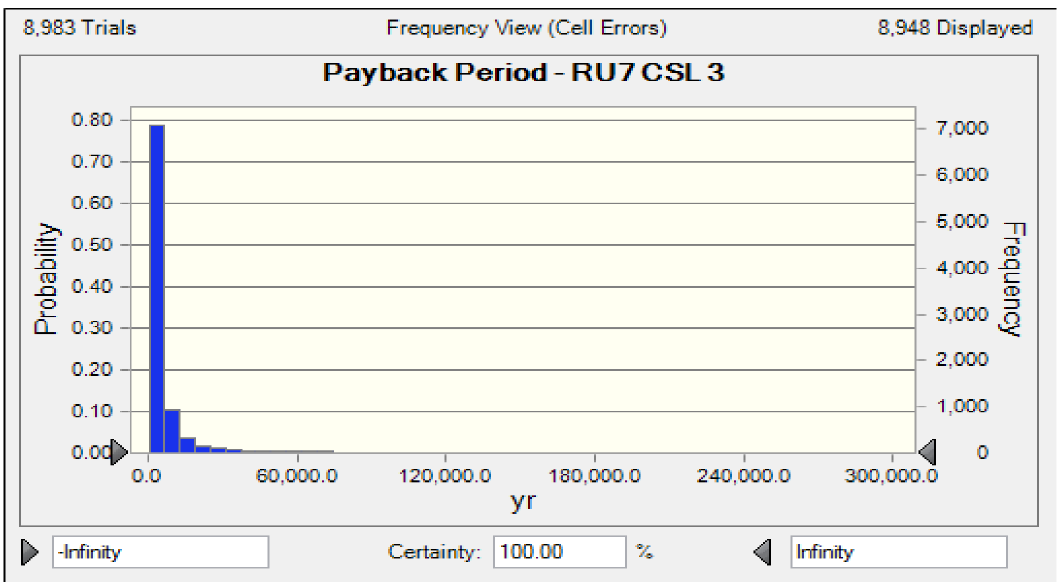

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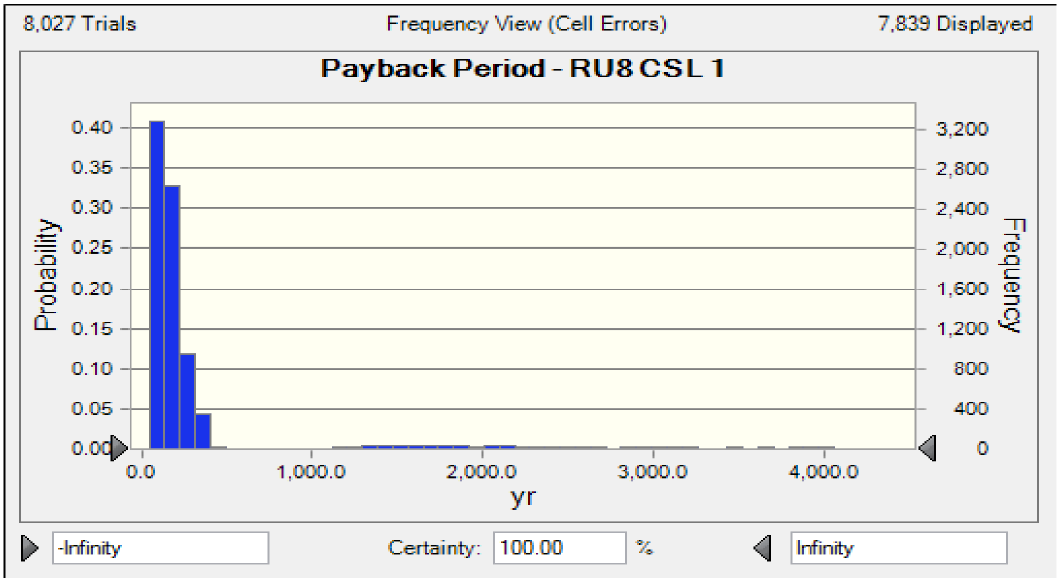

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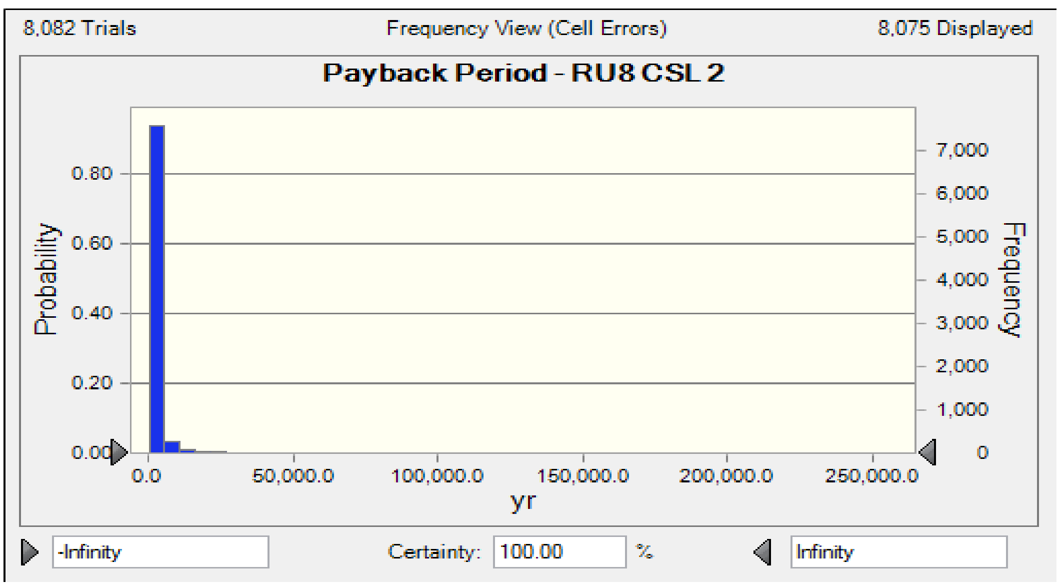

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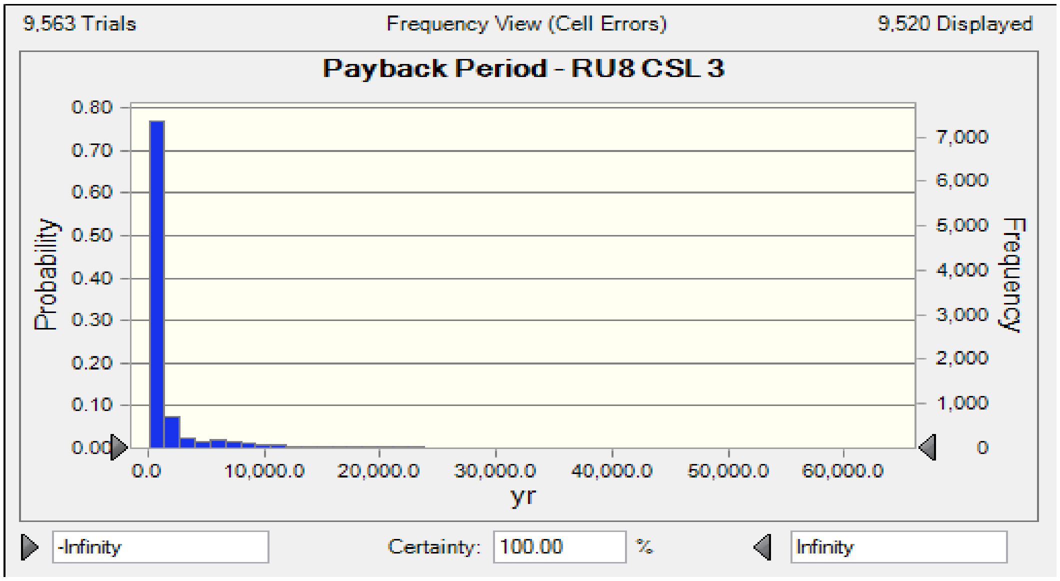

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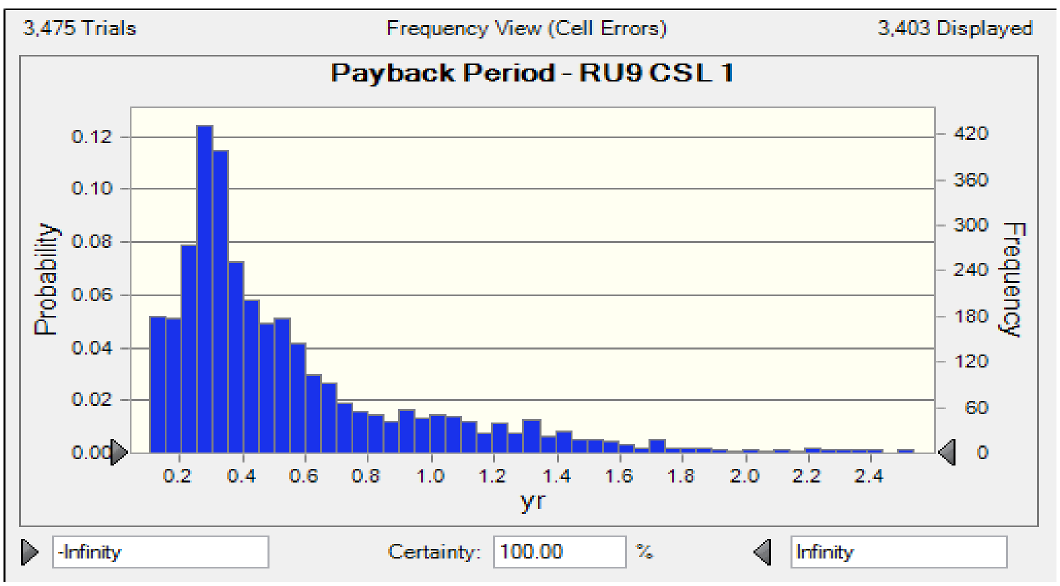
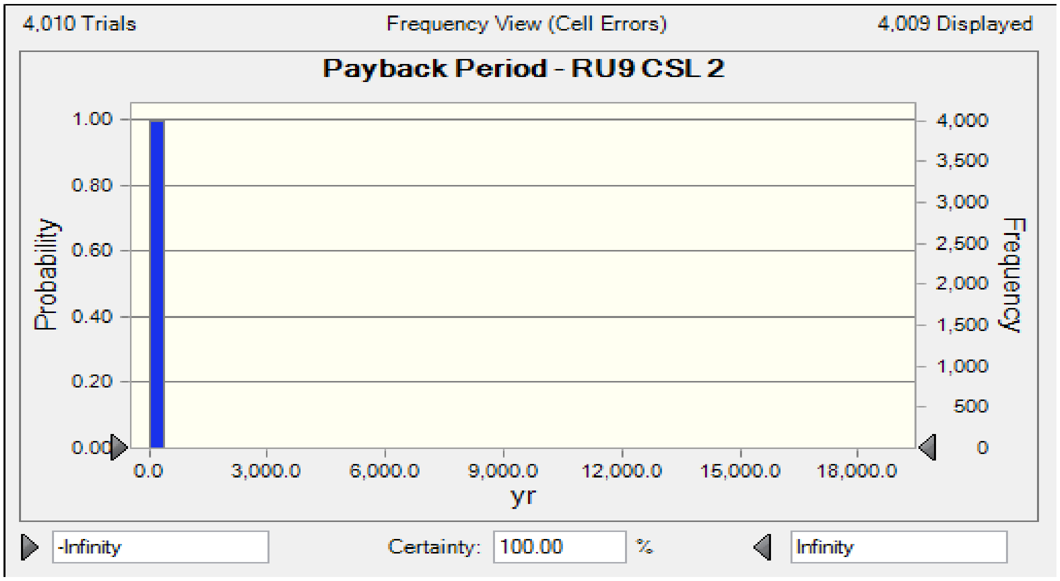


Figure 8B.2.26 Representative Unit 9: Distribution of Payback Periods for CSL 1



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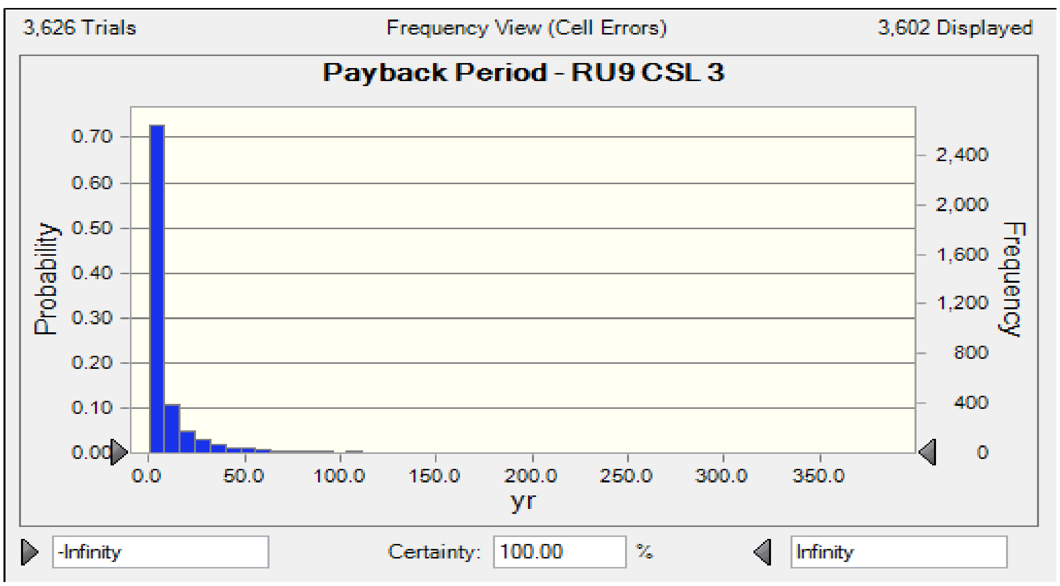

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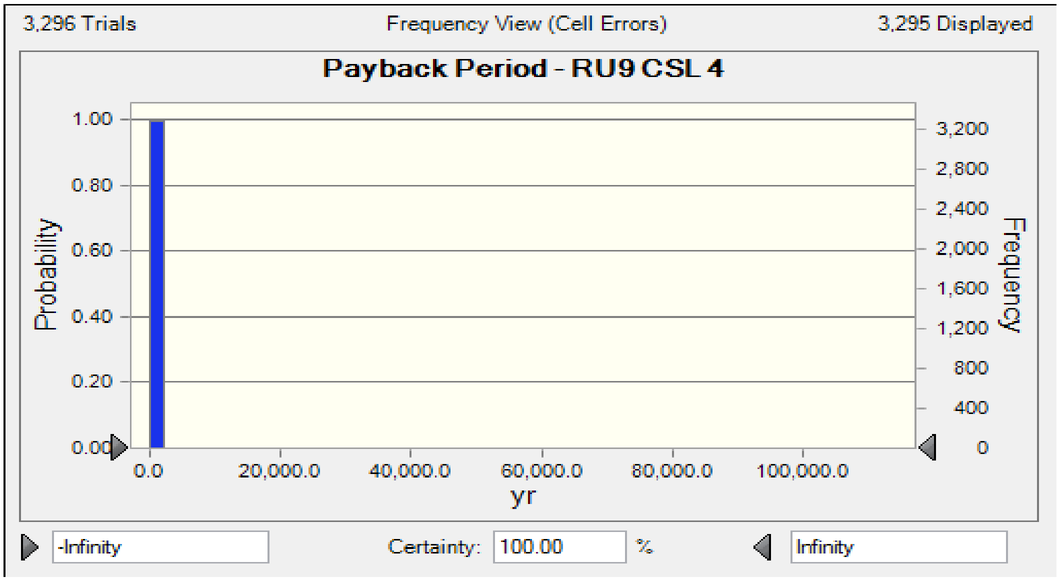

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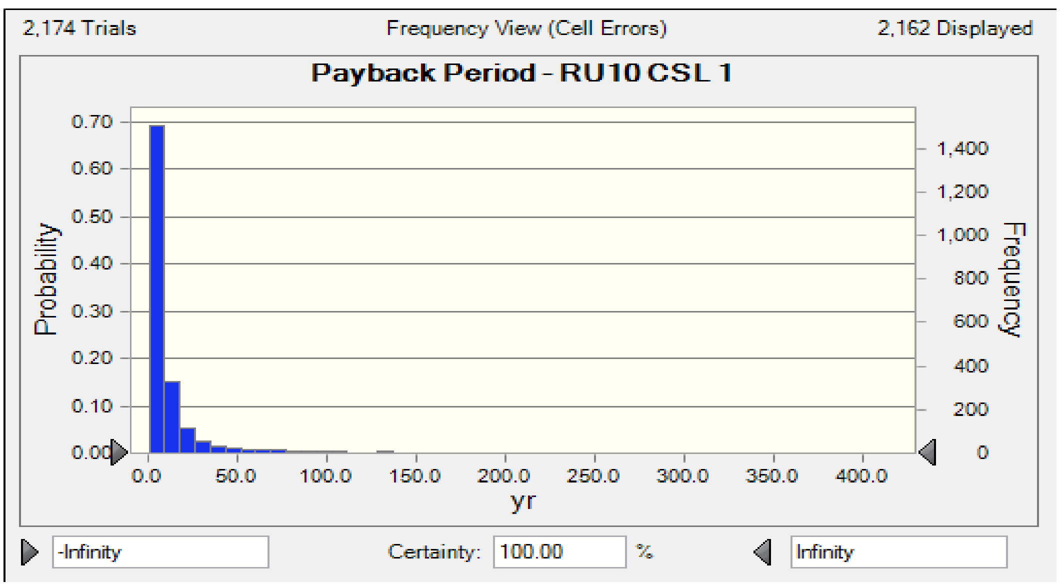

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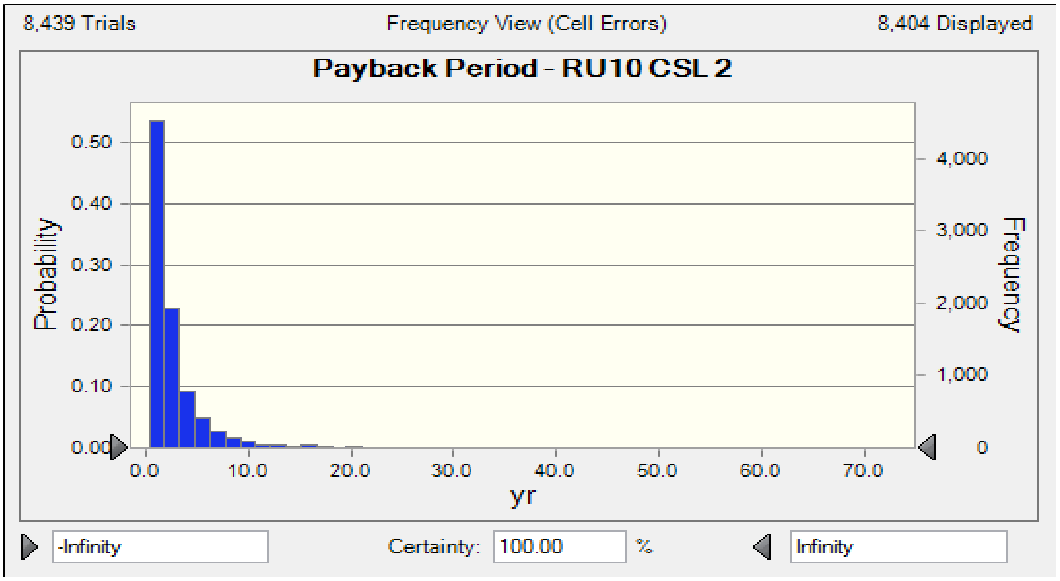

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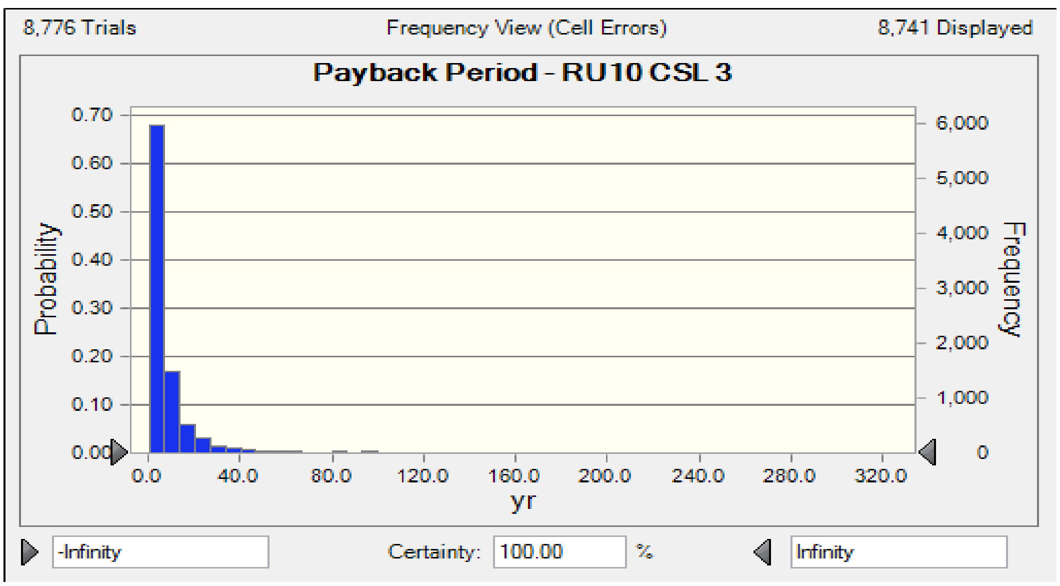

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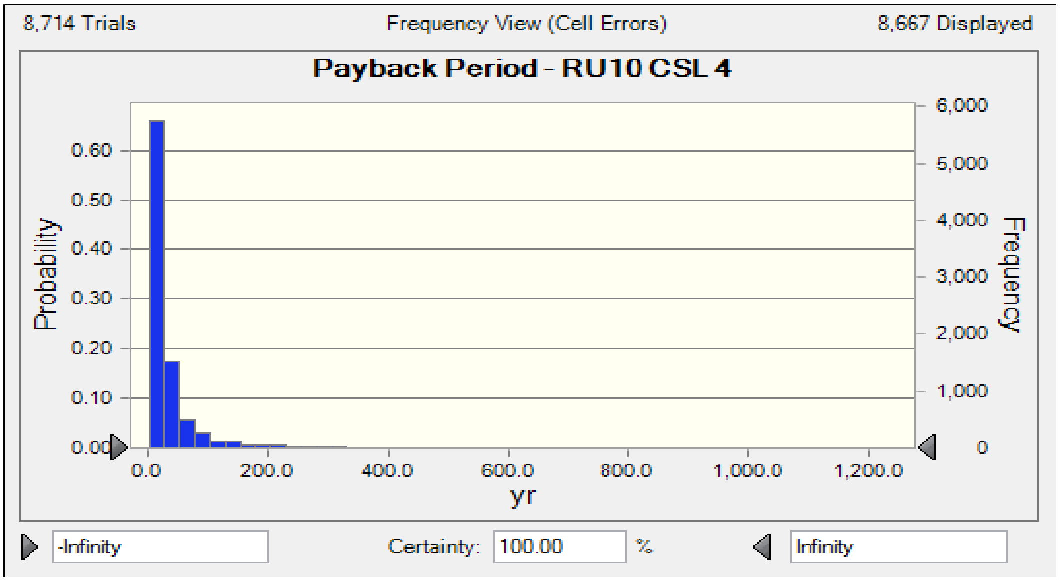

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APPENDIX 8C. LIFE-CYCLE COST SENSITIVITY ANALYSIS

8C.1 REPRESENTATIVE UNIT 1, NEMA DESIGN B, 5 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.1.1 Representative Unit 1: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,977	772	6,127	N/A	0.0	0.0	N/A	N/A
1	87.5	623	8,287	714	5,731	44	0.0	11.2	0.6	0.4
2	89.5	674	8,138	701	5,691	61	10.2	30.8	9.0	3.8
3	90.2	729	8,062	694	5,692	56	35.5	42.0	10.9	7.1
4	91.0	1,152	7,969	687	6,065	-283	85.4	6.8	63.3	31.4

Table 8C.1.2 Representative Unit 1: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,977	785	6,272	N/A	0.0	0.0	N/A	N/A
1	87.5	623	8,287	726	5,865	46	0.0	11.2	0.6	0.4
2	89.5	674	8,138	713	5,823	63	9.9	31.1	8.9	3.7
3	90.2	729	8,062	705	5,823	59	34.0	43.6	10.7	7.0
4	91.0	1,152	7,969	698	6,194	-279	85.1	7.1	62.1	30.9

Table 8C.1.3 Representative Unit 1: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,977	788	6,133	N/A	0.0	0.0	N/A	N/A
1	87.5	623	8,287	729	5,737	44	0.0	11.2	0.6	0.4
2	89.5	674	8,138	716	5,697	61	10.2	30.8	8.8	3.7
3	90.2	729	8,062	708	5,698	56	35.5	42.1	10.7	7.0
4	91.0	1,152	7,969	701	6,070	-283	85.4	6.8	61.7	30.7

Table 8C.1.4 Representative Unit 1: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	226	8,977	772	5,750	N/A	0.0	0.0	N/A	N/A
1	87.5	235	8,287	714	5,342	46	0.0	11.2	0.3	0.2
2	89.5	258	8,138	701	5,274	73	3.4	37.5	4.1	1.7
3	90.2	276	8,062	694	5,239	97	6.3	71.3	3.9	2.6
4	91.0	417	7,969	687	5,330	18	62.3	29.9	21.2	10.6

Table 8C.1.5 Representative Unit 1: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	333	8,977	772	5,858	N/A	0.0	0.0	N/A	N/A
1	87.5	346	8,287	714	5,453	45	0.0	11.2	0.4	0.2
2	89.5	377	8,138	701	5,393	70	5.4	35.6	5.5	2.3
3	90.2	406	8,062	694	5,369	85	13.0	64.5	5.9	3.9
4	91.0	627	7,969	687	5,540	-68	76.7	15.6	33.3	16.5

Table 8C.1.6 Representative Unit 1: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	82.5	441	8,977	772	5,965	N/A	0.0	0.0	N/A	N/A
1	87.5	457	8,287	714	5,564	45	0.0	11.2	0.5	0.3
2	89.5	496	8,138	701	5,512	66	7.3	33.7	6.9	2.9
3	90.2	535	8,062	694	5,498	74	21.6	56.0	7.9	5.2
4	91.0	837	7,969	687	5,750	-154	81.9	10.4	45.3	22.5

8C.2 REPRESENTATIVE UNIT 2, NEMA DESIGN B, 30 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.2.1 Representative Unit 2: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	89.5	1,610	61,611	5,440	48,514	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	60,164	5,318	47,862	36	1.2	3.7	16.9	3.8
2	93.6	2,133	58,778	5,210	47,040	359	1.5	37.7	13.0	1.3
3	94.1	2,378	58,698	5,213	47,304	139	46.8	36.1	226	5.0
4	94.5	3,639	58,511	5,207	48,511	-978	83.9	8.6	196	25.6

Table 8C.2.2 Representative Unit 2: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	89.5	1,610	61,611	5,530	49,832	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	60,164	5,405	49,150	38	1.2	3.8	16.6	3.7
2	93.6	2,133	58,778	5,296	48,298	372	1.4	37.7	4.5	1.3
3	94.1	2,378	58,698	5,298	48,560	154	46.3	36.6	31.5	4.9
4	94.5	3,639	58,511	5,292	49,763	-959	83.2	9.3	365	25.2

Table 8C.2.3 Representative Unit 2: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	61,611	5,553	48,391	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	60,164	5,428	47,742	36	1.2	3.7	16.5	3.7
2	93.6	2,133	58,778	5,318	46,923	358	1.5	37.7	2.9	1.2
3	94.1	2,378	58,698	5,321	47,187	138	46.8	36.1	38.2	4.9
4	94.5	3,639	58,511	5,314	48,394	-980	84.1	8.5	272	25.0

Table 8C.2.4 Representative Unit 2: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	641	61,611	5,440	47,546	N/A	0.0	0.0	N/A	N/A
1	92.4	803	60,164	5,318	46,644	48	0.4	4.5	6.7	1.5
2	93.6	840	58,778	5,210	45,747	401	0.7	38.5	4.3	0.4
3	94.1	939	58,698	5,213	45,865	302	38.0	44.9	91.9	1.9
4	94.5	1,400	58,511	5,207	46,272	-75	63.2	29.3	72.6	9.5

Table 8C.2.5 Representative Unit 2: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	918	61,611	5,440	47,822	N/A	0.0	0.0	N/A	N/A
1	92.4	1,151	60,164	5,318	46,992	45	0.6	4.3	9.6	2.2
2	93.6	1,209	58,778	5,210	46,116	389	0.9	38.3	6.8	0.7
3	94.1	1,351	58,698	5,213	46,276	255	40.4	42.5	130	2.8
4	94.5	2,040	58,511	5,207	46,912	-333	70.4	22.2	108	14.1

Table 8C.2.6 Representative Unit 2: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	89.5	1,195	61,611	5,440	48,099	N/A	0.0	0.0	N/A	N/A
1	92.4	1,499	60,164	5,318	47,340	41	0.9	4.1	12.5	2.8
2	93.6	1,579	58,778	5,210	46,486	377	1.1	38.0	9.3	0.9
3	94.1	1,762	58,698	5,213	46,688	209	42.8	40.1	169	3.7
4	94.5	2,680	58,511	5,207	47,551	-591	76.3	16.3	143	18.7

8C.3 REPRESENTATIVE UNIT 3, NEMA DESIGN B, 75 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.3.1 Representative Unit 3: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	93.0	3,576	195,566	15,283	131,207	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	194,167	15,194	130,778	48	2.9	5.2	20.8	3.5
2	95.4	4,344	190,458	14,929	129,034	626	2.7	30.1	5.2	1.9
3	95.8	5,082	190,392	14,944	129,898	-21	49.2	25.9	44.1	6.6
4	96.2	6,461	188,997	14,855	130,524	-594	70.3	21.2	65.4	16.1

Table 8C.3.2 Representative Unit 3: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	93.0	3,576	195,566	15,574	135,465	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	194,167	15,483	135,012	50	2.8	5.2	20.4	3.4
2	95.4	4,344	190,458	15,213	133,186	656	2.5	30.3	4.3	1.8
3	95.8	5,082	190,392	15,228	134,049	9	48.7	26.4	877	6.5
4	96.2	6,461	188,997	15,137	134,643	-536	69.1	22.5	73.9	15.7

Table 8C.3.3 Representative Unit 3: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	93.0	3,576	195,566	15,554	130,303	N/A	0.0	0.0	N/A	N/A
1	94.1	3,860	194,167	15,463	129,879	47	2.9	5.2	20.4	3.4
2	95.4	4,344	190,458	15,193	128,153	620	2.7	30.1	4.3	1.8
3	95.8	5,082	190,392	15,209	129,017	-28	49.3	25.8	51.5	6.5
4	96.2	6,461	188,997	15,118	129,649	-607	70.6	20.9	67.8	15.7

Table 8C.3.4 Representative Unit 3: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	93.0	1,415	195,566	15,283	129,046	N/A	0.0	0.0	N/A	N/A
1	94.1	1,534	194,167	15,194	128,453	61	1.9	6.2	8.8	1.5
2	95.4	1,724	190,458	14,929	126,415	736	0.8	32.0	2.0	0.7
3	95.8	1,990	190,392	14,944	126,807	441	39.9	35.2	16.0	2.5
4	96.2	2,483	188,997	14,855	126,546	680	37.5	54.1	23.5	5.8

Table 8C.3.5 Representative Unit 3: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	93.0	2,032	195,566	15,283	129,663	N/A	0.0	0.0	N/A	N/A
1	94.1	2,199	194,167	15,194	129,117	57	2.2	5.9	12.2	2.0
2	95.4	2,472	190,458	14,929	127,163	705	1.2	31.6	3.0	1.1
3	95.8	2,874	190,392	14,944	127,690	309	42.9	32.2	24.0	3.6
4	96.2	3,620	188,997	14,855	127,682	316	50.2	41.3	35.5	8.8

Table 8C.3.6 Representative Unit 3: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,650	195,566	15,283	130,281	N/A	0.0	0.0	N/A	N/A
1	94.1	2,863	194,167	15,194	129,782	53	2.5	5.6	15.7	2.6
2	95.4	3,221	190,458	14,929	127,912	673	1.8	31.0	3.9	1.4
3	95.8	3,757	190,392	14,944	128,574	177	45.7	29.4	32.1	4.8
4	96.2	4,756	188,997	14,855	128,819	-48	59.9	31.6	47.5	11.7

8C.4 REPRESENTATIVE UNIT 4, NEMA DESIGN C, 5 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.4.1 Representative Unit 4: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	596	8,376	720	5,952	N/A	0.0	0.0	N/A	N/A
1	89.5	641	8,206	706	5,896	52	18.8	73.1	10.6	4.2
2	91.0	1,059	8,078	694	6,223	-275	96.7	3.3	34.8	23.7

Table 8C.4.2 Representative Unit 4: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	596	8,376	732	6,096	N/A	0.0	0.0	N/A	N/A
1	89.5	641	8,206	718	6,037	54	18.1	73.8	10.5	4.1
2	91.0	1,059	8,078	706	6,361	-270	96.2	3.8	34.3	23.3

Table 8C.4.3 Representative Unit 4: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	87.5	596	8,376	735	5,953	N/A	0.0	0.0	N/A	N/A
1	89.5	641	8,206	721	5,897	52	18.9	73.1	10.4	4.1
2	91.0	1,059	8,078	708	6,224	-275	96.7	3.3	34.0	23.1

Table 8C.4.4 Representative Unit 4: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	87.5	218	8,376	720	5,574	N/A	0.0	0.0	N/A	N/A
1	89.5	238	8,206	706	5,493	75	5.7	86.3	4.7	1.9
2	91.0	376	8,078	694	5,540	28	49.2	50.8	11.8	8.1

Table 8C.4.5 Representative Unit 4: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	87.5	326	8,376	720	5,682	N/A	0.0	0.0	N/A	N/A
1	89.5	353	8,206	706	5,608	68	9.1	82.8	6.4	2.5
2	91.0	571	8,078	694	5,735	-59	75.5	24.5	18.4	12.5

Table 8C.4.6 Representative Unit 4: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with Net Cost %	Customers with Net Benefit %	Average	Median
0	87.5	434	8,376	720	5,790	N/A	0.0	0.0	N/A	N/A
1	89.5	468	8,206	706	5,723	61	12.5	79.5	8.1	3.2
2	91.0	766	8,078	694	5,930	-145	88.8	11.2	25.0	17.0

8C.5 REPRESENTATIVE UNIT 5, NEMA DESIGN C, 50 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.5.1 Representative Unit 5: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	79,551	6,940	67,316	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	78,276	6,854	67,465	-93	47.7	25.4	41.7	12.5
2	95.0	4,610	77,653	6,810	67,752	-380	75.4	24.6	38.9	14.6

Table 8C.5.2 Representative Unit 5: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	79,551	7,056	69,215	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	78,276	6,968	69,336	-72	46.5	26.7	32.3	12.2
2	95.0	4,610	77,653	6,923	69,606	-343	73.5	26.5	37.7	14.3

Table 8C.5.3 Representative Unit 5: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	93.0	2,941	79,551	7,082	67,013	N/A	0.0	0.0	N/A	N/A
1	94.5	3,910	78,276	6,994	67,167	-97	48.0	25.2	47.3	12.1
2	95.0	4,610	77,653	6,949	67,456	-386	75.8	24.2	70.0	14.2

Table 8C.5.4 Representative Unit 5: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	93.0	1,184	79,551	6,940	65,560	N/A	0.0	0.0	N/A	N/A
1	94.5	1,530	78,276	6,854	65,085	362	15.7	57.5	14.9	4.5
2	95.0	1,750	77,653	6,810	64,892	555	23.0	76.9	12.9	4.8

Table 8C.5.5 Representative Unit 5: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	93.0	1,686	79,551	6,940	66,062	N/A	0.0	0.0	N/A	N/A
1	94.5	2,210	78,276	6,854	65,765	232	25.1	48.0	22.6	6.8
2	95.0	2,567	77,653	6,810	65,709	288	39.6	60.4	20.3	7.6

Table 8C.5.6 Representative Unit 5: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with		Average	Median
							Net Cost %	Net Benefit %		
0	93.0	2,188	79,551	6,940	66,564	N/A	0.0	0.0	N/A	N/A
1	94.5	2,890	78,276	6,854	66,445	102	35.3	37.9	30.2	9.0
2	95.0	3,384	77,653	6,810	66,526	21	55.7	44.3	27.7	10.4

8C.6 REPRESENTATIVE UNIT 6, FIRE PUMP, 5 HORSEPOWER, FOUR POLES, ENCLOSED ELECTRIC MOTOR

Table 8C.6.1 Representative Unit 6: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	656	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	709	-43	82.0	0.0	6,162	4,086
2	90.2	731	9	2	759	-91	94.9	0.0	1,310	513
3	91.0	1,153	9	2	1,186	-518	100.0	0.0	76,460	14,484

Table 8C.6.2 Representative Unit 6: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	657	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	710	-44	82.0	0.0	6,062	4,026
2	90.2	731	9	2	760	-91	94.9	0.0	1,289	505
3	91.0	1,153	9	2	1,187	-518	100.0	0.0	75,319	14,262

Table 8C.6.3 Representative Unit 6: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	625	9	2	656	N/A	0.0	0.0	N/A	N/A
1	89.5	676	9	2	709	-43	82.0	0.0	6,034	3,991
2	90.2	731	9	2	759	-91	94.9	0.0	1,283	502
3	91.0	1,153	9	2	1,185	-518	100.0	0.0	74,737	14,157

Table 8C.6.4 Representative Unit 6: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	235	9	2	267	N/A	0.0	0.0	N/A	N/A
1	89.5	258	9	2	292	-20	82.0	0.0	2,784	1,858
2	90.2	277	9	2	305	-33	94.9	0.0	502	201
3	91.0	417	9	2	450	-178	100.0	0.0	25,956	4,910

Table 8C.6.5 Representative Unit 6: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	347	9	2	378	N/A	0.0	0.0	N/A	N/A
1	89.5	378	9	2	411	-27	82.0	0.0	3,749	2,492
2	90.2	406	9	2	435	-50	94.9	0.0	733	290
3	91.0	628	9	2	660	-275	100.0	0.0	40,385	7,629

Table 8C.6.6 Representative Unit 6: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	87.5	458	9	2	489	N/A	0.0	0.0	N/A	N/A
1	89.5	497	9	2	530	-34	82.0	0.0	4,714	3,125
2	90.2	536	9	2	565	-66	94.9	0.0	964	379
3	91.0	838	9	2	870	-372	100.0	0.0	54,815	10,373

8C.7 REPRESENTATIVE UNIT 7, FIRE PUMP, 30 HORSEPOWER, FOUR POLES, ENCLOSED ELECTRIC MOTOR

Table 8C.7.1 Representative Unit 7: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	2,052	53	12	2,230	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	12	2,338	-88	80.7	0.0	928	375
2	94.1	2,410	52	12	2,583	-302	87.4	0.0	3,294	1,339
3	94.5	3,670	52	12	3,839	-1,558	100.0	0.0	11,435	2,768

Table 8C.7.2 Representative Unit 7: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	2,052	53	12	2,236	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	12	2,345	-88	80.7	0.0	913	369
2	94.1	2,410	52	12	2,590	-301	87.4	0.0	3,240	1,318
3	94.5	3,670	52	12	3,846	-1,558	100.0	0.0	11,254	2,723

Table 8C.7.3 Representative Unit 7: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	2,052	53	12	2,227	N/A	0.0	0.0	N/A	N/A
1	93.6	2,164	52	12	2,336	-88	80.7	0.0	908	367
2	94.1	2,410	52	12	2,580	-302	87.4	0.0	3,225	1,311
3	94.5	3,670	52	12	3,837	-1,558	100.0	0.0	11,189	2,710

Table 8C.7.4 Representative Unit 7: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	812	53	12	990	N/A	0.0	0.0	N/A	N/A
1	93.6	849	52	12	1,023	-27	80.7	0.0	307	124
2	94.1	949	52	12	1,122	-114	87.4	0.0	1,274	513
3	94.5	1,409	52	12	1,579	-570	100.0	0.0	4,228	1,024

Table 8C.7.5 Representative Unit 7: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	1,166	53	12	1,344	N/A	0.0	0.0	N/A	N/A
1	93.6	1,225	52	12	1,399	-44	80.7	0.0	485	196
2	94.1	1,366	52	12	1,540	-167	87.4	0.0	1,851	750
3	94.5	2,055	52	12	2,224	-852	100.0	0.0	6,287	1,524

Table 8C.7.6 Representative Unit 7: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	92.4	1,521	53	12	1,698	N/A	0.0	0.0	N/A	N/A
1	93.6	1,601	52	12	1,775	-62	80.7	0.0	662	268
2	94.1	1,784	52	12	1,957	-221	87.4	0.0	2,428	985
3	94.5	2,701	52	12	2,870	-1,134	100.0	0.0	8,346	2,021

8C.8 REPRESENTATIVE UNIT 8, FIRE PUMP, 75 HORSEPOWER, FOUR POLES, ENCLOSED ELECTRIC MOTOR

Table 8C.8.1 Representative Unit 8: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	130	28	4,280	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	24	4,716	-350	80.3	0.0	503	151
2	95.8	5,102	128	26	5,483	-1,044	90.5	0.0	4,057	945
3	96.2	6,482	127	24	6,825	-2,386	100.0	0.0	3,258	728

Table 8C.8.2 Representative Unit 8: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	130	28	4,298	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	25	4,731	-348	80.3	0.0	494	149
2	95.8	5,102	128	27	5,499	-1,043	90.5	0.0	3,985	927
3	96.2	6,482	127	24	6,840	-2,384	100.0	0.0	3,196	715

Table 8C.8.3 Representative Unit 8: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	3,881	130	28	4,272	N/A	0.0	0.0	N/A	N/A
1	95.4	4,364	128	25	4,708	-350	80.3	0.0	494	149
2	95.8	5,102	128	27	5,474	-1,044	90.5	0.0	3,979	928
3	96.2	6,482	127	24	6,817	-2,387	100.0	0.0	3,200	715

Table 8C.8.4 Representative Unit 8: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	1,541	130	28	1,940	N/A	0.0	0.0	N/A	N/A
1	95.4	1,730	128	24	2,082	-114	80.3	0.0	197	59.4
2	95.8	1,997	128	26	2,377	-381	90.5	0.0	1,487	353
3	96.2	2,489	127	24	2,833	-837	100.0	0.0	1,181	266

Table 8C.8.5 Representative Unit 8: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	2,209	130	28	2,609	N/A	0.0	0.0	N/A	N/A
1	95.4	2,483	128	24	2,834	-181	80.3	0.0	285	85.6
2	95.8	2,884	128	26	3,264	-570	90.5	0.0	2,221	523
3	96.2	3,630	127	24	3,973	-1,279	100.0	0.0	1,775	398

Table 8C.8.6 Representative Unit 8: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	94.1	2,878	130	28	3,278	N/A	0.0	0.0	N/A	N/A
1	95.4	3,235	128	24	3,587	-249	80.3	0.0	372	112
2	95.8	3,771	128	26	4,152	-760	90.5	0.0	2,955	692
3	96.2	4,771	127	24	5,114	-1,722	100.0	0.0	2,368	529

8C.9 REPRESENTATIVE UNIT 9, BRAKE MOTOR, NEMA DESIGN B, T-FRAME, 5 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.9.1 Representative Unit 9: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,079	801	5,878	N/A	0.0	0.0	N/A	N/A
1	87.5	623	7,430	746	5,477	141	0.0	34.8	0.6	0.4
2	89.5	674	7,290	751	5,438	169	12.0	57.1	117	1.9
3	90.2	729	7,219	757	5,442	163	33.4	65.3	19.4	3.5
4	91.0	1,152	7,132	765	5,812	-203	78.6	20.9	809	15.6

Table 8C.9.2 Representative Unit 9: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,079	813	6,022	N/A	0.0	0.0	N/A	N/A
1	87.5	623	7,430	757	5,609	145	0.0	34.8	0.6	0.4
2	89.5	674	7,290	762	5,567	174	11.7	57.5	11.9	1.9
3	90.2	729	7,219	768	5,570	170	32.1	66.6	23.2	3.4
4	91.0	1,152	7,132	775	5,938	-195	77.9	21.6	88.9	15.6

Table 8C.9.3 Representative Unit 9: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	603	8,079	815	5,875	N/A	0.0	0.0	N/A	N/A
1	87.5	623	7,430	759	5,475	141	0.0	34.8	0.6	0.4
2	89.5	674	7,290	764	5,435	168	12.0	57.1	10.4	1.9
3	90.2	729	7,219	770	5,439	163	33.4	65.3	32.4	3.4
4	91.0	1,152	7,132	777	5,809	-204	78.6	20.9	353	15.4

Table 8C.9.4 Representative Unit 9: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	226	8,079	801	5,501	N/A	0.0	0.0	N/A	N/A
1	87.5	235	7,430	746	5,089	145	0.0	34.8	0.3	0.2
2	89.5	258	7,290	751	5,021	192	3.6	65.5	50.8	0.9
3	90.2	276	7,219	757	4,989	222	5.0	93.7	7.5	1.4
4	91.0	417	7,132	765	5,077	136	46.6	53.0	268	5.4

Table 8C.9.5 Representative Unit 9: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	333	8,079	801	5,609	N/A	0.0	0.0	N/A	N/A
1	87.5	346	7,430	746	5,200	144	0.0	34.8	0.4	0.2
2	89.5	377	7,290	751	5,140	185	6.0	63.2	69.8	1.2
3	90.2	406	7,219	757	5,118	205	11.9	86.8	10.9	2.0
4	91.0	627	7,132	765	5,287	39	63.2	36.3	422	8.3

Table 8C.9.6 Representative Unit 9: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	82.5	441	8,079	801	5,716	N/A	0.0	0.0	N/A	N/A
1	87.5	457	7,430	746	5,311	143	0.0	34.8	0.5	0.3
2	89.5	496	7,290	751	5,259	179	8.6	60.6	88.9	1.4
3	90.2	535	7,219	757	5,247	188	19.9	78.8	14.3	2.6
4	91.0	837	7,132	765	5,497	-58	71.1	28.5	577	11.2

8C.10 REPRESENTATIVE UNIT 10, BRAKE MOTOR, NEMA DESIGN B, T-FRAME, 30 HORSEPOWER, FOUR POLES, ENCLOSED MOTOR

Table 8C.10.1 Representative Unit 10: Reference Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	48,394	4,257	41,567	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	47,178	4,156	41,011	116	6.6	15.5	19.0	5.2
2	93.6	2,133	45,999	4,067	40,281	741	4.6	80.7	3.9	1.7
3	94.1	2,378	45,934	4,071	40,560	462	31.7	68.3	14.6	4.6
4	94.5	3,639	45,777	4,067	41,786	-764	85.2	14.8	63.2	18.1

Table 8C.10.2 Representative Unit 10: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	48,394	4,328	42,746	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	47,178	4,225	42,161	123	6.3	15.7	18.7	5.1
2	93.6	2,133	45,999	4,134	41,402	771	4.4	80.9	3.6	1.7
3	94.1	2,378	45,934	4,138	41,679	494	30.8	69.2	24.0	4.5
4	94.5	3,639	45,777	4,134	42,901	-727	83.8	16.2	83.4	17.7

Table 8C.10.3 Representative Unit 10: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,610	48,394	4,344	41,372	N/A	0.0	0.0	N/A	N/A
1	92.4	2,021	47,178	4,241	40,820	115	6.5	15.5	18.6	5.1
2	93.6	2,133	45,999	4,150	40,095	735	4.6	80.7	3.7	1.7
3	94.1	2,378	45,934	4,154	40,374	457	31.8	68.2	22.9	4.5
4	94.5	3,639	45,777	4,150	41,601	-770	85.5	14.5	96.9	17.6

Table 8C.10.4 Representative Unit 10: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	641	48,394	4,257	40,599	N/A	0.0	0.0	N/A	N/A
1	92.4	803	47,178	4,156	39,793	171	2.7	19.4	7.4	2.1
2	93.6	840	45,999	4,067	38,988	860	1.8	83.5	1.4	0.6
3	94.1	939	45,934	4,071	39,121	727	18.1	81.9	5.7	1.8
4	94.5	1,400	45,777	4,067	39,547	301	42.4	57.6	23.4	6.6

Table 8C.10.5 Representative Unit 10: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	918	48,394	4,257	40,875	N/A	0.0	0.0	N/A	N/A
1	92.4	1,151	47,178	4,156	40,141	156	3.7	18.3	10.7	3.0
2	93.6	1,209	45,999	4,067	39,358	826	2.4	82.9	2.1	0.9
3	94.1	1,351	45,934	4,071	39,532	651	22.0	78.0	8.3	2.6
4	94.5	2,040	45,777	4,067	40,187	-3	57.4	42.6	34.8	9.9

Table 8C.10.6 Representative Unit 10: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period years	
		Average Installed Price $	Average Energy Use kWh/yr	Average Annual Operating Cost $	Average Life-Cycle Cost $	Average Savings $	Customers with			
							Net Cost %	Net Benefit %	Average	Median
0	89.5	1,195	48,394	4,257	41,152	N/A	0.0	0.0	N/A	N/A
1	92.4	1,499	47,178	4,156	40,489	140	4.9	17.2	14.0	3.9
2	93.6	1,579	45,999	4,067	39,727	792	3.2	82.1	2.8	1.2
3	94.1	1,762	45,934	4,071	39,943	575	25.8	74.2	10.8	3.4
4	94.5	2,680	45,777	4,067	40,826	-308	71.0	29.1	46.2	13.2

APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEET MODELS

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APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEET MODELS

10-A.1 USER INSTRUCTIONS

The results obtained in the shipments analysis and the national impact analysis (NIA) can be examined and reproduced using the Microsoft Excel spreadsheet available on the U.S. Department of Energy's (DOE)'s website at:
http://www.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/42

The shipments model is in the spreadsheet called "mem_nopr_shipments_model.xls," and the NIA in the spreadsheets "mem_nopr_nia_summary.xlsm," "mem_nopr_nia_designab.xlsx," "mem_nopr_nia_designc.xlsx," "mem_nopr_nia_firepump.xlsx," and "mem_nopr_nia_brake.xlsx." These spreadsheets implement the calculations described in Chapters 9 and 10. Further, the NIA spreadsheets enable the user to simulate national impacts under different parameters and scenarios. To run the spreadsheets the user needs to have Microsoft Excel 2007 or a later version.

10-A.1.1 Shipments Model Spreadsheet Description

The shipments model spreadsheet performs calculations to forecast the shipments of motors covered by the rulemaking. The methodology for developing the shipments model is described in Chapter 9 of the Technical Support Document. The shipments model spreadsheet, or workbook, consists of the following worksheets:

(a) Shipments: Calculates and provides a summary of the shipment forecasts for the entire analysis period and beyond.

(b) Invest. vs. Ship.: Presents how DOE developed a relationship between shipments and private fixed investment in selected equipment and structure.

(c) Invest. vs. Tol. Invest.: Calculates projections for private fixed investment in equipment and structure for selected sectors.

(d) Tot. Invest. vs. GDP: Calculates projections for total private fixed investment.

(e) Census: Presents the Census data used to develop the historical shipments index.

(f) RSMeans: Presents the data used to estimate the percentage of private fixed investments in structures related to heating, ventilating and air conditioning (HVAC) equipment.

(g) Investment in Structure: Presents the data used to calculate private fixed investments in structures related to HVAC equipment.

(h) Investment in Equipment: Presents the data used to calculate private fixed investments in motor related equipment.

(i) Current Dollar and Real GDP: Presents the data used to adjust the value of dollar.

10-A.1.2 National Impact Analysis Spreadsheets Description

The NIA spreadsheets perform calculations to forecast the changes in national energy savings (NES) and net present value (NPV) due to an energy efficiency standard. For a standard set at a given trial standard level (TSL), the energy consumption and the costs associated with each equipment class, as well as the corresponding NES and NPV results rely on the shipments estimated in the shipments spreadsheet and on calculation performed by four *accountability spreadsheets*, each dedicated to a specific equipment class group. A fifth, *summary spreadsheet* provides the accountability spreadsheets with general parameters and tables, and summarizes their results. Figure 10-A.1.1 presents the general organization and interactions between the spreadsheets comprising the NIA model. The following subsections describe, respectively, the worksheets comprising the summary and the accountability spreadsheets, and provide instructions to operate the NIA model.

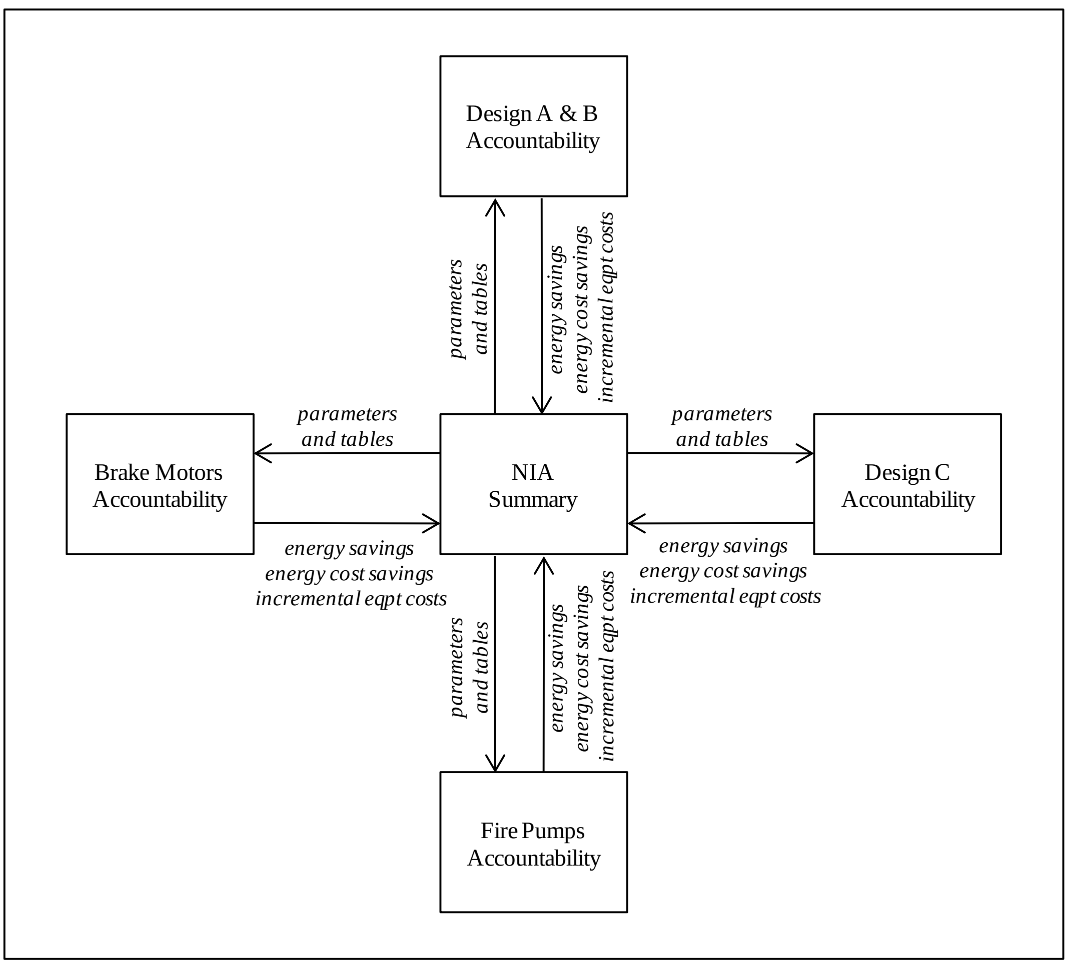

Figure 10-A.1.1 Spreadsheets Architecture of the NIA Model

10-A.1.2.1 Summary Spreadsheet Organization

The summary spreadsheet consists of the following six worksheets which support the accountability spreadsheets and summarize their results.

(a) Lifetime: Presents, for each equipment class group, motor survival probabilities by sector and horsepower (HP) range.

(b) Efficiency Tables: Presents, for each equipment class group, the efficiency levels by CSL and equipment class.

(c) General Tables & Parameters: Presents all tables and single-value parameters used by the accountability spreadsheets.

(d) Shipments: Presents forecast of total shipments, as well as shipment distributions across equipment class groups, and motor HP and configuration.

(e) Summary: Enables the user to select TSLs, scenarios and sensitivity levels to be simulated by the accountability spreadsheets, and summarize their results.

(f) Scenario Results: Automatically simulates pre-determined combinations of scenarios and sensitivity levels, and summarize results in a pivot-table.

10-A.1.2.2 Accountability Spreadsheets Organization

The accountability spreadsheets consist of the following 11 worksheets which calculate the national energy savings, the national energy cost savings, and the national (non-energy) incremental equipment costs for all equipment classes of each equipment class group.

(a) Shipments: Presents the base case shipments forecast by sector for all equipment classes, and estimates shipments for the standards case scenario depending on the elasticity scenario selected.

(b) Efficiency Distribution: Presents the base case energy efficiency distribution by motor HP, and calculates the corresponding distributions to the standards case according to the efficiency level corresponding to the TSL selected in the Summary spreadsheet.

(c) Unit Energy Consumption: Calculates, for all equipment classes and efficiency levels, the lifetime energy consumption of a unit shipped in each year of the analysis period, according to the sector to which it is shipped.

(d) Natl Energy Consumption: Calculates, for all equipment classes, the base case and the standards case national lifetime energy consumption from units shipped in each year of the analysis period. The calculation is disaggregated by sector. Additionally, this worksheet calculates the annual energy consumption from the existing stock not replaced due to effects from a non-zero elasticity scenario.

(e) Natl Energy Savings: Calculates, for all equipment classes, the national energy savings by sector.

(f) Unit Energy Cost: Calculates, for all equipment classes and efficiency levels, the lifetime energy cost of a unit shipped in each year of the analysis period, according to the sector to which it is shipped.

(g) Natl Energy Cost: Calculates, for all equipment classes, the base case and the standards case national lifetime energy costs from units shipped in each year of the analysis period. The calculation is disaggregated by sector. Additionally, this worksheet calculates the annual energy cost from the existing stock not replaced due to effects from a non-zero elasticity scenario.

(h) Natl Energy Cost Savings: Calculates, for all equipment classes, the present-value of the national energy cost savings by sector.

(i) Unit Eqpt Costs: Calculates, for all equipment classes and efficiency levels, the lifetime non-energy equipment costs of a unit shipped in each year of the analysis period, according to the sector to which it is shipped.

(j) Natl Eqpt Costs: Calculates, for all equipment classes, the base case and the standards case national lifetime non-energy equipment costs from units shipped in each year of the analysis period. The calculation is disaggregated by sector.

(k) Natl Eqpt Incr Costs: Calculates, for all equipment classes, the present-value of the national (non-energy) incremental equipment costs by sector.

10-A.1.2.3 National Impact Analysis Spreadsheet Operating Instructions

Basic instructions for operating the NIA spreadsheet are as follows:

1. After downloading the NIA set of spreadsheet files from DOE's website, open the Summary file using Excel. Once loaded, this spreadsheet will ask if the user wants to open the additional files. If you intend only to see the existing results, the answer maybe "No." However, if you plan to do your own simulations you must answer with "Yes," in which case Excel will automatically open the four additional accountability spreadsheet files and activate back the Summary spreadsheet.

2. If you intend only to see the existing results, click on the tab for the worksheet "Scenario Results." To select results for specific combinations of parameters and scenarios use: the pivot-table located at the right side of the results listing.[a]

[a] To learn more on how to use Excel pivot-tables refer to "PivotTable I: Get started with PivotTable reports in Excel 2007" in <http://office.microsoft.com/en-us/excel-help/pivottable-i-get-started-with-pivottable-reports-in-excel-2007-RZ010205886.aspx>.

3. If you intend to run your own simulations, there are two options: (a) running the model for a specific combination of parameters and scenarios, and (b) running the model for pre-determined combinations of parameters and scenarios. The two options can be operated as follows:

(a) For a specific combination of parameters and scenarios:

Click on the tab for the worksheet "Summary." This worksheet serves as the user interface for running the model for a particular combination of parameters and scenarios. To provide flexibility, the spreadsheet permits some user modifications to the model. The user may select a particular:

- *Discount rate*, which enables the user to set a discount rate (in percentage) and affects the present-values of energy savings and incremental equipment (non-energy) costs;
- *Economic growth* which enables the user to select an annual economic outlook (AEO) macroeconomic forecast and determines the electricity prices and level of shipments to be used by the model;
- *Product price trend*, which enables the user to select a scenario of motor price trends and affects motor manufacturer selling prices (MSPs) over the analysis period;
- *Energy savings*, which enables the user to select whether the energy savings are to be reported as site, primary or full-fuel-cycle energy savings;
- *Analysis period*, which enables the user to select between 30-year and 9-year impacts from standards;
- *TSL*, which enables the user to select a TSL that determines the standard level for each equipment class group, and affects the standards case efficiency distribution;
- *Elasticity*, which enables the user to select a scenario that will either account or not account for the effects of price elasticity on shipments; and
- *Sensitivity factors*, which enables the user to change (with a direct multiplier) all motors MSP, repair cost and operating hours values, and affects energy consumption and costs, as well as equipment non-energy costs.

Once the desired parameters are set, the user should start the spreadsheet calculation. This can be done either by pressing F9 or navigating through the Excel menu as follows: Formulas >> Calculate Now.

(b) For pre-determined combinations of parameters and scenarios:

Click on the tab for the worksheet "Results for All Scenarios." This worksheet can automatically calculate results for all equipment class groups, TSLs, and discount rates considering all Reference scenarios. It can further extend these calculations to selected alternative scenarios (including scenarios for sensitivity analysis). To enable the automatic calculation one must answer "Yes" to the "Recalculate all?" question, or otherwise the worksheet will just show the results from the earlier run (see item 2 above on how to examine results from a model run). After answering with a "Yes" to the "Recalculate all?" message, the following alternatives will be posted to the user:

- "Only Reference scenarios?"
  Yes: simulate only the Reference economic growth and the Constant product price trend scenarios over the 30-year analysis period with no elasticity
  No: enables the selection of additional scenarios to be simulated (see the next item).

- "Select scenarios to simulate:"
  "A=Economic growth,"
  "P=Prod price trend,"
  "E=Elasticity,"
  "Y=Analysis period,"
  "*=All"
  A: simulates the Low- and High AEO economic growth scenarios, in addition to the Reference one
  P: simulates the Decreasing and Increasing product price trend scenarios, in addition to the Constant one
  E: simulates the Yes elasticity scenario, in addition to the No one
  Y: simulates the 9-year analysis period, in addition to the 30-year period
  *: simulates all scenarios.

- "Include sensitivity analysis?"
  Yes: enables the user to setup the sensitivity level to be simulated (see the next item)
  No: only the reference values for hours of operation, MSP and repair cost will be simulated.

- "Enter percentage:"
  Enables the user to type the percentage corresponding to the desired sensitivity level to be simulated (for example, to simulate hours of operation, MSP and repair cost values 10 percent lower and higher than the former values just enter the number 10).

- "Run:"
  "<…> scenarios,"
  "<yes/no> sensitivity analysis."
  This message summarizes what it will be simulated. To start the simulation process, click Ok; otherwise, click Cancel.

During the simulation process, messages in the left side of the lower message bar will report the process progress and an estimate of the remaining time. Once the simulation is over, the user can then examine the results (see item 2 above on how to examine results from a model run).

APPENDIX 10-B. NATIONAL IMPACT ANALYSIS SENSITIVITY FOR ALTERNATIVE PRODUCT PRICE TREND SCENARIOS

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APPENDIX 10-B. NATIONAL IMPACT ANALYSIS SENSITIVITY ANALYSIS FOR ALTERNATIVE PRODUCT PRICE TREND SCENARIOS

10-B.1 INTRODUCTION

The U.S. Department of Energy (DOE) used a constant price assumption for the default forecast in the National Impact Analysis (NIA) described in Chapter 10. In order to investigate the impact of different equipment price forecasts (or product price forecasts) on the consumer net present value (NPV) for the considered trial standard levels (TSLs) for electric motors, DOE also considered two alternative price trends for a sensitivity analysis. This appendix describes the alternative price trends and compares NPV results for these scenarios with the default forecast.

10-B.2 ALTERNATIVE MOTOR PRICE TREND SCENARIOS

DOE considered two alternative price trends for a sensitivity analysis. One of these used an exponential fit on the deflated Producer Price Index (PPI) for electric motors, and the other is based on the "chained price index—industrial equipment" that was forecasted for EIA's *Annual Energy Outlook 2012* (*AEO2012)*.

10-B.2.1 Exponential Fit Approach (Increasing Price Scenario)

For this scenario, DOE used an inflation-adjusted integral horsepower motor and generator manufacturing Producer Price Index (PPI) from 1969-2012 to fit an exponential model with *year* as the explanatory variable. DOE obtained historical PPI data for integral horsepower motors and generators manufacturing spanning the time period 1969-2012 from the Bureau of Labor Statistics' (BLS).[a] The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for integral horsepower motors and generators manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index. The deflated price index is now presented in 2012 dollar values. In this case, the exponential function takes the form of:

$$Y = a \cdot e^{bX}$$

where Y is the motor price index, X is the time variable, *a* is the constant and *b* is the slope parameter of the time variable.

To estimate these exponential parameters, a least-square fit was performed on the inflation-adjusted motor price index versus *year* from 1969 to 2012. See Figure 10-B.2.1.

[a] Series ID PCU3353123353123; http://www.bls.gov/ppi/

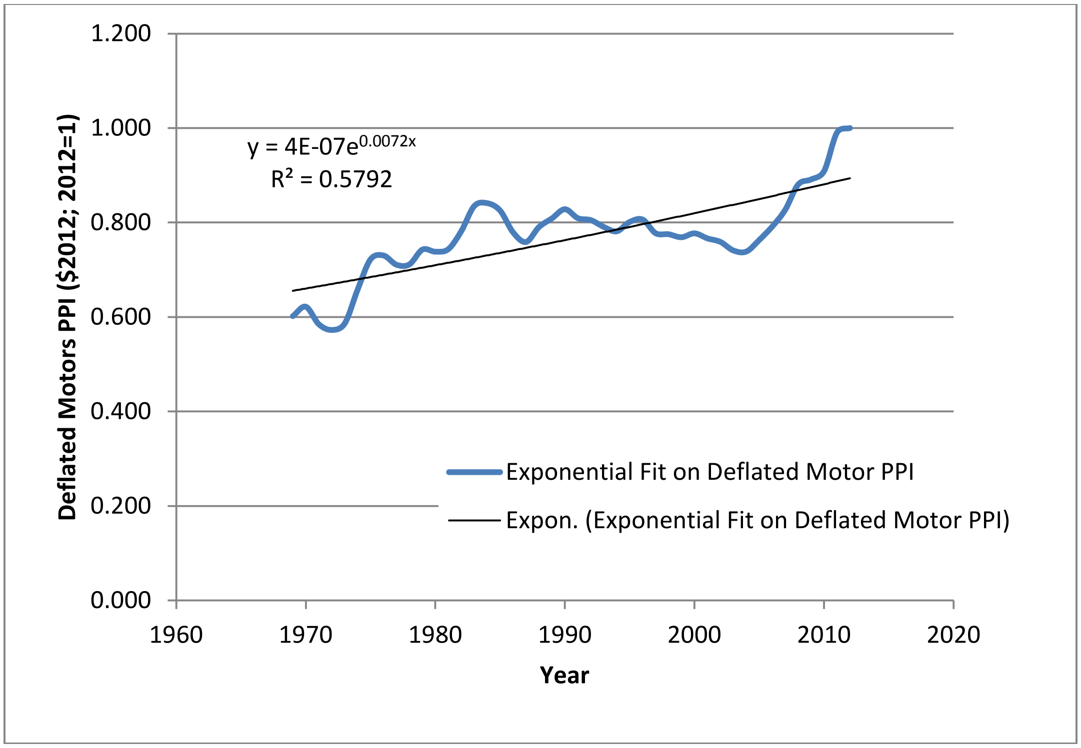

Figure 10-B.2.1 Relative Price of Electric Motors versus Year, with Exponential Fit

The regression performed as an exponential trend line fit results in an R-square of 0.58, which indicates a moderate fit to the data. The final estimated exponential function is:

$$Y = 4.49 \times 10^{(-7)} \cdot e^{0.00721X}$$

DOE then derived a price factor index for this scenario, with 2011 equal to 1, to project prices in each future year in the analysis period considered in the NIA since 2011. The index value in a given year is a function of the exponential parameter and *year*.

10-B.2.2 Annual Energy Outlook 2012 Price Forecast (Decreasing Price Scenario)

DOE also examined a forecast based on the "chained price index—industrial equipment" that was forecasted for *AEO2012* out to 2040. This index is the most disaggregated category that includes electric motors. To develop an inflation-adjusted index, DOE normalized the above index with the "chained price index—gross domestic product" forecasted for *AEO2012*. To extend the price index beyond 2040, DOE used the average annual price growth rate in 2031 to 2040.

10-B.2.3 Summary

Table 10-B.2.1 shows the summary of the average annual rates of changes for the product price index in each scenario. Figure 10-B.2.2 shows the resulting price trends.

Table 10-B.2.1 Price Trend Scenarios

Scenario	Price Trend	Average Annual Rate of Change (%)
Default	Constant Price Projection	0.0
Decreasing Price	AEO2012 "chained price index—industrial equipment"	-0.87
Increasing Price	Exponential Fit using data from 1969 to 2012	0.72

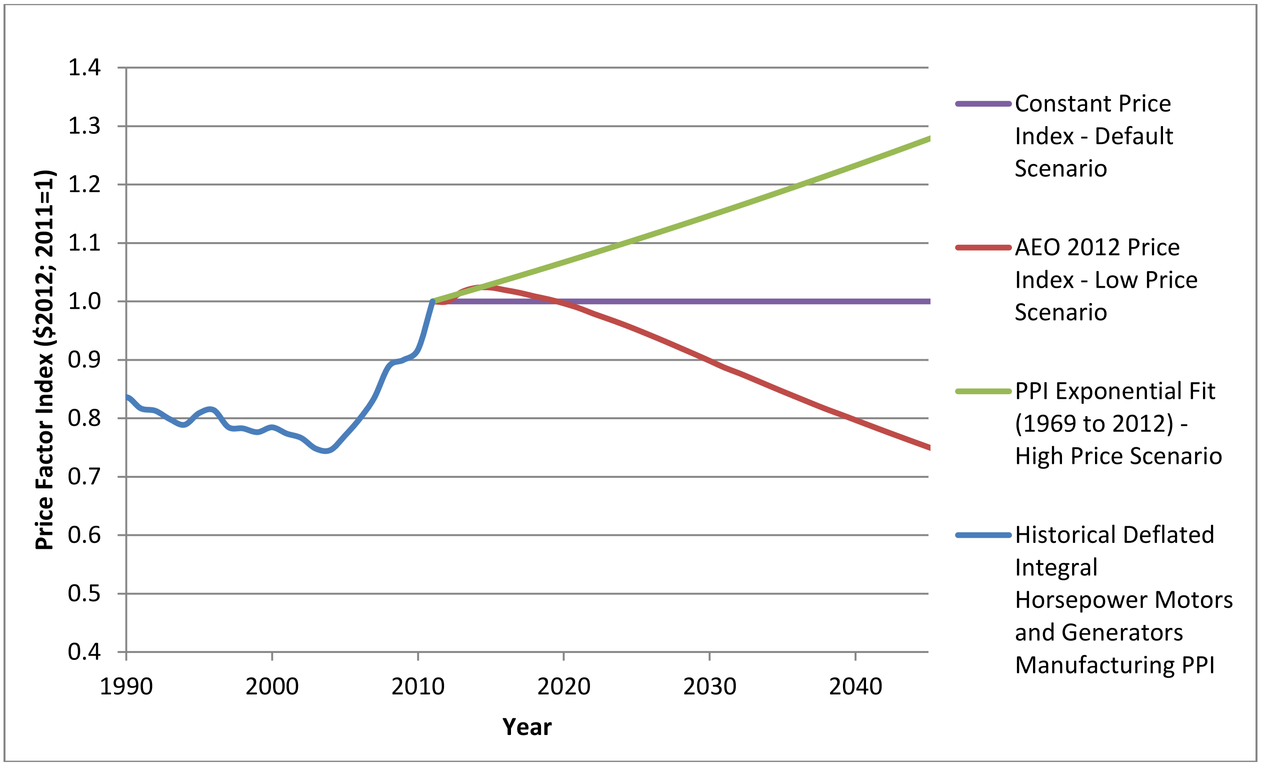

Figure 10-B.2.2 Electric Motor Price Forecast Indexes

10-B.3 NET PRESENT VALUE RESULTS BY PRICE TREND SCENARIO

Table 10-B.3.1 through Table 10-B.3.3 present, for each equipment class group and TSL, equipment incremental non-energy costs and energy cost savings, with their corresponding NPV results, across discount rates and the three product price trend scenarios.

Table 10-B.3.1 Detailed NPV Results for NEMA Designs A and B Motors (billion 2012$)

	7% discount rate			*3% discount rate*		
	Decreasing	Constant	Increasing	Decreasing	Constant	Increasing
TSL 1						
Incr Eqpt Costs	0.342	0.356	0.386	0.527	0.557	0.613
Energy Cost Savings	2.515	2.515	2.515	5.030	5.030	5.030
NPV	2.173	2.159	2.129	4.503	4.473	4.417
TSL 2						
Incr Eqpt Costs	6.247	6.697	7.392	12.435	13.549	15.088
Energy Cost Savings	14.378	14.378	14.378	34.254	34.254	34.254
NPV	8.131	7.681	6.986	21.819	20.704	19.165
TSL 3						
Incr Eqpt Costs	23.847	25.937	29.070	46.782	51.979	59.031
Energy Cost Savings	22.240	22.240	22.240	53.517	53.517	53.517
NPV	-1.607	-3.697	-6.830	6.735	1.538	-5.515
TSL 4						
Incr Eqpt Costs	53.503	57.759	64.510	99.394	109.911	124.682
Energy Cost Savings	28.674	28.674	28.674	68.728	68.728	68.728
NPV	-24.829	-29.086	-35.836	-30.666	-41.183	-55.954

Table 10-B.3.2 Detailed NPV Results for NEMA Design C Motors (billion 2012$)

	7% discount rate			*3% discount rate*		
	Decreasing	Constant	Increasing	Decreasing	Constant	Increasing
TSL 1						
Incr Eqpt Costs	0.025	0.027	0.030	0.048	0.052	0.059
Energy Cost Savings	0.041	0.041	0.041	0.101	0.101	0.101
NPV	0.016	0.014	0.011	0.053	0.049	0.042
TSL 2						
Incr Eqpt Costs	0.025	0.027	0.030	0.048	0.052	0.059
Energy Cost Savings	0.041	0.041	0.041	0.101	0.101	0.101
NPV	0.016	0.014	0.011	0.053	0.049	0.042
TSL 3						
Incr Eqpt Costs	0.093	0.100	0.112	0.172	0.191	0.217
Energy Cost Savings	0.066	0.066	0.066	0.163	0.163	0.163
NPV	-0.027	-0.034	-0.046	-0.009	-0.028	-0.054
TSL 4						
Incr Eqpt Costs	0.093	0.100	0.112	0.172	0.191	0.217
Energy Cost Savings	0.066	0.066	0.066	0.163	0.163	0.163
NPV	-0.027	-0.034	-0.046	-0.009	-0.028	-0.054

Table 10-B.3.3 Detailed NPV Results for Fire Pump Motors (billion 2012$)

	7% discount rate			*3% discount rate*		
	Decreasing	Constant	Increasing	Decreasing	Constant	Increasing
TSL 1						
Incr Eqpt Costs	0.000	0.000	0.000	0.000	0.000	0.000
Energy Cost Savings	0.000	0.000	0.000	0.000	0.000	0.000
NPV	0.000	0.000	0.000	0.000	0.000	0.000
TSL 2						
Incr Eqpt Costs	0.000	0.000	0.000	0.000	0.000	0.000
Energy Cost Savings	0.000	0.000	0.000	0.000	0.000	0.000
NPV	0.000	0.000	0.000	0.000	0.000	0.000
TSL 3						
Incr Eqpt Costs	0.001	0.002	0.002	0.003	0.003	0.003
Energy Cost Savings	0.000	0.000	0.000	0.000	0.000	0.000
NPV	-0.001	-0.002	-0.002	-0.003	-0.003	-0.003
TSL 4						
Incr Eqpt Costs	0.015	0.016	0.018	0.027	0.031	0.035
Energy Cost Savings	0.000	0.000	0.000	0.000	0.000	0.000
NPV	-0.015	-0.016	-0.018	-0.027	-0.031	-0.035

Table 10-B.3.4 Detailed NPV Results for Brake Motors (billion 2012$)

	7% discount rate			*3% discount rate*		
	Decreasing	Constant	Increasing	Decreasing	Constant	Increasing
TSL 1						
Incr Eqpt Costs	0.074	0.079	0.088	0.131	0.144	0.162
Energy Cost Savings	0.611	0.611	0.611	1.454	1.454	1.454
NPV	0.537	0.531	0.523	1.323	1.311	1.292
TSL 2						
Incr Eqpt Costs	0.354	0.381	0.423	0.664	0.731	0.824
Energy Cost Savings	1.339	1.339	1.339	3.245	3.245	3.245
NPV	0.985	0.957	0.915	2.580	2.514	2.421
TSL 3						
Incr Eqpt Costs	1.187	1.297	1.462	2.268	2.541	2.911
Energy Cost Savings	1.647	1.647	1.647	4.003	4.003	4.003
NPV	0.459	0.349	0.185	1.735	1.462	1.092
TSL 4						
Incr Eqpt Costs	2.818	3.053	3.426	5.138	5.719	6.534
Energy Cost Savings	1.883	1.883	1.883	4.567	4.567	4.567
NPV	-0.935	-1.170	-1.542	-0.571	-1.152	-1.967

APPENDIX 10-C. FULL-FUEL-CYCLE MULTIPLIERS

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APPENDIX 10-C. FULL-FUEL-CYCLE MULTIPLIERS

10-C.1 INTRODUCTION

This appendix summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from potential standards. The FFC measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's traditional approach encompassed only site energy and the energy losses associated with generation, transmission, and distribution of electricity.[1] Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses FFC measures of energy use and emissions in its energy conservation standards analyses. This appendix summarizes the methods used to incorporate the full-fuel-cycle impacts into the analysis.

This analysis uses several different terms to reference energy use. The physical sources of energy are the primary fuels such as coal, natural gas, liquid fuels, *etc*. Primary energy is equal to the heat content (Btu) of the primary fuels used to provide an end-use service. Site energy use is defined as the energy consumed at the point-of-use in a building or industrial process. Where natural gas and petroleum fuels are consumed at the site (for example in a furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed. For electricity, site energy is measured in kWh. In this case the primary energy – usually expressed in quadrillion Btus (quads) – is equal to the energy required to generate and deliver the site electricity. This primary energy is calculated by multiplying the site kWh times the site-to-power plant energy use factor given in chapter 10. For the FFC analysis, the upstream energy use is defined as the energy consumed in extracting, processing, and transporting or distributing primary fuels. FFC energy use is the sum of primary plus upstream energy use.

Both primary fuels and electricity are used in upstream activities. The treatment of electricity in fuel cycle analysis must distinguish between electricity generated by fossil fuels and uranium, and electricity generated from renewable fluxes (wind, solar and hydro). For the former, the upstream fuel cycle impacts are derived from the amount of fuel consumed at the power plant. For the latter, no fuel *per se* is used, so there is no upstream component.

10-C.2 METHODOLOGY

The mathematical approach is discussed in the paper *A Mathematical Analysis of Full Fuel Cycle Energy Use*,[2] and details on the fuel production chain analysis are presented in the paper *Projections of Full Fuel Cycle Energy and Emissions Metrics*.[3] The text below provides a brief summary of the methods used to calculate FFC energy.

When all energy quantities are normalized to the same units, the FFC energy use can be represented as the product of the primary energy use and an *FFC multiplier*. The FFC multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, so the calculations do not require any assumptions about prices or other economic data. While in general these parameter values may vary by geographic region, for this analysis national averages are used.

In the notation below, the indices x and y are used to indicate fuel type, with x=c for coal, x=g for natural gas, x=p for petroleum fuels, x=u for uranium and x=r for renewable fluxes. The fuel cycle parameters are:

- a_x is the quantity of fuel x burned per unit of electricity output, on average, for grid electricity. The calculation of a_x includes a factor to account for transmission and distribution system losses.
- b_y is the amount of grid electricity used in production of fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.
- q_x is the heat content of fuel x (MBtu/physical unit)
- $z_x(s)$ is the emissions intensity for fuel x (mass of pollutant s per physical unit of x)

The parameters are calculated as a function of time with an annual time step; hence, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period. Fossil fuel quantities are converted to energy units using the heat content factors q_x. To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the site-to-power plant energy use factor. The site-to-power plant energy use factor is defined as the ratio of the total quads of primary energy consumption by the electric power sector divided by the total electricity generation in each year.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. A multiplier is also calculated for electricity reflecting the fuel mix used in its generation. The multipliers are dimensionless numbers that are applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

For DOE's appliance standards energy savings estimates, the fuel cycle analysis methodology is designed to make use of data and projections published in the Annual Energy Outlook (AEO). Table 10-C.2.1 provides a summary of the AEO data used as inputs to the different parameter calculations. The AEO does not provide all the information needed to estimate total energy use in the fuel production chain. Reference [3] describes the additional data sources used to complete the analysis. However, the time dependence in the FFC multipliers arises exclusively from variables taken from the AEO. The FFC analysis for medium electric motors used data from *AEO-2012*.[4]

Table 10-C.2.1 Dependence of FFC Parameters on AEO Inputs

Parameter	Fuel	AEO Table	Variables
q_x	all	Conversion Factors	MMBtu per physical unit
a_x	all	Electricity Supply, Disposition, Prices, and Emissions	Generation by fuel type
		Energy Consumption by Sector and Source	Electric power sector energy consumption
b_c, c_{nc}, c_{pc}	coal	Coal Production by Region and Type	Production by coal type and sulfur content
b_p, c_{np}, c_{pp}	petroleum	Refining Industry Energy Consumption	Refining only energy use
		Liquid Fuels Supply and Disposition	Crude supply by source
		International Liquids Supply and Disposition	Crude oil imports
		Oil and Gas Supply	Crude oil domestic production
c_{nn}	natural gas	Oil and Gas Supply	US dry gas production
		Natural Gas Supply, Disposition and Prices	Pipeline, lease and plant fuel
z_x	all	Electricity Supply, Disposition, Prices and Emissions	Power sector emissions

10-C.3 FULL-FUEL-CYCLE ENERGY MULTIPLIERS

FFC energy multipliers are presented in Table 10-C.3.1 for selected years. To extend the analysis period beyond 2040, the value reported for year 2040 was extrapolated through the end of the projection period. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation over the forecast period.

Table 10-C.3.1 Full Fuel Cycle Energy Multipliers (Based on AEO 2012)

	2015	**2020**	**2025**	**2030**	**2035**	**2040**
Electricity (power plant primary energy use)	1.042	1.041	1.040	1.040	1.041	1.041
Natural Gas (site)	1.102	1.103	1.100	1.099	1.098	1.097
Petroleum Fuels (site)	1.142	1.146	1.153	1.163	1.172	1.181

REFERENCES

1. United States - Office of the Federal Register, *Federal Register, Volume 76, Number 160, August 18, 2011*. UNT Digital Library. Washington D.C. .

2. Coughlin, K., A Mathematical Analysis of Full Fuel Cycle Energy Use. *Energy*, 2012. 37(1): pp. 698-708 <http://www.sciencedirect.com/science/article/pii/S0360544211006803>

3. Coughlin, K., *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*, 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E.

4. Energy Information Administration, *Annual Energy Outlook 2012 with Projections to 2035*, 2012. Washington, DC. <http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf>

APPENDIX 10-D. NATIONAL IMPACT ANALYSIS SENSITIVITY FOR ALTERNATIVE SCENARIOS OF PRICE ELASTICITY OF DEMAND

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APPENDIX 10-D. NATIONAL IMPACT ANALYSIS SENSITIVITY ANALYSIS FOR ALTERNATIVE SCENARIOS OF PRICE ELASTICITY OF DEMAND

10-D.1 INTRODUCTION

The U.S. Department of Energy (DOE) used a zero price elasticity of demand assumption for the default projection in the National Impact Analysis (NIA) described in Chapter 10. In order to investigate, for the considered trial standard levels (TSLs) for electric motors, the impact from increased equipment cost on shipments, and consequently on national energy savings (NES) and consumers' net present value (NPV), DOE considered a non-zero price elasticity of demand for a sensitivity analysis. This appendix describes the method and data DOE used to estimate the price elasticity of demand by horsepower range, and compares NES and NPV results from this scenario with the default forecast presented in Chapter 10.

10-D.2 NON-ZERO PRICE ELASTICITY OF DEMAND

DOE considered one alternative scenario of price elasticity of demand for a sensitivity analysis. The elasticity values were estimated based on the following regression model:

$$\ln Q(t) = \ln \alpha + \varepsilon \cdot \ln P(t) + \epsilon \qquad \text{Eq. 1.1}$$

where:

$Q(t)$ = the amount of motors shipped in year t,

$P(t)$ = the (average) price of motors shipped in year t,

ε = the price elasticity of demand,

α = a constant, and

ϵ = the regression error.

The model on Eq. 1.1 was calibrated for each horsepower range based on historical data of annual shipments and value of shipments. DOE used historical data provided by the U.S. Census Bureau for *Motors and Generators*. DOE obtained these data on-line (for years 2001 through 2003[a,b]) and from a market report[c] (for years 1990 through 2000) for three phase AC

[a] U.S. Census Bureau (August 2003), Motors and Generators – 2002.MA335H(02)-1. http://www.census.gov/manufacturing/cir/historical_data/discontinued/ma335h/ma335h02.xls
[b] U.S. Census Bureau (November 2004), Motors and Generators – 2003.MA335H(03)-1. http://www.census.gov/manufacturing/cir/historical_data/discontinued/ma335h/index.html

induction motors between 1 and 500 horsepower. Whereas the data DOE obtained for the period 1998-2003 were reported separately for single- and polyphase motors and disaggregated across horsepower ranges, the remaining data available was aggregated at the level of all integral AC motors. DOE then used linear trends to extrapolate the disaggregated data available for 1998-2003 backwards through 1990. Table 10-D.2.1 and Table 10-D.2.2 present respectively the resulting historical time-series of shipments and value of shipments for induction motors between 1 and 500 horsepower as derived from the US Census data. Table 10-D.2.3 presents the historical unit average price by horsepower range calculated from the amount and value of shipments presented in Table 10-D.2.1 and Table 10-D.2.2 and adjusted to 2005 dollars based on GDP deflator. Note that the shipments presented here only cover US production and differs from the data presented in Chapter 3 which also include imports and exports.

Table 10-D.2.1 Estimated Historical Shipments (thousands of units)

	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
1990	2000.4	888.7	471.4	86.0	60.0	51.6
1991	1762.8	786.6	399.8	76.4	51.8	44.0
1992	1894.3	849.0	413.1	82.7	54.6	45.7
1993	1985.2	893.5	415.7	87.3	56.0	46.2
1994	2206.9	997.4	443.1	97.7	61.0	49.6
1995	2056.6	933.3	395.3	91.7	55.6	44.5
1996	2388.3	1088.3	438.9	107.3	63.2	49.7
1997	2457.1	1124.2	431.0	111.1	63.7	49.2
1998	1215.1	543.3	216.2	58.5	37.0	23.1
1999	1253.8	538.4	185.0	51.7	25.0	22.5
2000	1208.2	602.5	170.0	53.6	26.2	21.0
2001	969.0	497.5	145.7	48.9	24.0	17.5
2002	897.4	410.7	126.0	45.0	21.0	15.9
2003	931.9	410.4	115.5	40.7	22.2	12.8

Table 10-D.2.2 Estimated Historical Value of Shipments (millions of dollars)

	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
1990	111.0	112.2	110.4	80.1	115.7	458.7
1991	124.8	126.2	120.4	87.8	121.8	468.7
1992	121.6	123.0	114.1	83.5	111.4	415.6
1993	143.4	145.0	131.0	96.3	123.6	446.1
1994	169.2	171.1	150.8	111.3	137.7	479.8
1995	194.7	196.9	169.6	125.6	149.8	503.2
1996	225.6	228.1	192.5	143.1	164.5	531.5
1997	228.4	231.0	191.0	142.5	158.0	490.1

[c] Business Trend Analysts, The Motor and Generator Industry, 2002.

1998	205.4	205.2	173.4	133.8	161.6	412.8
1999	206.0	191.4	158.2	115.1	105.4	356.3
2000	205.5	216.4	152.9	113.9	107.3	316.4
2001	154.3	175.8	133.5	101.3	94.3	217.0
2002	138.1	141.1	112.4	84.2	81.6	213.2
2003	153.2	144.0	109.0	83.9	79.2	165.7

Table 10-D.2.3 Estimated Historical Unit Average Prices (2005 dollars)

	1-5 hp	**6-20 hp**	**21-50 hp**	**51-100 hp**	**101-200 hp**	**201-500 hp**
1990	40.09	91.22	169.23	672.87	1393.48	6424.50
1991	52.98	120.04	225.34	859.79	1758.90	7975.25
1992	49.19	110.97	211.53	773.51	1564.57	6970.76
1993	56.54	127.02	246.65	863.26	1728.02	7557.75
1994	61.29	137.14	272.16	910.34	1804.94	7740.97
1995	77.24	172.12	350.17	1117.73	2196.86	9228.05
1996	78.55	174.33	364.70	1109.06	2162.61	8885.52
1997	78.65	173.85	375.11	1084.85	2100.31	8428.29
1998	144.67	323.24	686.41	1957.46	3737.94	15293.97
1999	142.68	308.72	742.62	1933.37	3661.26	13751.91
2000	150.91	318.67	797.99	1885.36	3633.58	13367.60
2001	144.48	320.54	831.40	1878.56	3568.74	11247.36
2002	141.91	316.70	822.26	1723.79	3581.37	12391.51
2003	154.76	330.24	888.60	1941.38	3361.64	12202.28

DOE used the shipments time-series by horsepower range in Table 10-D.2.1 ($Q(t)$) and the price time-series by horsepower range in Table 10-D.2.3 ($P(t)$) to estimate the price elasticity of demand (ε) for each horsepower range according to Eq. 1.1. Table 10-D.2.4 shows the resulting elasticity values with additional statistical indicators.

Table 10-D.2.4 Estimated Price elasticity of Demand by Horsepower Range

	1-5 hp	**6-20 hp**	**21-50 hp**	**51-100 hp**	**101-200 hp**	**201-500 hp**
Elasticity	-0.862	-0.863	-1.111	-1.051	-1.568	-1.658
p-Value	0.000	0.001	0.000	0.001	0.000	0.036
R^2	0.661	0.642	0.856	0.632	0.679	0.316

10-D.3 EFFECTS OF PRICE ELASTICITY OF DEMAND ON SHIPMENTS

DOE calculated the effects on non-zero price elasticity of demand on motors shipments based on the following model:

$$Q_{std}(t) = Q_{bc}(t) \cdot \left(1 + \varepsilon \cdot \left(\frac{P_{std}(t)}{P_{bc}(t)} - 1\right)\right) \qquad \text{Eq. 1.2}$$

where:

$Q_{std}(t)$ = the amount of motors shipped in year t in the standards case,

$Q_{bc}(t)$ = the amount of motors shipped in year t in the base case,

$P_{std}(t)$ = the unit average price of motors shipped in year t in the standards case,

$P_{bc}(t)$ = the unit average price of motors shipped in year t in the base case, and

ε = the price elasticity of demand.

The model on Eq. 1.2 was evaluated for each horsepower range based on shipments projected for 2016 through 2045 ($Q_{bc}(t)$), the market average equipment cost for the base case ($P_{bc}(t)$) and the standards case ($P_{std}(t)$), and the price elasticity (ε) values estimated from Eq. 1.1 and presented in Table 10-D.2.4. Figure 10-D.4.1 compares, for equipment class group 1, the shipments projected for the base case and the standards case considering non-zero price elasticity of demand.

10-D.4 EFFECTS OF PRICE ELASTICITY OF DEMAND ON NATIONAL ENERGY SAVINGS

DOE calculated the effects of non-zero price elasticity of demand on NES based on a model similar to the one presented in Chapter 10 and used to calculate NES for zero price elasticity of demand. All formulas and parameters remain the same but (a) shipments in the standards case are calculated as described in Section 10-D-4, and (b) the energy consumption that would correspond to the units not shipped due to the non-zero price elasticity of demand assumption is calculated as the energy consumed by the less efficient, non-replaced motors in the stock. A simplified description of the model that accounts for non-zero price elasticity of demand to calculate NES is as following:[d]

$$NES = \sum_{2016}^{2045} Q_{bc}(t) \cdot U_{bc}(t) - \left(Q_{std}(t) \cdot U_{std}(t) + \Delta Q(t) \cdot U_{stk}(t)\right) \qquad \text{Eq. 1.3}$$

[d] The analysis used January 1st 2016 to model the December 19th, 2015 compliance date.

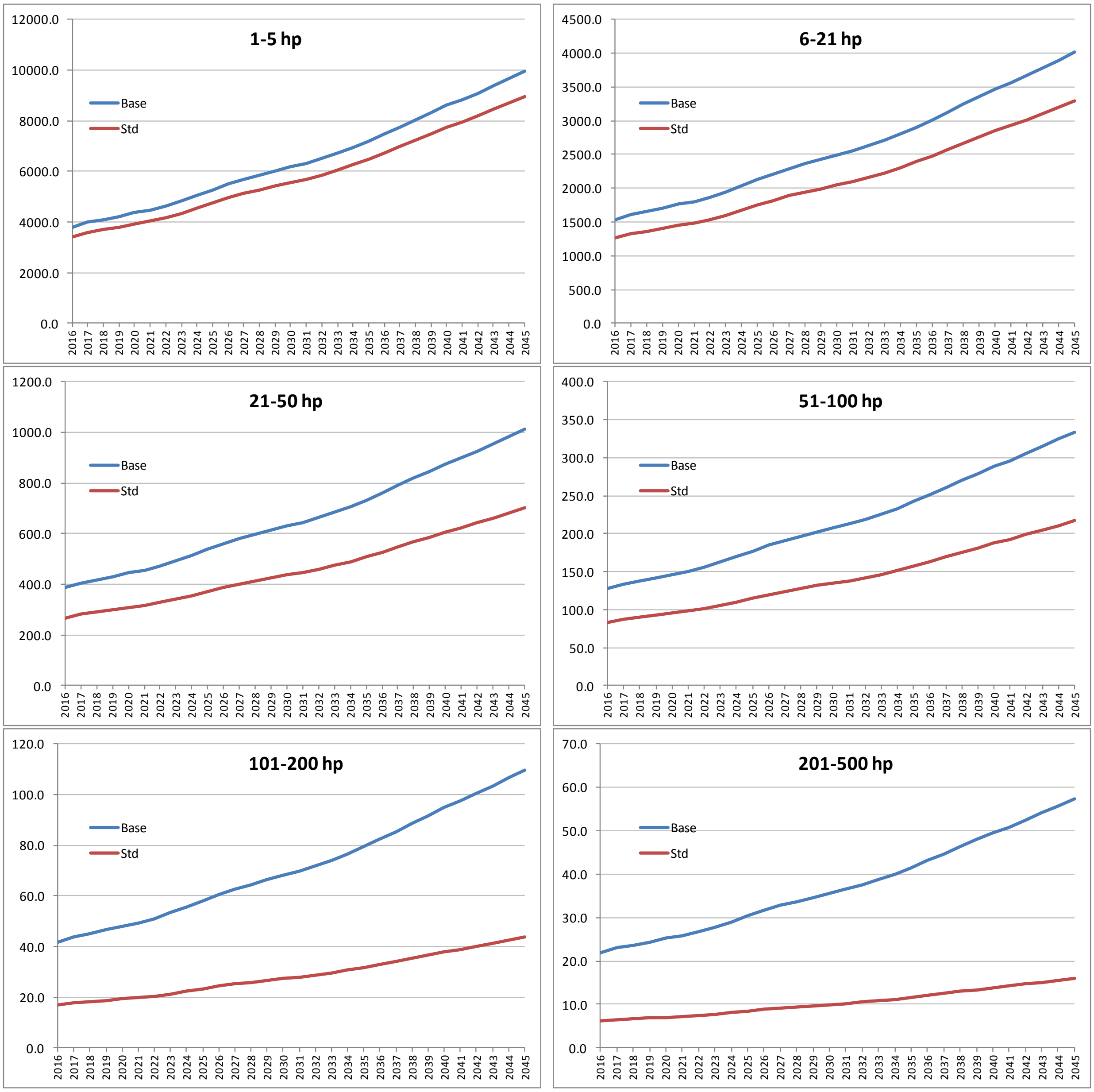

Figure 10-D.4.1 Shipments Projected for the Base Case and the Standards Case for Equipment Class Group 1 (TSL 2)

where:

NES = the cumulative national energy savings,

$Q_{bc}(t)$ = the amount of motors shipped in year t in the base case,

$U_{bc}(t)$ = the base case average unit lifetime energy consumption of motors shipped in year t,

$Q_{std}(t)$ = the amount of motors shipped in year t in the standards case,

$U_{std}(t)$ = the standards case average unit lifetime energy consumption of motors shipped in year t,

$\Delta Q(t)$ = the amount of non-shipped motors in year t due to the effect of non-zero price elasticity of demand ($\Delta Q(t) = Q_{bc}(t) - Q_{std}(t)$),

$U_{stk}(t)$ = the average unit lifetime energy consumption of the non-replaced motors in stock in year t.

DOE evaluated NES for non-zero price elasticity of demand values for each horsepower range using the model above. Results are presented in Section 10-D.6. Because in **Error! Reference source not found.**, $U_{stk}(t)$ is greater than $U_{std}(t)$, the resulting national energy savings is lower than its corresponding value presented in Chapter 10.

10-D.5 EFFECTS OF PRICE ELASTICITY OF DEMAND ON NET PRESENT VALUE

DOE calculated the effects of non-zero price elasticity of demand on NPV based on a model similar to the one presented in Chapter 10 and used to calculate NPV for zero price elasticity of demand. All formulas and parameters remain the same but (a) shipments in the standards case are calculated as described in Section 10-D-4, (b) the energy cost that would correspond to the units not shipped due to the non-zero price elasticity of demand assumption is calculated as the energy cost of the less efficient, non-replaced motors in the stock, and (c) the equipment costs that would correspond to the units not shipped due to the non-zero price elasticity of demand assumption are assumed zero. A simplified description of the model that accounts for non-zero price elasticity of demand to calculate NPV is as following:

$$NPV = \sum_{2016}^{2045} \left(nECS(t) - nIEC(t) + nECK(t) \right) \cdot (1 + dRate)^{2013-t} \quad \text{Eq. 1.4}$$

$$nECS(t) = Q_{bc}(t) \cdot uNC_{bc}(t) - Q_{std}(t) \cdot uNC_{std}(t) \quad \text{Eq. 1.5}$$

$$nIEC(t) = Q_{std}(t) \cdot uQC_{std}(t) - Q_{bc}(t) \cdot uQC_{bc}(t) \quad \text{Eq. 1.6}$$

$$nECK(t) = \Delta Q(t) \cdot uNC_{stk}(t) \quad \text{Eq. 1.7}$$

where:

NPV = the net present value,

$nECS(t)$ = the national lifetime energy cost savings from motors shipped in year t,

$nIEC(t)$ = the national lifetime incremental equipment non-energy costs from motors shipped in year t,

$nECK(t)$ = the national lifetime energy cost of the non-replaced motors in stock in year t,

$Q_{bc}(t)$ = the amount of motors shipped in year t in the base case,

$Q_{std}(t)$ = the amount of motors shipped in year t in the standards case,

$uNC_{bc}(t)$ = the base case average unit lifetime energy cost of motors shipped in year t,

$uNC_{std}(t)$ = the standards case average unit lifetime energy cost of motors shipped in year t,

$uQC_{bc}(t)$ = the base case average unit lifetime equipment non-energy cost of motors shipped in year t,

$uQC_{std}(t)$ = the standards case average unit lifetime equipment non-energy cost of motors shipped in year t,

$\Delta Q(t)$ = the amount of non-shipped motors in year t due to the effect of non-zero price elasticity of demand ($\Delta Q(t) = Q_{bc}(t) - Q_{std}(t)$),

$uNC_{stk}(t)$ = the average unit lifetime energy cost of the non-replaced motors in stock in year t.

DOE evaluated NPV for non-zero price elasticity of demand values for each horsepower range using the model above. Results are presented in Section 10-D.6. Because the national lifetime energy cost from the existing, non-replaced stock outweighs the reduction in the national lifetime incremental non-energy costs due to the non-zero price elasticity od demand, the resulting NPV is lower than its corresponding value presented in Chapter 10.

10-D.6 RESULTS FOR NON-ZERO PRICE ELASTICITY OF DEMAND

DOE evaluated the effects of non-zero price elasticity of demand on NES and NPV. Table 10-D.6.1 and Table 10-D.6.2 compare respectively, for each TSL and equipment class group, NES and NPV results for non-zero price elasticity of demand with their corresponding results calculated for zero price elasticity of demand as presented in Chapter 10.

Table 10-D.6.1 Cumulative National Energy Savings (quads)

TSL Equipment Class Group	***Primary***		***Full-Fuel Cycle***	
	Elasticity		**Elasticity**	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	0.821	0.437	0.834	0.445
2: NEMA Design C	0.019	0.011	0.019	0.011
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.256	0.209	0.261	0.212
Total for All Groups	1.096	0.656	1.114	0.667
TSL 2				
1: NEMA Design A and B	6.273	2.912	6.377	2.960
2: NEMA Design C	0.019	0.011	0.019	0.011
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.578	0.352	0.587	0.358
Total for All Groups	6.869	3.275	6.983	3.329
TSL 3				
1: NEMA Design A and B	9.860	2.972	10.023	3.021
2: NEMA Design C	0.030	0.002	0.030	0.002
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.714	0.362	0.726	0.368
Total for All Groups	10.604	3.336	10.780	3.392
TSL 4				
1: NEMA Design A and B	12.642	1.876	12.852	1.907
2: NEMA Design C	0.030	0.002	0.030	0.002
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.814	0.131	0.827	0.134
Total for All Groups	13.486	2.010	13.709	2.043

Table 10-D.6.2 Net Present Value (billion 2012$)

TSL Equipment Class Group	*7% discount rate*		*3% discount rate*	
	Elasticity		***Elasticity***	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	2.159	1.265	4.473	2.466
2: NEMA Design C	0.014	0.010	0.049	0.032
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.531	0.433	1.311	1.068
Total for All Groups	2.704	1.708	5.832	3.566
TSL 2				
1: NEMA Design A and B	7.681	3.835	20.704	10.075
2: NEMA Design C	0.014	0.010	0.049	0.032
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.957	0.586	2.514	1.538
Total for All Groups	8.652	4.431	23.267	11.645
TSL 3				
1: NEMA Design A and B	-3.697	-3.198	1.538	-3.671
2: NEMA Design C	-0.034	-0.002	-0.028	-0.002
3: Fire Pump Electric Motors	-0.002	-0.001	-0.003	-0.002
4: Brake Motors	0.349	0.177	1.462	0.744
Total for All Groups	-3.384	-3.025	2.969	-2.931
TSL 4				
1: NEMA Design A and B	-29.086	-1.636	-41.183	-1.203
2: NEMA Design C	-0.034	-0.002	-0.028	-0.002
3: Fire Pump Electric Motors	-0.016	-0.001	-0.031	-0.001
4: Brake Motors	-1.170	-0.202	-1.152	-0.205
Total for All Groups	-30.306	-1.841	-42.394	-1.412

DOE additionally evaluated the effects of non-zero price elasticity of demand on alternative scenarios. Because under non-zero price elasticity of demand equipment prices affect shipments, DOE evaluated the effects of the non-zero price elasticity of demand estimated on Section 10-D.2 for the non-default scenarios of product price trend and economic growth. Table 10-D.6.3 through Table 10-D.6.10 compare, for each TSL and equipment class group, results for NES and NPV considering zero and non-zero price elasticity of demand values. Table 10-D.6.3 through Table 10-D.6.6 present results for scenarios with decreasing and increasing product price trends, and Table 10-D.6.7 through Table 10-D.6.10 present results for the low and high economic growth rate scenarios.

Table 10-D.6.3 Cumulative National Energy Savings with Decreasing Equipment Price (quads)

TSL Equipment Class Group	***Primary***		***Full-Fuel Cycle***	
	Elasticity		**Elasticity**	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	0.821	0.450	0.834	0.458
2: NEMA Design C	0.019	0.011	0.019	0.011
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.256	0.211	0.261	0.214
Total for All Groups	1.096	0.672	1.114	0.683
TSL 2				
1: NEMA Design A and B	6.273	3.035	6.377	3.086
2: NEMA Design C	0.019	0.011	0.019	0.011
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.578	0.363	0.587	0.369
Total for All Groups	6.869	3.410	6.983	3.466
TSL 3				
1: NEMA Design A and B	9.860	3.087	10.023	3.138
2: NEMA Design C	0.030	0.003	0.030	0.003
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.714	0.378	0.726	0.385
Total for All Groups	10.604	3.468	10.780	3.525
TSL 4				
1: NEMA Design A and B	12.642	1.173	12.852	1.193
2: NEMA Design C	0.030	0.003	0.030	0.003
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.814	0.152	0.827	0.154
Total for All Groups	13.486	1.328	13.709	1.350

Table 10-D.6.4 Net Present Value with Decreasing Equipment Price (billion 2012$)

TSL Equipment Class Group	***7% discount rate***		***3% discount rate***	
	Elasticity		***Elasticity***	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	2.173	1.290	4.503	2.545
2: NEMA Design C	0.016	0.011	0.053	0.035
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.537	0.440	1.323	1.089
Total for All Groups	2.725	1.742	5.880	3.668
TSL 2				
1: NEMA Design A and B	8.131	4.164	21.819	11.020
2: NEMA Design C	0.016	0.011	0.053	0.035
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.985	0.614	2.580	1.620
Total for All Groups	9.131	4.788	24.453	12.676
TSL 3				
1: NEMA Design A and B	-1.607	-2.338	6.735	-1.427
2: NEMA Design C	-0.027	-0.002	-0.009	-0.001
3: Fire Pump Electric Motors	-0.001	-0.001	-0.003	-0.002
4: Brake Motors	0.459	0.239	1.735	0.918
Total for All Groups	-1.176	-2.102	8.458	-0.512
TSL 4				
1: NEMA Design A and B	-24.829	-1.395	-30.666	-1.227
2: NEMA Design C	-0.027	-0.002	-0.009	-0.001
3: Fire Pump Electric Motors	-0.015	-0.001	-0.027	-0.001
4: Brake Motors	-0.935	-0.171	-0.571	-0.109
Total for All Groups	-25.806	-1.568	-31.274	-1.337

Table 10-D.6.5 Cumulative National Energy Savings with Increasing Equipment Price (quads)

TSL Equipment Class Group	*Primary*		*Full-Fuel Cycle*	
	Elasticity		**Elasticity**	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	0.821	0.408	0.834	0.415
2: NEMA Design C	0.019	0.010	0.019	0.010
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.256	0.204	0.261	0.207
Total for All Groups	1.096	0.622	1.114	0.632
TSL 2				
1: NEMA Design A and B	6.273	2.676	6.377	2.720
2: NEMA Design C	0.019	0.010	0.019	0.010
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.578	0.332	0.587	0.338
Total for All Groups	6.869	3.018	6.983	3.068
TSL 3				
1: NEMA Design A and B	9.860	2.756	10.023	2.802
2: NEMA Design C	0.030	0.001	0.030	0.001
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.714	0.333	0.726	0.338
Total for All Groups	10.604	3.090	10.780	3.141
TSL 4				
1: NEMA Design A and B	12.642	3.031	12.852	3.081
2: NEMA Design C	0.030	0.001	0.030	0.001
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.814	0.094	0.827	0.095
Total for All Groups	13.486	3.126	13.709	3.177

Table 10-D.6.6 Net Present Value with Increasing Equipment Price (billion 2012$)

TSL Equipment Class Group	*7% discount rate*		*3% discount rate*	
	Elasticity		***Elasticity***	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	2.129	1.186	4.417	2.281
2: NEMA Design C	0.011	0.008	0.042	0.027
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.523	0.418	1.292	1.031
Total for All Groups	2.662	1.612	5.751	3.340
TSL 2				
1: NEMA Design A and B	6.986	3.266	19.165	8.613
2: NEMA Design C	0.011	0.008	0.042	0.027
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.915	0.534	2.421	1.403
Total for All Groups	7.912	3.808	21.628	10.044
TSL 3				
1: NEMA Design A and B	-6.830	-4.278	-5.515	-6.268
2: NEMA Design C	-0.046	-0.002	-0.054	-0.002
3: Fire Pump Electric Motors	-0.002	-0.001	-0.003	-0.003
4: Brake Motors	0.185	0.089	1.092	0.517
Total for All Groups	-6.694	-4.192	-4.481	-5.756
TSL 4				
1: NEMA Design A and B	-35.836	-2.863	-55.954	-3.066
2: NEMA Design C	-0.046	-0.002	-0.054	-0.002
3: Fire Pump Electric Motors	-0.018	0.000	-0.035	-0.001
4: Brake Motors	-1.542	-0.203	-1.967	-0.252
Total for All Groups	-37.443	-3.068	-58.010	-3.321

Table 10-D.6.7 Cumulative National Energy Savings for Low Economic Growth (quads)

TSL Equipment Class Group	***Primary***		***Full-Fuel Cycle***	
	Elasticity		**Elasticity**	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	0.709	0.378	0.721	0.384
2: NEMA Design C	0.016	0.009	5.513	2.559
3: Fire Pump Electric Motors	0.000	0.000	8.666	2.612
4: Brake Motors	0.222	0.180	11.112	1.649
Total for All Groups	0.947	0.567	26.011	7.205
TSL 2				
1: NEMA Design A and B	5.423	2.517	0.016	0.009
2: NEMA Design C	0.016	0.009	0.016	0.009
3: Fire Pump Electric Motors	0.000	0.000	0.026	0.002
4: Brake Motors	0.500	0.305	0.026	0.002
Total for All Groups	5.938	2.831	0.085	0.022
TSL 3				
1: NEMA Design A and B	8.525	2.569	0.000	0.000
2: NEMA Design C	0.026	0.002	0.000	0.000
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.617	0.313	0.000	0.000
Total for All Groups	9.168	2.885	0.000	0.000
TSL 4				
1: NEMA Design A and B	10.931	1.623	0.225	0.183
2: NEMA Design C	0.026	0.002	0.508	0.310
3: Fire Pump Electric Motors	0.000	0.000	0.628	0.319
4: Brake Motors	0.703	0.114	0.715	0.116
Total for All Groups	11.660	1.738	2.076	0.927

Table 10-D.6.8 Net Present Value for Low Economic Growth (billion 2012$)

TSL Equipment Class Group	*7% discount rate*		*3% discount rate*	
	Elasticity		***Elasticity***	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	1.807	1.063	3.713	2.058
2: NEMA Design C	0.011	0.008	0.038	0.025
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.441	0.359	1.079	0.879
Total for All Groups	2.258	1.430	4.830	2.962
TSL 2				
1: NEMA Design A and B	6.173	3.101	16.543	8.099
2: NEMA Design C	0.011	0.008	0.038	0.025
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.786	0.481	2.049	1.254
Total for All Groups	6.969	3.590	18.630	9.379
TSL 3				
1: NEMA Design A and B	-3.906	-2.970	-0.792	-3.785
2: NEMA Design C	-0.032	-0.002	-0.031	-0.002
3: Fire Pump Electric Motors	-0.001	-0.001	-0.003	-0.002
4: Brake Motors	0.251	0.127	1.112	0.566
Total for All Groups	-3.688	-2.846	0.287	-3.223
TSL 4				
1: NEMA Design A and B	-26.057	-1.551	-38.309	-1.486
2: NEMA Design C	-0.032	-0.002	-0.031	-0.002
3: Fire Pump Electric Motors	-0.014	0.000	-0.026	-0.001
4: Brake Motors	-1.069	-0.184	-1.168	-0.205
Total for All Groups	-27.172	-1.738	-39.534	-1.695

Table 10-D.6.9 Cumulative National Energy Savings for High Economic Growth (quads)

TSL Equipment Class Group	*Primary*		*Full-Fuel Cycle*	
	Elasticity		**Elasticity**	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	0.946	0.502	0.961	0.511
2: NEMA Design C	0.022	0.012	7.406	3.438
3: Fire Pump Electric Motors	0.000	0.000	11.646	3.510
4: Brake Motors	0.298	0.242	14.929	2.217
Total for All Groups	1.265	0.757	34.942	9.675
TSL 2				
1: NEMA Design A and B	7.285	3.381	0.022	0.012
2: NEMA Design C	0.022	0.012	0.022	0.012
3: Fire Pump Electric Motors	0.000	0.000	0.035	0.002
4: Brake Motors	0.671	0.409	0.035	0.002
Total for All Groups	7.978	3.803	0.115	0.029
TSL 3				
1: NEMA Design A and B	11.456	3.453	0.000	0.000
2: NEMA Design C	0.035	0.002	0.000	0.000
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.830	0.421	0.000	0.000
Total for All Groups	12.320	3.876	0.000	0.000
TSL 4				
1: NEMA Design A and B	14.685	2.180	0.303	0.246
2: NEMA Design C	0.035	0.002	0.683	0.416
3: Fire Pump Electric Motors	0.000	0.000	0.843	0.428
4: Brake Motors	0.945	0.153	0.961	0.155
Total for All Groups	15.665	2.335	2.790	1.246

Table 10-D.6.10 Net Present Value for High Economic Growth (billion 2012$)

TSL Equipment Class Group	*7% discount rate*		*3% discount rate*	
	Elasticity		***Elasticity***	
	Zero	**Non-Zero**	**Zero**	**Non-Zero**
TSL 1				
1: NEMA Design A and B	2.603	1.517	5.439	2.980
2: NEMA Design C	0.019	0.013	0.064	0.041
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	0.648	0.528	1.614	1.315
Total for All Groups	3.270	2.059	7.117	4.336
TSL 2				
1: NEMA Design A and B	9.737	4.834	26.366	12.755
2: NEMA Design C	0.019	0.013	0.064	0.041
3: Fire Pump Electric Motors	0.000	0.000	0.000	0.000
4: Brake Motors	1.184	0.724	3.131	1.916
Total for All Groups	10.940	5.571	29.561	14.712
TSL 3				
1: NEMA Design A and B	-2.944	-3.303	5.454	-3.192
2: NEMA Design C	-0.035	-0.003	-0.021	-0.002
3: Fire Pump Electric Motors	-0.002	-0.001	-0.003	-0.003
4: Brake Motors	0.498	0.252	1.960	0.997
Total for All Groups	-2.482	-3.054	7.389	-2.200
TSL 4				
1: NEMA Design A and B	-31.739	-1.637	-42.865	-0.630
2: NEMA Design C	-0.035	-0.003	-0.021	-0.002
3: Fire Pump Electric Motors	-0.019	-0.001	-0.035	-0.001
4: Brake Motors	-1.235	-0.214	-1.026	-0.188
Total for All Groups	-33.029	-1.854	-43.947	-0.821

APPENDIX 12-A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

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APPENDIX 12-A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

12-A.1 ELECTRIC MOTORS RULEMAKING MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

As part of the rulemaking process for new energy conservation standards for electric motors, the Department of Energy (DOE) conducts the manufacturer impact analysis (MIA). In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to new energy conservation standards. DOE is currently considering five candidate standard levels of efficiency (referred to as CSLs) for electric motors in the scope of this rulemaking, including a baseline CSL. The motor types covered in this rulemaking are separated into four equipment class groups (ECGs), as shown below.

Table 1.1 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design	Horsepower	Poles	Enclosure
I	NEMA Design A & B*	1-500	2, 4, 6, 8	Open
				Closed
II	NEMA Design C*	1-200	4, 6, 8	Open
				Closed
III	Fire Pump*	1-500	2, 4, 6, 8	Open
				Closed
IV	Integral Brake Motors*	1-30	4, 6, 8	Open
				Closed

*Including IEC equivalents.

DOE analyzed three representative units for ECG I (which are also used to represent ECG III and ECG IV) and two representative units for ECG II. The results obtained were then extrapolated to other ratings within the respective ECGs.

In responding to this questionnaire, please refer to the CSLs in the table below.

Table 1.2 Nominal Efficiency Levels Under Consideration for Equipment Class Group I and III

Equipment Class	CSL 1	CSL 2	CSL 3	CSL 4*
5 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (87.5%)	NEMA MG1 Table 12-12 (89.5%)	1 Band Above NEMA MG1 Table 12-12 (90.2%)	3 Bands Above NEMA MG1 Table 12-12 (91.7%)
30 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (92.4%)	NEMA MG1 Table 12-12 (93.6%)	1 Band Above NEMA MG1 Table 12-12 (94.1%)	2 Bands Above NEMA MG1 Table 12-12 (94.5%)
75 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (94.1%)	NEMA MG1 Table 12-12 (95.4%)	1 Band Above NEMA MG1 Table 12-12 (95.8%)	2 Bands Above NEMA MG1 Table 12-12 (96.2%)

*All representative units at this CSL use copper rotor technology.

Table 1.3 Nominal Efficiency Levels under Consideration for Equipment Class Group II

Equipment Class	CSL 1	CSL 2*
5 horsepower, 4-pole enclosed	NEMA MG1 Table 12-12 (89.5%)	2 Bands Above NEMA MG1 Table 12-12 (91.0%)
50 horsepower, 4-pole enclosed	NEMA MG1 Table 12-12 (94.5%)	1 Band Above NEMA MG1 Table 12-12 (95.0%)

*All representative units at this CSL use copper rotor technology.

A KEY ISSUES

A.1 In general, what are the key issues for your company regarding new energy conservation standards for electric motors and this rulemaking?

A.2 For the issues identified, how significant are they at each listed CSL?

A.3 How can we most effectively incorporate these issues in the MIA?

B ENGINEERING ANALYSIS

The purpose of the engineering analysis is to estimate the relationship between the manufacturer's selling price of an electric motor and its corresponding efficiency rating. This relationship serves as the basis for the subsequent cost-benefit calculations for individual consumers, manufacturers, and the nation.

In the engineering analysis, DOE groups electric motors subject to minimum efficiency standards into four ECGs that are based on NEMA Design type, and whether the motor is a fire pump motor or an integral brake motor. Within the ECGs, each electric motor rating (i.e. horsepower rating, enclosure type, and pole configuration) is considered an "equipment class," and unique CSLs are assessed for each individual equipment class.

Within each ECG, DOE selects representative units for study in the engineering analysis. DOE then extrapolates the results from these representative units to the other motor ratings within the same ECG. DOE is using this approach because there are over 500 unique equipment classes across all covered electric motors, and individually assessing each of these classes is not feasible. The representative units and CSLs currently selected for this engineering analysis are similar to the ones presented in the preliminary analysis with a few changes and additions. The table below illustrates the equipment class groups, as well as characteristics which comprise the equipment classes.

Table 1.4 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design	Horsepower	Poles	Enclosure
I	NEMA Design A & B*	1-500	2, 4, 6, 8	Open
				Closed
II	NEMA Design C*	1-200	4, 6, 8	Open
				Closed
III	Fire Pump*	1-500	2, 4, 6, 8	Open
				Closed
IV	Integral Brake Motors*	1-30	4, 6, 8	Open
				Closed

*Including IEC equivalents.

B.1 NEMA Design A and Design B Electric Motors (Equipment Class Group I)

B.1.1 Efficiency Levels and Representative Units: DOE analyzed three representative units for ECG I and III and then extrapolated the results to other ratings within the respective ECGs. The table below shows the equipment class and the CSLs analyzed.

Table 1.5 Nominal Efficiency Levels under Consideration for Equipment Class Group I and III

Equipment Class	CSL 1	CSL 2	CSL 3	CSL 4
5 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (87.5%)	NEMA MG1 Table 12-12 (89.5%)	1 Band Above NEMA MG1 Table 12-12 (90.2%)	3 Bands Above NEMA MG1 Table 12-12 (91.7%)
30 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (92.4%)	NEMA MG1 Table 12-12 (93.6%)	1 Band Above NEMA MG1 Table 12-12 (94.1%)	2 Bands Above NEMA MG1 Table 12-12 (94.5%)
75 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (94.1%)	NEMA MG1 Table 12-12 (95.4%)	1 Band Above NEMA MG1 Table 12-12 (95.8%)	2 Bands Above NEMA MG1 Table 12-12 (96.2%)

B.1.2 ECG I Efficiency Levels: Please comment on the appropriateness of the CSLs and representative units chosen for ECG I. Does your company produce electric motors at or above CSL 3? Are these motors typically NEMA Design A or NEMA Design B motors?

B.1.3 Dimension Constraints: DOE utilized an increase in the length of the electric motor stack to increase the efficiency while keeping the NEMA frame designation the same for that representative unit. The table below lists the maximum stack lengths that DOE used for the highest-efficiency software models. Do these numbers look practical for electric motors of these horsepower ratings? For each of the representative units, are there any dimensional constraints, especially with respect to an increased stack length, for customer applications that DOE should be aware of? If so, please specify the maximum C-dimensions or stack length of the representative units that would still be feasible for building those motors. Could you provide feedback on how stack length is restricted as pole configurations change but horsepower remains constant? DOE is also looking for feedback on how stack length is restricted as the frame enclosure changes from open to enclosed.

Table 1.6 Maximum Stack Lengths Used for ECG I Software Modeling

Representative Unit	Stack Length (in)
5 Horsepower, NEMA Design B	5.32
30 Horsepower, NEMA Design B	7.00
75 Horsepower, NEMA Design B	12.0

B.1.4 Design Option Combinations: For each representative unit, DOE is considering several design option combinations that characterize a range of CSLs. This range spans from the CSL requirements set forth in EISA 2007 (NEMA MG1-2011 Table 12-11 and Table 12-12) to the maximum technologically feasible level (“max tech”) The following tables present the CSLs and requests feedback on the primary design options available to reach that CSL, as well as the associated burdens with reaching those CSLs.

Table 1.7 Design Options for 5 Horsepower, NEMA Design B, 4-pole Enclosed Motors

Efficiency Level	Observed Design Options	Associated Burden
Baseline (82.5%)	Stack Length = 2.69” Stator Copper Weight = 8.4 lbs Electrical Steel = M56	
CSL 1 (NEMA MG1 Table 12-11)	Stack Length = 3.47” Stator Copper Weight = 10.1 lbs Electrical Steel = M56	
CSL 2 (NEMA MG1 Table 12-12)	Stack Length = 5.14” Stator Copper Weight = 10.1 lbs Electrical Steel = M47	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	Stack Length = 4.65” Stator Copper Weight = 12.2 lbs Electrical Steel = M47	
CSL 4 (3 Bands Above NEMA MG1 Table 12-12)	Stack Length = 5.32” Stator Copper Weight = 14.4 lbs Electrical Steel = M36 Rotor Conductor = Copper	

Table 1.8 Design Options for 30 Horsepower, NEMA Design B, 4-pole Enclosed Motors

Efficiency Level	Design Options	Associated Burden
Baseline (89.5%)	Stack Length = 7.96” Stator Copper Weight = 20.2 lbs Electrical Steel = M56	
CSL 1 (NEMA MG1 Table 12-11)	Stack Length = 5.53” Stator Copper Weight = 43.5 lbs Electrical Steel = M47/M56	
CSL 2 (NEMA MG1 Table 12-12)	Stack Length = 6.00” Stator Copper Weight = 45.2 lbs Electrical Steel = M47	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	Stack Length = 6.74” Stator Copper Weight = 47.4 lbs Electrical Steel = M47	
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)	Stack Length = 7.00” Stator Copper Weight = 74.5 lbs Electrical Steel = M36 Rotor Conductor = Copper	

Table 1.9 Design Options and for 75 Horsepower, NEMA Design B, 4-pole Enclosed Motors

Efficiency Level	Design Options	Associated Burden
Baseline (93.0%)	Stack Length = 8.02” Stator Copper Weight = 77.8 lbs Electrical Steel = M56	
CSL 1 (NEMA MG1 Table 12-11)	Stack Length = 10.23” Stator Copper Weight = 71.0 lbs Electrical Steel = M47	
CSL 2 (NEMA MG1 Table 12-12)	Stack Length = 10.58” Stator Copper Weight = 81.8 lbs Electrical Steel = M22/M27	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	Stack Length = 11.33” Stator Copper Weight = 136 lbs Electrical Steel = M36	
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)	Stack Length = 12.0” Stator Copper Weight = 127 lbs Electrical Steel = M36 Rotor Conductor = Copper	

B.2 NEMA Design C (Equipment Class Group II)

B.2.1 Design Lines and Representative Units: The following table represents the CSLs and representative units DOE is considering for ECG II.

Table 1.10 Efficiency Levels under Consideration for Equipment Class Group II

Equipment Class	CSL 1	CSL 2
5 horsepower, 4-pole enclosed	NEMA MG1 Table 12-12 (89.5%)	2 Bands Above NEMA MG1 Table 12-12 (91.0%)
50 horsepower, 4-pole enclosed	NEMA MG1 Table 12-12 (94.5%)	1 Band Above NEMA MG1 Table 12-12 (95.0%)

B.2.2 ECG II Efficiency Levels: Please comment on the appropriateness of the CSLs and representative units chosen for ECG II. Does your company produce ECG II-type electric motors at or above CSL 2?

B.2.3 Dimension Constraints: For each of the representative units, are there any dimensional constraints for customer applications that DOE should be aware of? If so, please specify the maximum dimensions that are feasible. Are there any additional design constraints for NEMA Design C motors when compared to Design A or B motors?

Table 1.11 Maximum Stack Lengths Used for ECG II Software Modeling

Representative Unit	Stack Length (in)
5 Horsepower, NEMA Design C	5.32
50 Horsepower, NEMA Design C	9.55

B.2.4 Design Option Combinations: For each representative unit, DOE is considering several design option combinations that characterize a range of CSLs electric motors. This range spans from the CSL requirements set forth in EISA 2007 (NEMA MG1-2011 Table 12-11 and Table 12-12) to the maximum technologically available level (“max tech”). The following tables present the CSLs and requests feedback on the primary design options available to reach each CSL, as well as the associated burdens with reaching those CSLs.

Table 1.12 Design Options for 5 Horsepower, NEMA Design C, 4-pole Enclosed Motors

Efficiency Level	Observed Design Options	Associated Burden
Baseline (NEMA MG1 Table 12-11)	Stack Length = 4.75” Stator Copper Weight = 10.0 lbs Electrical Steel = M47	
CSL 1 (NEMA MG1 Table 12-12)	Stack Length = 4.25” Stator Copper Weight = 9.90 lbs Electrical Steel = M36	
CSL 2 (2 Bands Above NEMA MG1 Table 12-12)	Stack Length = 5.32” Stator Copper Weight = 12.8 lbs Electrical Steel = M36 Rotor Conductor = Copper	

Table 1.13 Design Options for 50 Horsepower, NEMA Design C, 4-pole Enclosed Motors

Efficiency Level	Observed Design Options	Associated Burden
Baseline (NEMA MG1 Table 12-11)	Stack Length = 8.67” Stator Copper Weight = 66.0 lbs Electrical Steel = M47	
CSL 1 (NEMA MG1 Table 12-12)	Stack Length = 9.55” Stator Copper Weight = 89.5 lbs Electrical Steel = M36	
CSL 2 (1 Band Above NEMA MG1 Table 12-12)	Stack Length = 9.55” Stator Copper Weight = 85.0 lbs Electrical Steel = M36 Rotor Conductor = Copper	

B.3 Materials Prices, Markups, and Labor Rates

DOE gathers materials price data for the five years between 2008 and 2012, and plans to use a 2012 materials price for the reference case of its analysis. The current materials prices DOE uses are based on a 2012 reference price.

B.3.1 Copper: Due to copper’s relatively large price fluctuations, DOE sets its copper materials prices based on a 5-year-avergae of the commodity’s index price plus a processing cost markup. DOE is considering the current (2012) index value and will scale it back through 2008 using the producer price index. DOE will then apply a processing cost to the commodity price that varies for each of DOE’s groupings (e.g., wire vs. casting material). Please comment on DOE’s proposed methodology for deriving copper prices.

B.3.2 Copper Wire Processing Costs: To account for the processing costs of converting copper into wire, is it more appropriate to apply a percentage markup to the underlying commodity price, or a straight adder? DOE currently assumes that converting all copper wire gauges cost the same. If this is not accurate, please indicate the appropriate markup for each of the types of copper in the table below. Also, please comment on the base commodity price.

Table 1.14 Five Year Average Copper Prices and Markups (2012-2008)

Item	Cost (lb)	Markup	5 yr Avg.	Year				
				2012	2011	2010	2009	2008
Cu Wire, Gauge 14 & 14.5	$4.14	30%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92
Cu Wire, Gauge 15 & 15.5	$4.14	30%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92
Cu Wire, Gauge 16 & 16.5	$4.14	30%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92
Cu Wire, Gauge 17 & 17.5	$4.14	30%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92
Cu Wire, Gauge 18 & 18.5	$4.14	30%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92
Cu Wire, Gauge 19 - 20.5	$4.14	30%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92
Casting Materials – Copper	$3.18	0%	$3.18	$3.61	$4.00	$3.15	$2.22	$2.92

B.3.3 Materials Prices: The following table contains DOE's estimates for material prices used in the preliminary analysis. The prices listed do not include any markups for scrap, handling, factory overhead, non-production costs, or profit, but rather represent the price a manufacturer would pay for the material, including any bulk purchase discounts. All prices are listed in 2012 dollars. Does your company pay a similar price for these materials? If not, what price does your company pay?

Table 1.15 Metal Prices (2012$)

Item	Cost per lb	Manufacturer Feedback
Frame Material		
Cast Aluminum*	$1.30	
Cast Iron	$0.60	
Rolled Steel	$0.47	
Core Steels	-	
M15, fully/semi-processed	$1.10	
M19, fully/semi-processed	$1.05	
M22, fully/semi-processed	$1.02	
M27, fully/semi-processed	$0.95	
M36, fully/semi-processed	$0.89	
M47, fully/semi-processed	$0.80	
M56, fully/semi-processed	$0.78	
Shaft Steels	-	
Hot Rolled Steel	$0.52	

*Same cost used for housing material and rotor conductor bar material.

B.3.4 Aggregated Costs: DOE seeks feedback on the costs of components of electric motors that DOE aggregated into a bulk price. The table below lists DOE's estimates of the costs for those components. Do these costs seem appropriate? If not, can you provide another estimate? Would these costs remain constant regardless of CSL?

Table 1.16 Electric Motor Purchased Components and Aggregated Costs

Item	Unit of Measure	Cost	Manufacturer Feedback
Bearings			
Front Bearing, 5HP	each	$10	
Back Bearing, 5HP	each	$5	
Front Bearing, 30HP	each	$31	
Back Bearing, 30HP	each	$14	
Front Bearing, 50HP	each	$49	
Back Bearing, 50HP	each	$25	
Front Bearing, 75HP	each	$67	
Back Bearing, 75HP	each	$36	
Aggregate			
Hardware*, 5HP	each	$8	
Hardware*, 30HP	each	$10	
Hardware*, 50HP	each	$15	
Hardware*, 75HP	each	$20	
Stator Insulation, 5HP	each	$40	
Stator Insulation, 30HP	each	$60	
Stator Insulation, 50HP	each	$70	
Stator Insulation, 75HP	each	$80	

*Includes nuts, bolts, fan apparatus, and other hardware used to assemble the motor.

B.3.5 Additional Comments on Table 1.16: Do you have any comments on DOE's approach to aggregate hardware and stator insulation for each representative horsepower rating? Do hardware or insulation costs change significantly as efficiency changes?

B.4 Markups

DOE applies markups to all costs to reflect a manufacturer's internal markups. A summary of the markups used in the analysis is provided in Table 1.17 below.

DOE uses the following three markups when generating it Manufacturer Selling Prices for electric motors:

Handling and scrap factor: This markup was applied to the direct material production costs of each electric motor. It accounts for the handling of material (loading into assembly or winding equipment) and the scrap material that cannot be used in the production of a finished electric motor (e.g., lengths of wire too short to wind).

Factory overhead: Factory overhead includes all the indirect costs associated with production, indirect materials and energy use, taxes, and insurance. DOE only applies factory overhead to the direct material production costs (including the handling and scrap factor). The overhead increases when copper die casting is used in the rotor. This accounts for additional energy, insurance, and other indirect costs associated with the copper die-casting process.

Non-production: This markup reflects costs including sales and general administrative, research and development, interest payments, and profit factor. DOE applies the non-production markup to the sum of the direct material production, the direct labor, and the factory overhead. For ECG I, analyzed electric motors at or below 5-horsepower this markup was 37 percent and for electric motors above 5-horsepower this markup was 45 percent. This increase accounts for the extra profit margin manufacturers may receive on larger electric motors that are sold in smaller volumes. DOE assumed a 45 percent markup for all ECG II motors due to the low production volume of NEMA Design C motors.

Table 1.17 Markups Used in the Engineering Analysis

Markup	Percentage	Manufacturer Comment
Scrap Costs	2.50%	
Overhead Costs*	17.5%	
Non-Production Markup (1-5 Horsepower Motors)	37.0%	
Non-Production Markup (7.5-500 Horsepower Motors)	45.0%	

*DOE used an 18.0% markup for copper rotor overhead production costs.
**Manufacturer Production Cost is the sum of the bill of material, labor, scrap, and overhead costs.

B.5 Labor Rates

DOE used the same hourly labor rate for all electric motors analyzed. The base hourly rate was developed from the 2007 Economic Census of Industry, published by the U.S. Census Bureau, as well as manufacturer and subject matter expert (SME) input. The base hourly rate is an aggregate rate of a foreign and domestic labor rates. DOE weighed the foreign labor rate more than the domestic labor rate due to manufacturer feedback indicating off-shore production accounts for a majority of electric motor production by American-based companies. Several markups were applied to this hourly rate to obtain a fully burdened rate which was intended to be representative of the labor costs associated with manufacturing electric motors. Table 1.18 shows the labor markups that were applied, their corresponding markup percentage, and the new burdened labor rate.

Indirect Production: Accounts for the cost of production managers, quality control, and other indirect costs associated with production.

Fringe: Includes pension contributions, group insurance premiums, workers compensation, etc.

Assembly Labor Up-Time: Accounts for the time that workers are not assembling products and/or reworking unsatisfactory units.

B.5.1 Aggregate Hourly Labor Rate: Please comment on the appropriateness of the following labor rate, as well as the labor rate markups. Does the fully-burdened cost of labor represent your company's fully-burdened labor rate for production? If not, what is your company's fully-burdened labor rate, and which markups would you adjust?

Table 1.18 Labor Markups for Electric Motor Manufacturers

Type of Markup	Markup	Rate ($/hr)	Comments
Aggregate labor cost per hour*		10.87	
Indirect Production**	33 %	14.46	
Overhead***	30 %	18.79	
Fringe†	24 %	23.40	
Assembly Labor Up-time††	43 %	33.46	
Fully-Burdened Cost of Labor		33.46	

* Cost per hour is an aggregate number drawn from U.S. Census Bureau, 2007 Economic Census of Industry, published December 2010 and foreign labor rate estimates based on manufacturer feedback.
** Indirect Production Labor (Production managers, quality control, etc.) as a percent of direct labor on a cost basis. Navigant Consulting, Inc. (NCI) estimate.
*** Overhead includes commissions, dismissal pay, bonuses vacation, sick leave, and social security contributions. NCI estimate.
† Fringe includes pension contributions, group insurance premiums, workers compensation. Source: U.S. Census Bureau, 2007 Economic Census of Industry, published December 2010. Data for NAICS code 335312 "Electric Motor and Generator Manufacturer" total fringe benefits as a percent of total compensation for all employees (not just production workers).
†† Assembly labor up-time is a factor applied to account for the time that workers are not assembling product and/or reworking unsatisfactory units. The markup of 43 percent represents a 70 percent utilization (multiplying by 100/70). NCI estimate.

B.5.2 Labor Time Estimates: Below are DOE's labor time estimates for each representative unit as the CSLs increase. These estimates are based on SME and manufacturer feedback. Do these numbers accurately reflect how long it takes or would take to make each horsepower rating, and are labor hour increases accurate for the efficiency increases? If not, please comment on what adjustments you would make.

Table 1.19 Labor Hour Estimates (And Percentage Increase Over Baseline) For Equipment Class Group I Candidate Standard Levels

	ECG I Representative Units		
Efficiency Level	**5HP, Design B**	**30HP, Design B**	**75HP, Design B**
Baseline (Below NEMA MG1 Table 12-11)	1.25 Hours	2.00 Hours	3.50 Hours
CSL 1 (NEMA MG1 Table 12-11)	1.31 Hours (+5%)	2.10 Hours (+5%)	3.68 Hours (+5%)
CSL 2 (NEMA MG1 Table 12-12)	1.38 Hours (+10%)	2.21 Hours (+10%)	3.86 Hours (+10%)
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	1.45 Hours (+16%)	2.32 Hours (+16%)	4.06 Hours (+16%)
CSL 4* (2 Bands Above NEMA MG1 Table 12-12)	3.68 Hours (+155%)**	6.00 Hours (+184%)**	9.45 Hours (+170%)**

*CSL 4 for the 5 horsepower representative unit is 3 bands above NEMA MG1 Table 12-12.
**This motor has a hand wound stator.

Table 1.20 Labor Hour Estimates (And Percentage Increase Over Baseline) For Equipment Class Group II Candidate Standard Levels

ECG II Representative Unit	
Efficiency Level	**5HP, Design C**
Baseline (NEMA MG1 Table 12-11)	1.25 hours
CSL 1 (NEMA MG1 Table 12-12)	1.31 hours (+5%)
CSL 2 (2 Bands Above NEMA MG1 Table 12-12)	3.50 hours (+184%)*

ECG II Representative Unit	
Efficiency Level	**50HP, Design C**
Baseline (NEMA MG1 Table 12-11)	2.75 hours
CSL 1 (NEMA MG1 Table 12-12)	2.89 hours (+5%)
CSL 2 (1 Band Above NEMA MG1 Table 12-12)	7.50 hours (+173%)*

*This motor has a hand-wound stator.

B.5.3 Part of the manufacturing selling prices calculation relates to labor expenses. DOE applied a fully burdened labor rate to estimated manufacturing time. DOE estimates that additional manufacturing time will be needed to implement the design options shown below. Are these assumptions fair? If not, how much of a change in manufacturing time would you expect by implementing each of the design options listed? Please comment on the table below.

Table 1.21 Additional Manufacturing Times for Design Options

Design Option	Additional Time
Increasing Slot Fill (70% to 85%)	
Lengthening Stack (20%-30% increase)	
Changing Grades of Steel (no increase)	
Die-Casting Copper Rotor Cage (no increase)	

B.6 SCALING RESULTS

DOE scales its analysis of the representative units to the other horsepower and pole configurations that are not directly analyzed. In the preliminary analysis, DOE relied on an incremental improvement of motor losses for each CSL.

B.6.1 When selecting its representative units, DOE also considered horsepower ratings which were built in the last iteration of their frame designation. For example, both a 3 and 5 horsepower motor are designated as 180-frame series motors in NEMA MG1, but the 5 horsepower is the largest rating to be built in a 180-frame series designation. Which other horsepower ratings are currently at or near their maximum achievable efficiencies for their frame designations when they are produced at the NEMA MG1 Table 12-12 efficiency level?

B.6.2 Software Modeling: In an effort to analyze more ratings, DOE is considering analyzing additional models using software analysis. This would allow DOE to assess many additional ratings that would not be feasible to purchase, test, and teardown. Are there any particular characteristics or design parameters DOE should consider when conducting software modeling for un-analyzed ratings?

B.6.3 DOE was unable to directly analyze all equipment classes and must scale the efficiencies from the motors analyzed in the engineering analysis to the remaining equipment classes. DOE has examined the product lines of various manufacturers and created efficiency relationships based on data found in manufacturer catalogs. Is it appropriate to assume that manufacturers will use the same design options for a given product line and thus create a line of motors with similar efficiency ratings for their given equipment class?

C COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to electric motors. However, the context within which the plant operates and the details of plant production and costs are not readily available from the published literature. Therefore, DOE invites you to provide these details confidentially in your own words to the extent possible and practical. Understanding the organizational setting around the electric motor industry profit center will help DOE understand the probable future of the manufacturing activity with and without new energy conservation standards.

C.1 Do you have a parent company, and/or any subsidiaries relevant to the electric motor industry?

C.2 Do you manufacture any equipment other than electric motors? If so, what other equipment do you manufacture?

C.3 What percentage of your total manufacturing corresponds to electric motors covered by this rulemaking?

C.4 Where are your production facilities located, and what type of equipment is manufactured at each location? Could you provide figures for your company's manufacturing at each location by equipment type, horsepower, number of poles and efficiency?

C.5 At your manufacturing facilities, would potential electric motor redesigns be difficult to implement? If so, would your company modify the existing facility or develop a new facility?

C.6 What are your employment levels at each of these facilities?

C.7 What are your product lines, niches, and relative strengths in the electric motors market?

C.8 What is your company's approximate market share for polyphase electric motors from 1-500 horsepower covered in this rulemaking?

C.9 Would you expect your market share to change once new energy conservation standards become effective?

D MANUFACTURER PRODUCTION COSTS AND SCALING PRICES

For the MIA, DOE defines manufacturer production cost as all direct costs associated with manufacturing a piece of equipment. It includes direct labor, direct materials,[1] and overhead (which includes depreciation costs). The breakdown of manufacturer production cost has implications for the quantitative impacts on electric motors manufacturers. The per unit production costs are necessary for DOE to estimate labor expenditures and other cash flow calculations.

Manufacturer selling price is the average cost manufacturers charge their first consumers, but does not include costs along distribution channels. The manufacturer selling price includes a per unit research and development cost; selling, general, and administrative expense; shipping cost; and profit. The manufacturer markup is a multiplier applied to manufacturer production cost to cover the per-unit research and development, selling, general, and administrative expense, shipping, and profit.

In the engineering analysis, DOE developed manufacturer production costs for one representative motor in each motor equipment class grouping. By multiplying the manufacturer production costs by the manufacturer markup, DOE calculated the manufacturer selling prices for these motors at each CSL. In order to determine manufacturer selling prices for all other equipment classes (over 500 in total), DOE scaled the manufacturer selling prices to all covered equipment classes (i.e., scale the prices developed using the motors analyzed in the engineering analysis by horsepower, number of poles, and enclosure type). For scaling, DOE is using engineering data as a basis for examining how prices vary by horsepower, and catalog prices to assess how prices vary by enclosure and number of poles for each of the efficiency levels analyzed.

To calculate manufacturer production costs for all other covered equipment (i.e., all equipment classes other than the three representative units for ECG I, III and IV and the two representative units for ECG II), DOE will divide the scaled manufacturer selling prices by the manufacturer markup. As shown in Equation 1.1 below, the manufacturer selling price divided by the baseline manufacturer markup would convert the scaled manufacturer selling price to a manufacturer production cost.

Equation 1.1 Calculation of Manufacturer Production Costs and Manufacturer Selling Price

$$\frac{\text{Manufacturer Selling Price}}{\text{Manufacturer Markup}} = \text{Manufacturer Production Cost}$$

[1] Included in direct materials are the costs associated with the handling of material (loading into assembly or winding equipment) and the scrap material that cannot be used in the production of a finished electric motor (e.g., lengths of wire too short to wind).

D.1 Table 1.22 through Table 1.26 provide DOE's estimates of the manufacturer production costs and manufacturer selling prices for electric motors at the representative horsepower, number of poles, and enclosure type as well as each CSL being considered. Could you please provide any comments on the estimated values?

Table 1.22 Estimated Manufacturer Production Costs and Manufacturer Selling Prices for 5 Horsepower, NEMA Design B, 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	DOE's Manufacturer Production Cost Estimates (2012$)	DOE's Manufacturer Selling Price Estimates (2012$)	Manufacturer Comments or Revised Estimates
Baseline Level (82.5%)	230	316	
CSL 1 (NEMA MG1 Table 12-11)	233	320	
CSL 2 (NEMA MG1 Table 12-12)	256	350	
CSL 3 (1 Band Above NEMA Premium)	263	361	
CSL 4 (3 Bands Above NEMA Premium)	414	567	

Table 1.23 Estimated Manufacturer Production Costs and Manufacturer Selling Prices for 30 Horsepower, NEMA Design B, 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	DOE's Manufacturer Production Cost Estimates (2012$)	DOE's Manufacturer Selling Price Estimates (2012$)	Manufacturer Comments or Revised Estimates
Baseline Level (89.5%)	553	801	
CSL 1 (NEMA MG1 Table 12-11)	699	1,014	
CSL 2 (NEMA MG1 Table 12-12)	797	1,156	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	804	1,166	
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)	1,293	1,875	

Table 1.24 Estimated Manufacturer Production Costs and Manufacturer Selling Prices for 75 Horsepower, NEMA Design B, 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	DOE's Manufacturer Production Cost Estimates* (2012$)	DOE's Manufacturer Selling Price Estimates (2012$)	Manufacturer Comments or Revised Estimates
Baseline Level (93.0%)	1,221	1,771	
CSL 1 (NEMA MG1 Table 12-11)	1,329	1,927	
CSL 2 (NEMA MG1 Table 12-12)	1,511	2,191	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	1,715	2,486	
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)	2,235	3,240	

Table 1.25 Estimated Manufacturer Production Costs and Manufacturer Selling Prices for 5 Horsepower, NEMA Design C, 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	DOE's Manufacturer Production Cost Estimates* (2012$)	DOE's Manufacturer Selling Price Estimates (2012$)	Manufacturer Comments or Revised Estimates
Baseline Level (NEMA MG1 Table 12-11)	232	336	
CSL 1 (NEMA MG1 Table 12-12)	248	360	
CSL 2 (2 Bands Above NEMA MG1 Table 12-12)	400	580	

Table 1.26 Estimated Manufacturer Production Costs and Manufacturer Selling Prices for 50 Horsepower, NEMA Design C, 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	DOE's Manufacturer Production Cost Estimates* (2012$)	DOE's Manufacturer Selling Price Estimates (2012$)	Manufacturer Comments or Revised Estimates
Baseline Level (NEMA MG1 Table 12-11)	1,026	1,487	
CSL 1 (NEMA MG1 Table 12-12)	1,410	2,045	
CSL 2 (1 Band Above NEMA MG1 Table 12-12)	1,534	2,225	

D.2 Please compare your manufacturer production cost percentages[2] to the estimates tabulated below. The manufacturer production cost breakdown is used to calculate the total cost of goods sold (COGS) for the industry. Having an accurate estimate of the production costs for the industry allows DOE to better examine impacts on profitability and employment due to new energy conservation standards. Are the different percentages of each cost representative of your company or the electric motor industry? Please explain any differences. As mentioned in section D, the overhead component of the manufacturer production cost includes depreciation. In the tables below could you separate depreciation from overhead and include it as a percentage of manufacturer production cost?

Table 1.27 Breakdown of Manufacturer Production Costs for ECG I, CSL 1, 5 Horsepower, 4-pole Enclosed Motor

Components of Manufacturer Production Cost	DOE's Estimated Percentage of Manufacturer Production Cost	Manufacturer Feedback
Materials	66%	
Labor	18%	
Overhead	15%	
Depreciation	Included in overhead	

Table 1.28 Breakdown of Manufacturer Production Costs for ECG I, CSL 1, 30 Horsepower, 4-pole Enclosed Motor

Components of Manufacturer Production Cost	DOE's Estimated Percentage of Manufacturer Production Cost	Manufacturer Feedback
Materials	75%	
Labor	10%	
Overhead	15%	
Depreciation	Included in overhead	

Table 1.29 Breakdown of Manufacturer Production Costs for ECG I, CSL 1, 75 Horsepower, 4-pole Enclosed Motor

Components of Manufacturer Production Cost	DOE's Estimated Percentage of Manufacturer Production Cost	Manufacturer Feedback
Materials	76%	
Labor	9%	
Overhead	15%	
Depreciation	Included in overhead	

D.3 Do the percentages presented on Table 1.27 through Table 1.29 change at higher

2 The manufacture production cost percentages shown in Table 1.27 through Table 1.29 are the values that make up COGS. These are percentages of total COGS.

efficiencies? Do the percentages change for NEMA Design C motors? Please explain any differences.

D.4 Within a motor ECG, does the production cost breakdown change with horsepower? Does it vary with the number of poles?

E MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of new energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how setting a new energy conservation standard would impact your company's markup structure and profitability. As discussed in Section D, the manufacturer markup is a multiplier applied to manufacturer production cost to cover per unit research and development, selling, general, and administrative expenses, shipping costs, and profit. Currently, DOE estimates an industry-wide markup of 37%–45% for electric motor equipment classes.

E.1 Do profit levels currently vary by equipment class? Do profit levels vary by CSL? Please explain why or why not.

E.2 Within each motor ECG, do profit levels vary by horsepower, number of poles, and/or enclosure type?

E.3 DOE currently assumes that the manufacturer markup does not vary by motor ECG, CSL, or equipment class. DOE would like to understand how the manufacturer markup changes at higher CSLs. If so, could you provide your company's markup for any motors that meet the CSLs shown below?

Table 1.30 Manufacturer Markups for 5 Horsepower, NEMA Design B, 4-pole Enclosed Motors

Efficiency Level (Full Load Efficiency)	Estimated Manufacturer Markup
Baseline (82.5%)	
CSL 1 (NEMA MG1 Table 12-11)	
CSL 2 (NEMA MG1 Table 12-12)	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	
CSL 4 (3 Bands Above NEMA MG1 Table 12-12)	

Table 1.31 Manufacturer Markups for 30 Horsepower, NEMA Design B 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	Estimated Manufacturer Markup
Baseline (89.5%)	
CSL 1 (NEMA MG1 Table 12-11)	
CSL 2 (NEMA MG1 Table 12-12)	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)	

Table 1.32 Manufacturer Markups for 75 Horsepower, NEMA Design B 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	Estimated Manufacturer Markup
Baseline (93.0%)	
CSL 1 (NEMA MG1 Table 12-11)	
CSL 2 (NEMA MG1 Table 12-12)	
CSL 3 (1 Band Above NEMA MG1 Table 12-12)	
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)	

Table 1.33 Manufacturer Markups for 5 Horsepower, NEMA Design C 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	**Estimated Manufacturer Markup**
Baseline (NEMA MG1 Table 12-11)	
CSL 1 (NEMA MG1 Table 12-12)	
CSL 2 (2 Bands Above NEMA MG1 Table 12-12)	

Table 1.34 Manufacturer Markups for 50 Horsepower, NEMA Design C 4-pole Enclosed Motor

Efficiency Level (Full Load Efficiency)	**Estimated Manufacturer Markup**
Baseline (NEMA MG1 Table 12-11)	
CSL 1 (NEMA MG1 Table 12-12)	
CSL 2 (1 Band Above NEMA MG1 Table 12-12)	

E.4 Could you explain how the manufacturer markup varies for each motor ECG as the horsepower, number of poles, and enclosure type varies.

E.5 Would you expect changes in your estimated profitability following a new energy conservation standard? If so, please explain why.

F SHIPMENT PROJECTIONS AND MARKET SHARES

A new energy conservation standard can change overall shipments by altering equipment attributes, marketing approaches, equipment availability, and price. The industry revenue calculations are based on the shipment projections developed by DOE's shipments model.

F.1 Please compare DOE's projections of annual industry-wide shipments for covered electric motors with your company's projections of industry-wide shipments.

Table 1.35 Annual Industry-Wide Shipment Projections for Polyphase Motors Absent Amended Energy Conservation Standards

	2008 Total Industry-Wide Shipments	Projected Total Industry-Wide Shipments in 2015*	Projected Total Industry-Wide Shipments in 2025	Projected Total Industry-Wide Shipments in 2035
DOE's Estimate for Total Industry Shipments (Millions)	.750	.838	.990	1.22
Manufacturer Feedback				

G EQUIPMENT MIX

Equipment mix describes the distribution of current shipments by CSL. Changes in the equipment mix due to new energy conservation standards can have a large impact on industry revenues. Having an accurate estimate of the current equipment mix allows DOE to better estimate how revenues might change due to new energy conservation standards.

G.1 Does your company offer multiple product lines at different CSLs? Could you provide a description of your company's product lines and their respective CSLs?

G.2 Table 1.36 through Table 1.38 shows DOE's estimate for the mix of shipments by efficiency in 2015. Could you provide feedback on DOE's estimates based on your knowledge of the industry? Note: Though the CSLs defined in the introduction of this interview guide apply to one representative motor in each motor ECG, the CSLs in the following tables are meant to represent levels that would require manufacturers to implement similar design options for all horsepower, enclosure and pole configurations for a given motor ECG.

Table 1.36 Percentage of Industry-Wide Shipments by Efficiency Level for Equipment Class Group I Motors in 2015

Percentage of Total Shipments at Each Efficiency	Horsepower range	CSL 0 Baseline	CSL 1 (NEMA MG1 Table 12-11)	CSL 2 (NEMA MG1 Table 12-12)	CSL 3	CSL 4
DOE's estimate 2015	1 - 5	10.3%	36.8%	41.5%	10.1%	1.3%
	6 - 20	4.7%	35.3%	44.3%	12.0%	3.6%
	21 - 50	5.3%	30.3%	47.8%	8.8%	7.9%
	51 - 100	5.4%	28.6%	48.4%	10.1%	7.5%
	101 -200	5.4%	23.3%	53.9%	12.0%	5.4%
	201 -500	11.2%	49.9%	32.0%	5.9%	0.9%
Manufacturer feedback	1 - 5					
	6 - 20					
	21 - 50					
	51 - 100					
	101 -200					
	201 -500					

Table 1.37 Percentage of Industry-Wide Shipments by Efficiency Level for Equipment Class Group II Motors in 2015

Percentage of Total Shipments at Each Efficiency	Horsepower range	CSL 0 (NEMA MG1 Table 12-11)	CSL 1 (NEMA MG1 Table 12-12)	CSL 2 (1 to 2 Bands Above NEMA MG1 Table 12-12)
DOE's estimate 2015	1 - 5	23.1%	69.2%	7.7%
	6 - 20	0.0%	100.0%	0.0%
	21 - 50	73.3%	26.7%	0.0%
	51 - 100	50.0%	50.0%	0.0%
	101 -200	47.8%	30.4%	21.7%
Manufacturer feedback	1 - 5			
	6 - 20			
	21 - 50			
	51 - 100			
	101 -200			

Table 1.38 Percentage of Industry-Wide Shipments by Efficiency Level for Equipment Class Group III Motors in 2015

Percentage of Total Shipments at Each Efficiency	Horsepower range	CSL 0 Baseline	CSL 1 (NEMA MG1 Table 12-11)	CSL 2 (NEMA MG1 Table 12-12)	CSL 3	CSL 4
DOE's estimate 2015	1 - 5	94.9%	5.1%	0.0%	0.0%	0.0%
	6 - 20	Close to 100%	Insignificant			
	21 - 50	81.7%	5.5%	12.8%	0.0%	0.0%
	51 - 100	80.6%	2.0%	17.3%	0.0%	0.0%
	101 -200	73.5%	17.6%	8.8%	0.0%	0.0%
	201 -500	75.0%	25.0%	0.0%	0.0%	0.0%
Manufacturer feedback	1 - 5					
	6 - 20					
	21 - 50					
	51 - 100					
	101 -200					
	201 -500					

H FINANCIAL PARAMETERS

Navigant Consulting, Inc. (NCI) has developed a "strawman" model of the electric motor industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. This section attempts to understand how your company's financial situation differs from our industry aggregate picture.

H.1 Please compare your financial parameters to the GRIM parameters tabulated below.

Table 1.39 Financial Parameters for Electric Motor Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	28.6%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.1%	
Working Capital	Current assets less current liabilities (percentage of revenues)	2.5%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	16.6%	
R&D	Research and development expenses (percentage of revenues)	4.2%	
Depreciation	Amortization of fixed assets (percentage of revenues)	5.1%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	5.1%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	71.9%	

H.2 How would you expect an amended energy conservation standard to impact any of the financial parameters for the industry?

I CONVERSION COSTS

New and amended energy conservation standards may cause your company to incur capital and equipment conversion costs to redesign existing equipment and make changes to existing production lines to be compliant with the new and amended energy conservation standards. Capital conversion costs are one-time investments in plant, property, and equipment (PPE) necessitated by new and amended energy conservation standards. These may be incremental changes to existing PPE or the replacement of existing PPE. Replacing existing PPE could strand existing assets before the end of their useful lives. In addition to capital conversion costs, equipment conversion costs are costs related to research, product development, testing, marketing and other costs for redesigning equipment necessitated by new and amended energy conservation standards. For the industry cash flow model, DOE must estimate the conversion costs for all covered equipment. It is difficult to estimate these costs due to variations in efficiency between equipment classes. The questions below attempt to capture the capital and equipment conversion costs that would be required to convert all covered equipment at the CSLs studied by DOE.

I.1 Are different motor categories manufactured on the same line? Within a motor ECG, are motors of varying horsepower and number of poles manufactured on the same line?

I.2 Does the production equipment and manufacturing processes used to manufacturer motors differ by motor ECG, horsepower, or number of poles?

I.3 Are production lines shared between covered general purpose motors and motors not-currently covered by standards?

I.4 What capitol conversion costs do you expect if your company had to manufacture die-cast copper rotor motors? How would these costs change if only motors from 1-30 horsepower were die-cast copper rotor motors?

In the tables below, DOE asks you to provide your expected capital and equipment conversion costs for the representative combination of horsepower and number of poles for each electric motor ECG. Following the tables, DOE asks a series of questions to determine how the capital conversion and equipment conversion costs for these motors compare to costs to convert the remaining combinations of horsepower and number of poles.

Table 1.40 Conversion Costs for 5 Horsepower, NEMA Design B, 4-pole Enclosed Motors

Efficiency Level (Full Load Efficiency)	**5 Horsepower, NEMA Design B, 4-pole Enclosed Motor**		
	Capital Conversion Costs (2012$)	**Equipment Conversion Costs (2012$)**	**Stranded Assets (2012$)**
Baseline (82.5%)			
CSL 1 (NEMA MG1 Table 12-11)			
CSL 2 (NEMA MG1 Table 12-12)			
CSL 3 (1 Band Above NEMA MG1 Table 12-12)			
CSL 4 (3 Bands Above NEMA MG1 Table 12-12)			

Table 1.41 Conversion Costs for 30 Horsepower, NEMA Design B 4-pole Enclosed Motors

Efficiency Level (Full Load Efficiency)	30 Horsepower, NEMA Design B, 4-pole Enclosed Motor		
	Capital Conversion Costs (2012$)	Equipment Conversion Costs (2012$)	Stranded Assets (2012$)
Baseline (89.5%)			
CSL 1 (NEMA MG1 Table 12-11)			
CSL 2 (NEMA MG1 Table 12-12)			
CSL 3 (1 Band Above NEMA MG1 Table 12-12)			
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)			

Table 1.42 Conversion Costs for 75 Horsepower, NEMA Design B 4-pole Enclosed Motors

Efficiency Level (Full Load Efficiency)	75 Horsepower, NEMA Design B, 4-pole Enclosed Motor		
	Capital Conversion Costs (2012$)	Equipment Conversion Costs (2012$)	Stranded Assets (2012$)
Baseline Level (93.0%)			
CSL 1 (NEMA MG1 Table 12-11)			
CSL 2 (NEMA MG1 Table 12-12)			
CSL 3 (1 Band Above NEMA MG1 Table 12-12)			
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)			

Table 1.43 Conversion Costs for 5 Horsepower, NEMA Design C 4-pole Enclosed Motors

Efficiency Level (Full Load Efficiency)	5 Horsepower, NEMA Design C, 4-pole Enclosed Motor		
	Capital Conversion Costs (2012$)	Equipment Conversion Costs (2012$)	Stranded Assets (2012$)
Baseline (NEMA MG1 Table 12-11)			
CSL 1 (NEMA MG1 Table 12-12)			
CSL 2 (2 Bands Above NEMA MG1 Table 12-12)			

Table 1.44 Conversion Costs for 50 Horsepower, NEMA Design C 4-pole Enclosed Motors

Efficiency Level (Full Load Efficiency)	50 Horsepower, NEMA Design C, 4-pole Enclosed Motor		
	Capital Conversion Costs (2012$)	**Equipment Conversion Costs (2012$)**	**Stranded Assets (2012$)**
Baseline (NEMA MG1 Table 12-11)			
CSL 1 (NEMA MG1 Table 12-12)			
CSL 2 (1 Band Above NEMA MG1 Table 12-12)			

Table 1.45 Conversion Costs for all Covered Fire Pump Motors

Efficiency Level (Percentage increase over baseline)	Covered Fire Pump Motors		
	Capital Conversion Costs (2012$)	**Equipment Conversion Costs (2012$)**	**Stranded Assets (2012$)**
CSL 1 (NEMA MG1 Table 12-11)			
CSL 2 (NEMA MG1 Table 12-12)			
CSL 3 (1 Band Above NEMA MG1 Table 12-12)			
CSL 4 (2 Bands Above NEMA MG1 Table 12-12)			

I.5 Within each motor ECG, will the conversion costs presented above be shared across equipment with different horsepower and number of poles? For example, will the conversion costs for 5 hp, 4-pole enclosed motors include the conversion costs for a 10 hp, 6-pole motors open frame motors, 3 hp, 2-pole enclosed motors, etc.?

I.6 For the conversion costs provided above, would any of these conversion costs be shared across different motor types?

I.7 In order to increase the efficiencies by the percentages shown in the tables above, would non-covered motors also require a corresponding improvement in efficiency?

J CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards, voluntary standards, and/or other regulatory actions affecting the same equipment or industry.

J.1 Are there other recent or impending regulations that electric motor manufacturers face (from DOE or otherwise)? If so, could you identify the regulation and the corresponding possible effective dates for those regulations?

J.2 What level of expense are you expecting to incur as a result of these regulations?

J.3 Under what circumstances would you be able to coordinate any expenditures related to these other regulations with this electric motor energy conservation standard, thereby lessening the cumulative burden?

K DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of new and amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in electric motor production employment and solicit manufacturer views on how domestic employment patterns might be affected by new and amended energy conservation standards.

K.1 Where are your facilities that produce electric motors for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's electric motor manufacturing at each location by equipment class. Please also provide employment levels at each of these facilities.

Table 1.46 Electric Motor Manufacturing Facilities

Facility	Location	Equipment Types Manufactured	Employees	Annual Shipments
Example	*Jackson, TN*	*Equipment Class Group I, II*	*650*	*300,000 for ECG 1, 200,000 for ECG 2*
1				
2				
3				
4				
5				

K.2 Would your domestic employment levels be expected to change significantly under new and amended energy conservation standards? If so, please explain how they would change if higher efficiency levels are required.

K.3 Would the workforce skills necessary under new and amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

L EXPORTS / FOREIGN COMPETITION / OUTSOURCING

Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes, resulting from new and amended energy conservation standards, may impact sourcing decisions.

L.1 What percentage of your company's electric motors sales is domestic? Absent new and amended energy conservation standards, are production facilities being relocated to foreign countries? Would new and amended energy conservation standards impact your domestic vs. foreign manufacturing decision?

L.2 If applicable, to what foreign countries or regions do you export your equipment? What percentage of sales can be attributed to each?

L.3 Would new and amended energy conservation standards be expected to affect your export sales? What would the resulting impact be, if any, on your manufacturing operations and profitability?

L.4 Are your foreign exports affected by new and amended energy conservation standards in other countries?

L.5 What percentage of the U.S. market for electric motor is imported? Would new and amended energy conservation standards have an impact on foreign competition?

L.6 What is your outlook for electric motors exports?

M CONSOLIDATION

New and amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from new and amended energy conservation standards.

M.1 Please comment on industry consolidation and related trends over the last 5 years.

M.2 In the absence of new and amended energy conservation standards, do you expect any further industry consolidation? Please describe your expectations.

M.3 How would new and amended energy conservation standards affect your ability to compete?

N IMPACTS ON SMALL BUSINESS

N.1 The Small Business Association (SBA) denotes a small business in the electric motor industry as having less than 1,000 employees3. By this definition, is your company considered a small business?

N.2 Are there any reasons that a small business might be at a disadvantage relative to a larger business under new and amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

N.3 Are there any niche manufacturers, small businesses, and/or component manufacturers for which the adoption of new and amended energy conservation standards would have a severe impact? If so, would manufacturers of these motors have different incremental impacts from implemented new and amended energy conservation standards than the rest of the industry?

[3] DOE uses the small business size standards published on August 22, 2008, as amended, by the Small Business Administration (SBA) to determine whether a company is a small business. To be categorized as a small business, an electric motor manufacturer and its affiliates may employ a maximum of 1,000 employees. The 1,000 employee threshold includes all employees in a business's parent company and any other subsidiaries.

12-A.2 ELECTRIC MOTOR SMALL BUSINESS MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

As part of the rulemaking process for new energy conservation standards for electric motors, the Department of Energy (DOE) conducts the manufacturer impact analysis (MIA). In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to new energy conservation standards. DOE is currently considering five candidate standard levels of efficiency (referred to as CSLs) for electric motors in the scope of this rulemaking, including a baseline CSL. The motor types covered in this rulemaking are separated into four equipment class groups (ECGs), as shown below.

Table 2.1 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design	Horsepower	Poles	Enclosure
I	NEMA Design A & B*	1-500	2, 4, 6, 8	Open
				Closed
II	NEMA Design C*	1-200	4, 6, 8	Open
				Closed
III	Fire Pump*	1-500	2, 4, 6, 8	Open
				Closed
IV	Integral Brake Motors*	1-30	4, 6, 8	Open
				Closed

*Including IEC equivalents.

DOE analyzed three representative units for ECG I (which are also used to represent ECG III and ECG IV) and two representative units for ECG II. The results obtained were then extrapolated to other ratings within the respective ECGs.

In responding to this questionnaire, please refer to the CSLs in the table below.

Table 2.2 Nominal Efficiency Levels Under Consideration for Equipment Class Group I and III

Equipment Class	CSL 1	CSL 2	CSL 3	CSL 4*
5 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (87.5%)	NEMA MG1 Table 12-12 (89.5%)	1 Band Above NEMA MG1 Table 12-12 (90.2%)	3 Bands Above NEMA MG1 Table 12-12 (91.7%)
30 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (92.4%)	NEMA MG1 Table 12-12 (93.6%)	1 Band Above NEMA MG1 Table 12-12 (94.1%)	2 Bands Above NEMA MG1 Table 12-12 (94.5%)
75 horsepower, 4-pole enclosed	NEMA MG1 Table 12-11 (94.1%)	NEMA MG1 Table 12-12 (95.4%)	1 Band Above NEMA MG1 Table 12-12 (95.8%)	2 Bands Above NEMA MG1 Table 12-12 (96.2%)

*All representative units at this CSL use copper rotor technology.

Table 2.3 Nominal Efficiency Levels under Consideration for Equipment Class Group II

Equipment Class	CSL 1	CSL 2*
5 horsepower, 4-pole enclosed	NEMA MG1 Table 12-12 (89.5%)	2 Bands Above NEMA MG1 Table 12-12 (91.0%)
50 horsepower, 4-pole enclosed	NEMA MG1 Table 12-12 (94.5%)	1 Band Above NEMA MG1 Table 12-12 (95.0%)

*All representative units at this CSL use copper rotor technology.

A INTRODUCTION

Are you aware of DOE's ongoing rulemaking to establish new national minimum energy conservation standards for electric motors above 1 horsepower? If you are not already in it, would you like to be added to DOE's email database for updates relating to this rulemaking?

We are assessing the impacts of a potential energy conservation standard on small businesses. Is your company a small business (defined as less than 1,000 employees by the US Small Business Administration (SBA), including all subsidiaries and parent companies, and employees in all countries where you operate)?

A.1 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under adopted energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

A.2 To your knowledge, are there any small businesses for which the adoption of energy conservation standards would have a particularly severe impact? If so, why?

B KEY ISSUES

B.1 In general, what are the key issues for your company regarding new energy conservation standards for electric motors and this rulemaking?

B.2 For the issues identified, how significant are they at each listed CSL?

C COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

C.1 Do you have a parent company, and/or any subsidiaries relevant to the electric motor industry?

C.2 What types of electric motors do you manufacture? What is your company's approximate market share of the electric motors market?

C.3 Do you manufacture any equipment other than electric motors? If so, what other equipment do you manufacture? What percentage of your total manufacturing corresponds to electric motors covered by this rulemaking?

C.4 Please complete Table 2.4 to the best of your ability. If possible, please express revenue in both dollar amount and in percentage of total electric motor sales. Additionally, please express shipments in both volume and percentage of electric motor shipments. Please indicate if you do not manufacture products in any given equipment class group.

Table 2.4 Electric Motor Revenue and Shipment Volumes

ECG	ECG Description	2012 Revenue *($)*	*(%)*	2012 Shipments *(volume)*	*(%)*
1	NEMA Design A & B*: 1-500 horsepower				
2	NEMA Design C*: 1-200 horsepower				
3	Fire Pump*				
4	Integral Brake Motors*				

*Including IEC equivalents

D MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of new energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how setting a new energy conservation standard would impact your company's markup structure and profitability. The manufacturer markup is a multiplier applied to manufacturer production cost (which DOE defines as all direct costs associated with manufacturing a product: direct labor, direct materials, overhead, and depreciation) to cover per unit research and development; selling, general, and administrative expenses; shipping costs; and profit. *It does not reflect a "profit margin."*

The manufacturer production cost times the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but *does not* include additional costs along the distribution channels.

DOE estimates an industry-wide markup of 37% - 45% for electric motor equipment classes.

D.1 Is the 37% - 45% markup representative of an average industry markup?

D.2 Do profit levels currently vary by equipment class? Do profit levels vary by CSL? Please explain why or why not.

D.3 Would you expect changes in your estimated profitability following a new energy conservation standard? If so, please explain why.

E FINANCIAL PARAMETERS

Navigant Consulting, Inc. (NCI) has developed a "strawman" model of the electric motor industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. This section attempts to understand how your company's financial situation differs from our industry aggregate picture.

E.1 Please compare your financial parameters to the GRIM parameters tabulated below.

Table 2.5 Financial Parameters for Electric Motor Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	28.6%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.1%	
Working Capital	Current assets less current liabilities (percentage of revenues)	2.5%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	16.6%	
R&D	Research and development expenses (percentage of revenues)	4.2%	
Depreciation	Amortization of fixed assets (percentage of revenues)	5.1%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	5.1%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	71.9%	

E.2 How would you expect a new energy conservation standard to impact any of the financial parameters for the industry?

F CONVERSION COSTS

New and amended energy conservation standards may cause your company to incur capital and equipment conversion costs to redesign existing equipment and make changes to existing production lines to be compliant with the new and amended energy conservation standards.

Capital conversion costs are one-time investments in plant, property, and equipment (PPE) necessitated by new and amended energy conservation standards. These may be incremental changes to existing PPE or the replacement of existing PPE. Replacing existing PPE could strand existing assets before the end of their useful lives.

Equipment conversion costs are costs related to research, product development, testing, marketing, and other costs for redesigning equipment necessitated by new and amended energy conservation standards.

For the industry cash flow model, DOE must estimate the conversion costs for all covered equipment. It is difficult to estimate these costs due to variations in efficiency between equipment classes. The questions below attempt to capture the capital and equipment conversion costs that would be required to convert all covered equipment at the CSLs studied by DOE.

F.1 For the electric motors you manufacture within each product class, what capitol and equipment conversion costs do you expect to incur at each designated CSL?

Table 2.6 Expected Capital and Equipment Conversion Costs for Electric Motors

ECG	ECG Description	CSL	Total Capital Conversion Costs ($)	Total Equipment Conversion Costs ($)	Notes
1	NEMA Design A & B: 1 - 500 hp	CSL 1			
		CSL 2			
		CSL 3			
		CSL 4			
2	NEMA Design C: 1 - 200 hp	CSL 1			
		CSL 2			

F.2 Please provide additional qualitative information to help DOE understand the types and nature of your investments, including the plant and tooling changes and the product development effort required at different efficiency levels.

G DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of new and amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in electric motor production employment and solicit manufacturer views on how domestic employment patterns might be affected by new and amended energy conservation standards.

G.1 Where are your facilities that produce electric motors for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's electric motor manufacturing at each location by equipment class. Please also provide employment levels at each of these facilities.

Table 2.7 Electric Motor Manufacturing Facilities

Facility	**Location**	**Equipment Types Manufactured**	**Employees**	**Annual Shipments**
Example	*Jackson, TN*	*Equipment Class Group I, II*	*650*	*300,000 for ECG 1, 200,000 for ECG 2*
1				
2				
3				
4				
5				

G.2 Would your domestic employment levels be expected to change significantly under new and amended energy conservation standards? If so, please explain how they would change if higher efficiency levels are required.

APPENDIX 12-B GOVERNMENT REGULATORY IMPACT MODEL (GRIM) OVERVIEW

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12-B.1 INTRODUCTION AND PURPOSE

The purpose of the Government Regulatory Impact Model (GRIM) is to help quantify the impacts of energy conservation standards and other regulations on manufacturers. The basic mode of analysis is to estimate the change in the value of the industry or manufacturers following a regulation or a series of regulations. The model structure also allows an analysis of multiple products with regulations taking effect over a period of time, and of multiple regulations on the same products.

Industry net present value is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the base case) and under different trial standard levels (TSLs) (*i.e.*, the standards case).

Output from the model consists of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

12-B.2 ELECTRIC MOTORS MODEL DESCRIPTION

DOE analyzed the impacts of standards on the electric motor manufacturers. The basic structure of the GRIM is a standard annual cash flow analysis that uses manufacturer selling prices, manufacturing costs, a shipments forecast, and financial parameters as inputs and accepts a set of regulatory conditions as changes in costs and investments. The cash flow analysis is separated into two major blocks: income and cash flow. The income calculation determines net operating profit after taxes. The cash flow calculation converts net operating profit after taxes into an annual cash flow by including investment and non-cash items. The line items below relate to the electric motor manufacturers and are definitions of listed items on the printout of the output sheet (see section 12-B.3).

(1) Revenues: Annual revenues - computed by multiplying products' unit prices at each efficiency level by the appropriate manufacturer markup;

(2) Material: The portion of cost of goods sold (COGS) that includes materials;

(3) Labor: The portion of COGS that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time;

(4) Depreciation: The portion of COGS that includes an allowance for the total amount of fixed assets used to produce that one unit;

(5) Development Amortization: The portion of COGS that includes an allowance for the total product and capital conversion costs needed to produce that one unit. This is only applied to electric motors above NEMA Premium efficiency levels;

(6) Overhead: The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, property taxes, and insurance related to assets;

(7) Standard SG&A: Selling, general, and administrative costs are computed as a percentage of ***Revenues (2)***;

(8) R&D: GRIM separately accounts for ordinary research and development (R&D) as a percentage of ***Revenues (2)***;

(9) Product Conversion Costs: Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making products designs comply with the new and amended energy conservation standard. The GRIM allocates these costs over the period between the standard's announcement and compliance dates;

(10) Stranded Assets: In the year the standard becomes effective, a one-time write-off of stranded assets is accounted for;

(11) Earnings Before Interest and Taxes (EBIT): Includes profits before deductions for interest paid and taxes;

(12) EBIT/Revenues: GRIM calculates EBIT as a percentage of sales to compare with the industry's average reported in financial statements;

(13) Taxes: Taxes on ***EBIT (11)*** are calculated by multiplying the tax rate contained in the Financials tab by ***EBIT (11)***;

(14) Net Operating Profits After Taxes (NOPAT): Computed by subtracting ***Taxes (13)*** from ***EBIT (12)***;

(15) NOPAT repeated: NOPAT (14) is repeated in the Statement of Cash Flows;

(16) Depreciation repeated: Depreciation (4) is added back in the Statement of Cash Flows because it is a non-cash expense;

(17) Development Amortization repeated: Development Amortization (5) is added back in the Statement of Cash Flows because it is already accounted for in product and capital conversion costs;

(18) Loss on Disposal of Stranded Assets repeated: Stranded Assets (10) is added back in the Statement of Cash Flows because it is a non-cash expense;

(19) Change in Working Capital: Change in cash tied up in accounts receivable, inventory, and other cash investments necessary to support operations is calculated by multiplying working capital (as a percentage of revenues) by the change in annual revenues;

(20) Cash Flow From Operations: Calculated by taking ***NOPAT (15)***, adding back non-cash items such as ***Depreciation (16)***, ***Development Amortization (17)***, and ***Stranded Assets (18)***, and subtracting the ***Change in Working Capital (19)***;

(21) Ordinary Capital Expenditures: Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of ***Revenues (2)***;

(22) Capital Conversion Costs: Capital conversion costs are one-time investments in property, plant, and equipment to adapt or change existing production facilities so that new product designs can be fabricated and assembled under the new regulation; the GRIM allocates these costs over the period between the standard's announcement and compliance dates;

(23) Production Equipment Maintenance: The additional costs associated with maintaining capital equipment purchased due to a standard.

(24) Free Cash Flow: Annual cash flow from operations and investments; computed by subtracting ***(21) Ordinary Capital Expenditures*** and ***(22) Capital Conversion Costs*** from ***Cash Flows from Operations (20)***;

(25) Free Cash Flow repeated: Free Cash Flow (24) is repeated in the Discounted Cash Flow section;

(26) Terminal Value: Estimate of the continuing value of the industry after the analysis period. Computed by growing the Free Cash Flow at the beginning of 2045 at a constant rate in perpetuity;

(27) Present Value Factor: Factor used to calculate an estimate of the present value of an amount to be received in the future;

(28) Discounted Cash Flow: Free Cash Flow (24) multiplied by the ***Present Value Factor (27)***. For the end of 2045, the discounted cash flow includes the discounted ***Terminal Value (26)***; and

Industry Value thru the end of 2045: The sum of ***Discounted Cash Flows (28)***.

12-B.3 ELECTRIC MOTORS DETAILED CASH FLOW EXAMPLE

Industry Income Statement	**2012**	**Ancmt Yr 2013**	**2014**	**2015**	**Std Yr 2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Revenues	$ 2,933.3	$ 2,936.6	$ 3,229.5	$ 3,542.0	$ 3,801.3	$ 4,023.1	$ 4,155.7	$ 4,301.3	$ 4,446.9	$ 4,568.4	$ 4,735.4
- Materials	$ 1,366.7	$ 1,368.5	$ 1,505.2	$ 1,651.1	$ 1,815.4	$ 1,917.4	$ 1,978.3	$ 2,046.1	$ 2,114.1	$ 2,170.8	$ 2,249.3
- Labor	$ 385.4	$ 385.7	$ 423.9	$ 464.7	$ 500.0	$ 526.9	$ 543.0	$ 561.1	$ 579.4	$ 594.7	$ 615.9
- Depreciation	$ 123.2	$ 123.3	$ 135.6	$ 148.8	$ 163.2	$ 172.7	$ 178.4	$ 184.7	$ 190.9	$ 196.1	$ 203.3
- Development Amortization	$ 23.6	$ 23.6	$ 25.9	$ 28.4	$ 37.0	$ 46.5	$ 52.1	$ 56.8	$ 61.0	$ 64.6	$ 68.6
- Overhead	$ 184.7	$ 184.9	$ 203.3	$ 223.0	$ 243.6	$ 256.7	$ 264.5	$ 273.3	$ 282.3	$ 289.7	$ 300.0
- Standard SG&A	$ 440.0	$ 440.5	$ 484.4	$ 531.3	$ 570.2	$ 603.5	$ 623.4	$ 645.2	$ 667.0	$ 685.3	$ 710.3
- R&D	$ 140.8	$ 141.0	$ 155.0	$ 170.0	$ 182.5	$ 193.1	$ 199.5	$ 206.5	$ 213.5	$ 219.3	$ 227.3
- Product Conversion Costs	$ -	$ 11.2	$ 19.7	$ 25.3	$ 1.1	$ -	$ -	$ -	$ -	$ -	$ -
- Stranded Assets	$ -	$ -	$ -	$ -	$ 2.1	$ -	$ -	$ -	$ -	$ -	$ -
Earnings Before Interest and Taxes (EBIT)	$ 268.9	$ 258.0	$ 276.4	$ 299.5	$ 286.2	$ 306.4	$ 316.5	$ 327.6	$ 338.7	$ 347.9	$ 360.7
EBIT/Revenues	*9.2%*	*8.8%*	*8.6%*	*8.5%*	*7.5%*	*7.6%*	*7.6%*	*7.6%*	*7.6%*	*7.6%*	*7.6%*
- Taxes	$ 89.5	$ 85.9	$ 92.1	$ 99.7	$ 95.3	$ 102.0	$ 105.4	$ 109.1	$ 112.8	$ 115.9	$ 120.1
Net Operating Profit after Taxes (NOPAT)	**$ 179.4**	**$ 172.1**	**$ 184.4**	**$ 199.8**	**$ 190.9**	**$ 204.4**	**$ 211.1**	**$ 218.5**	**$ 225.9**	**$ 232.1**	**$ 240.6**
Cash Flow Statement											
NOPAT	$ 179.4	$ 172.1	$ 184.4	$ 199.8	$ 190.9	$ 204.4	$ 211.1	$ 218.5	$ 225.9	$ 232.1	$ 240.6
+ Depreciation	$ 123.2	$ 123.3	$ 135.6	$ 148.8	$ 163.2	$ 172.7	$ 178.4	$ 184.7	$ 190.9	$ 196.1	$ 203.3
+ Development Amortization	$ 23.6	$ 23.6	$ 25.9	$ 28.4	$ 37.0	$ 46.5	$ 52.1	$ 56.8	$ 61.0	$ 64.6	$ 68.6
+ Loss on Disposal of Stranded Assets	$ -	$ -	$ -	$ -	$ 2.1	$ -	$ -	$ -	$ -	$ -	$ -
- Change in Working Capital	$ -	$ 0.5	$ 46.9	$ 50.0	$ 41.5	$ 35.5	$ 21.2	$ 23.3	$ 23.3	$ 19.4	$ 26.7
Cash Flows from Operations	$ 326.2	$ 318.5	$ 299.1	$ 326.9	$ 351.8	$ 388.1	$ 420.4	$ 436.7	$ 454.5	$ 473.3	$ 485.7
- Ordinary Capital Expenditures	$ 140.8	$ 141.0	$ 155.0	$ 170.0	$ 182.5	$ 193.1	$ 199.5	$ 206.5	$ 213.5	$ 219.3	$ 227.3
- Capital Conversion Costs	$ -	$ 5.3	$ 9.2	$ 11.9	$ -	$ -	$ -	$ -	$ -	$ -	$ -
- Production Equipment Maintenance	$ 5.9	$ 5.9	$ 6.5	$ 7.1	$ 9.3	$ 11.6	$ 13.0	$ 14.2	$ 15.3	$ 16.1	$ 17.1
Free Cash Flow	**$ 179.5**	**$ 166.3**	**$ 128.4**	**$ 138.0**	**$ 160.0**	**$ 183.4**	**$ 207.9**	**$ 216.0**	**$ 225.8**	**$ 237.9**	**$ 241.3**
Discounted Cash Flow											
Free Cash Flow	$ 179.5	$ 166.3	$ 128.4	$ 138.0	$ 160.0	$ 183.4	$ 207.9	$ 216.0	$ 225.8	$ 237.9	$ 241.3
Terminal Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Present Value Factor	*0.000*	*1.000*	*0.917*	*0.840*	*0.770*	*0.706*	*0.647*	*0.593*	*0.544*	*0.498*	*0.457*
Discounted Cash Flow	**$ -**	**$ 166.3**	**$ 117.7**	**$ 115.9**	**$ 123.2**	**$ 129.4**	**$ 134.5**	**$ 128.1**	**$ 122.7**	**$ 118.5**	**$ 110.2**

INPV at TSL 2 $ 3,189.6

APPENDIX 14-A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14-A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866[a]

14-A.1 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

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[a] Prepared by Interagency Working Group on Social Cost of Carbon, United States Government.
With participation by:
Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Table 14-A.1.1 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

	Discount Rate			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

14-A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. We report estimates of the SCC in dollars per metric ton of carbon dioxide throughout this document.[b]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

[b] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See section 16-A.5 for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

14-A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of \$2 per ton of CO_2 and a "global" SCC value of \$33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at \$80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of \$7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of \$0-\$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of \$0 to \$20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were \$68 and \$40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO_2. The \$33 and \$5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The \$55 and \$10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The \$19 value was chosen as a central value between the \$5 and \$33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

14-A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, the interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable, since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

14-A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[c] These models are frequently cited in the peer-

[c] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socioeconomic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socioeconomic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[d]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on

[d] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

the absolute temperature change but also on the rate of temperature change and level of regional income.[e] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns": for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figures 16A.4.1 and 16A.4.2, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 16A.4.2) and higher (figure 16A.4.1) increases in global-average temperature.

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[e] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

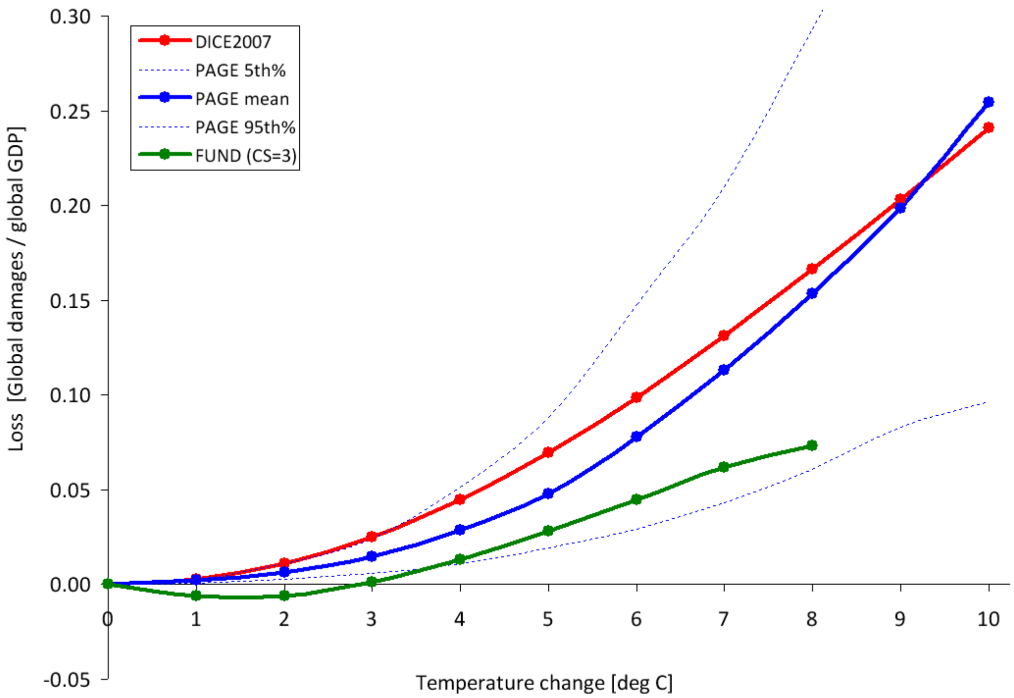

Figure 14-A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models[f]

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is

[f] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socioeconomic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

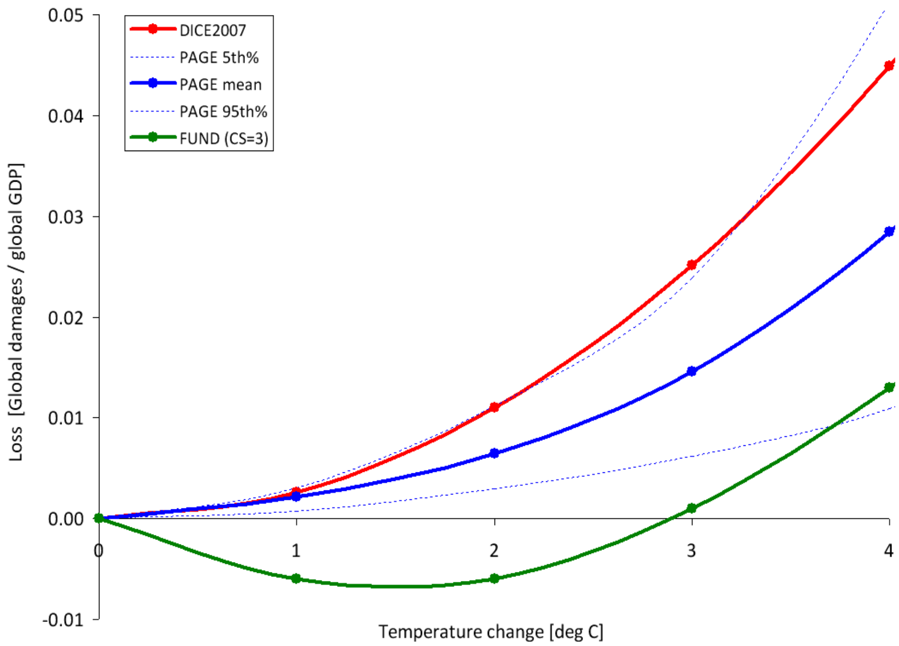

Figure 14-A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

14-A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[g]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the

[g] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[h] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[i]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are

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[h] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

[i] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

14-A.4.3 Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

14-A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[j] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

[j] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C. [k]

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 14-A.4.1 included below gives summary statistics for the four calibrated distributions.

Table 14-A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

[k] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[1]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007, Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

[1] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

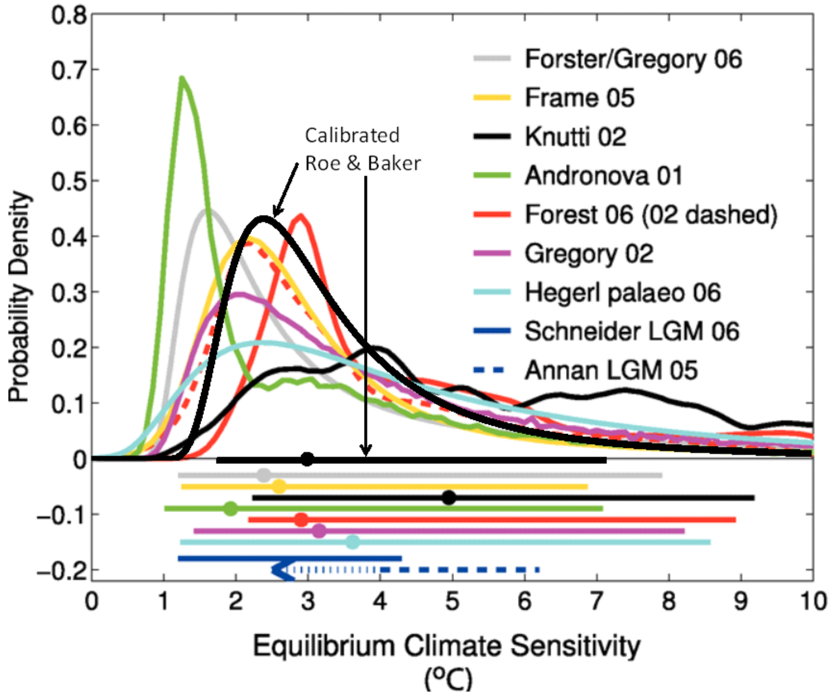

Figure 14-A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 16A.4.3 (above) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[m]

14-A.4.5 Socioeconomic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socioeconomic and emissions parameters for use in PAGE, DICE, and FUND. Socioeconomic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

[m] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socioeconomic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 14-A.4.2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.e., CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[n] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

[n] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 14-A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[o]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways.

[o] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).[p] Second, the socioeconomic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[q] We chose not to include socioeconomic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be \$51.8, \$71.0 and \$93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Annex for greater detail.

14-A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated

[p] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[q] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent." For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled "descriptive" and "prescriptive." The descriptive approach reflects a positive (non-normative) perspective based on observations of people's actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return "because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use" (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word "potentially" is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is "ethically indefensible" to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high-cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[r] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[s] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity

[r] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[s] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes, which yields a real rate of roughly 5 percent.[t]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[u] These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[v] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[w] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

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[t] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[u] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[v] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

[w] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an intergenerational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socioeconomic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed a η ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[x]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate of greater than 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the

[x] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and the variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.[y] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[z]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously

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[y] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[z] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[aa] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

14-A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population, and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMs, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

[aa] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t*. (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10-year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Annex.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no IAM or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Annex.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high-temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 14-A.5.1, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 14-A.5.1 Disaggregated Social Cost of CO_2 Values by Model, Socioeconomic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around $9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around $9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to $8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[bb]

[bb] Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 16A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

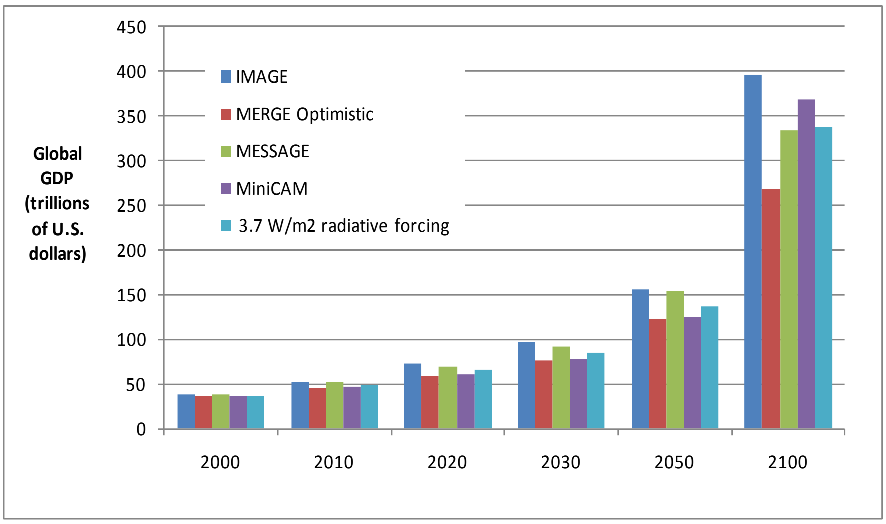

Figure 14-A.5.1 Level of Global GDP across EMF Scenarios

Table 14-A.5.2 shows the four selected SCC values in five-year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

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endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

Table 14-A.5.2 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 14-A.5.3 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14-A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[cc]

14-A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold "are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-

[cc] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

impact, low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[dd] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs understate or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability, but lower-impact, damages with the same expected cost. (The inclusion of the 95^{th} percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

[dd] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

14-A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 14-A.7.1. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 16A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socioeconomic and emission trajectories of $113 per ton of CO_2 is almost double the value estimated by DICE, $58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 14-A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

14-A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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14-A.9 ANNEX

Table 14-A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Annex provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300 and shows the full distribution of 2010 SCC estimates by model and scenario combination.

14-A.9.1 Other (non-CO2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[ee] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[ff], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was $0.48 + 0.16 + 0.34 = 0.98$ W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be

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[ee] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial, and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[ff] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter; and
(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulfur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.[gg]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, the figure below shows that the sulfur dioxide emissions peak over the short term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[hh] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[ii] The lower-bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

[gg] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[hh] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[ii] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

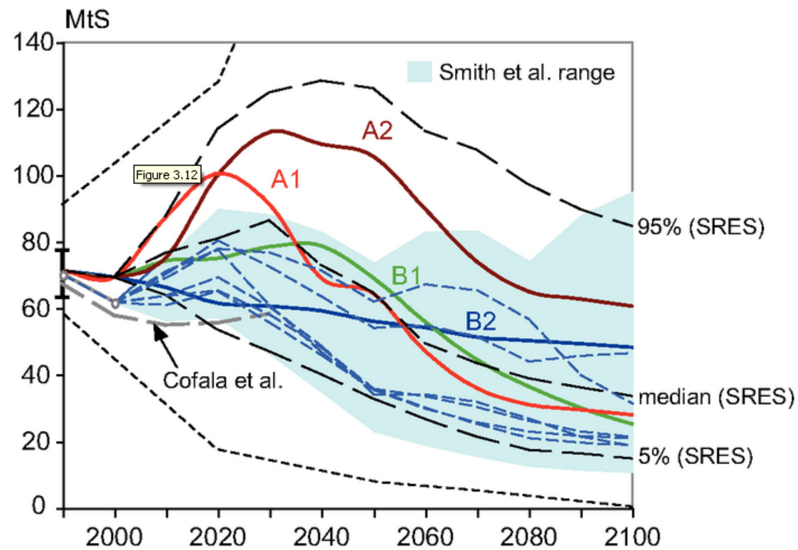

Figure 14-A.9.2 Sulfur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th, and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

14-A.9.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[jj] The resulting range of EMF population trajectories (figure below) also encompass the UN medium scenario forecasts through 2300—global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

[jj] United Nations. 2004. *World Population to 2300*. http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf

Figures below show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

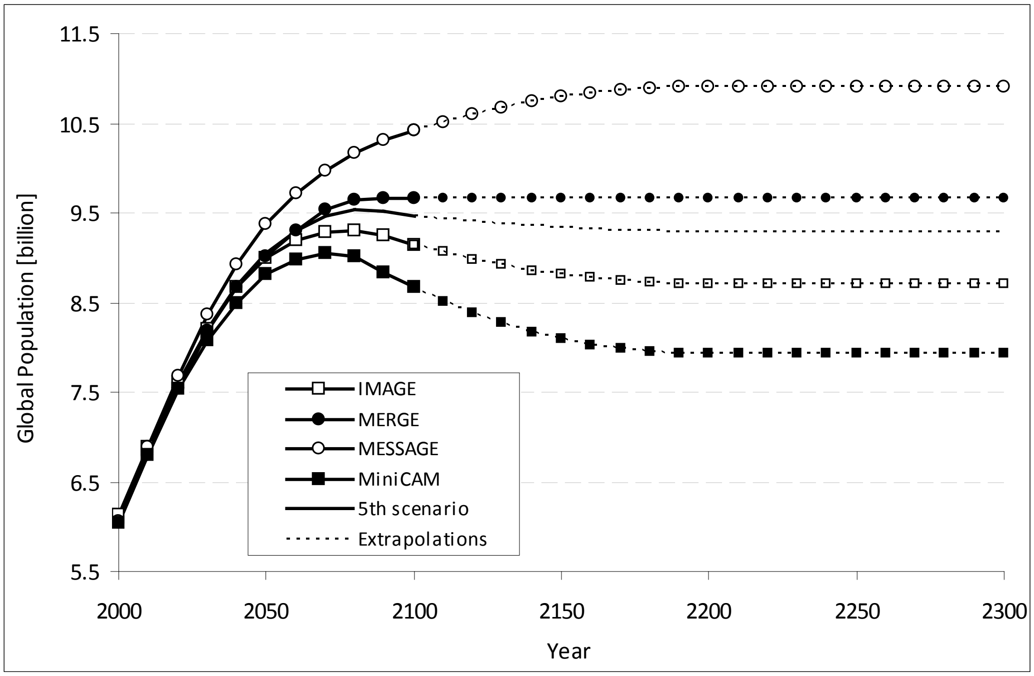

Figure 14-A.9.3 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

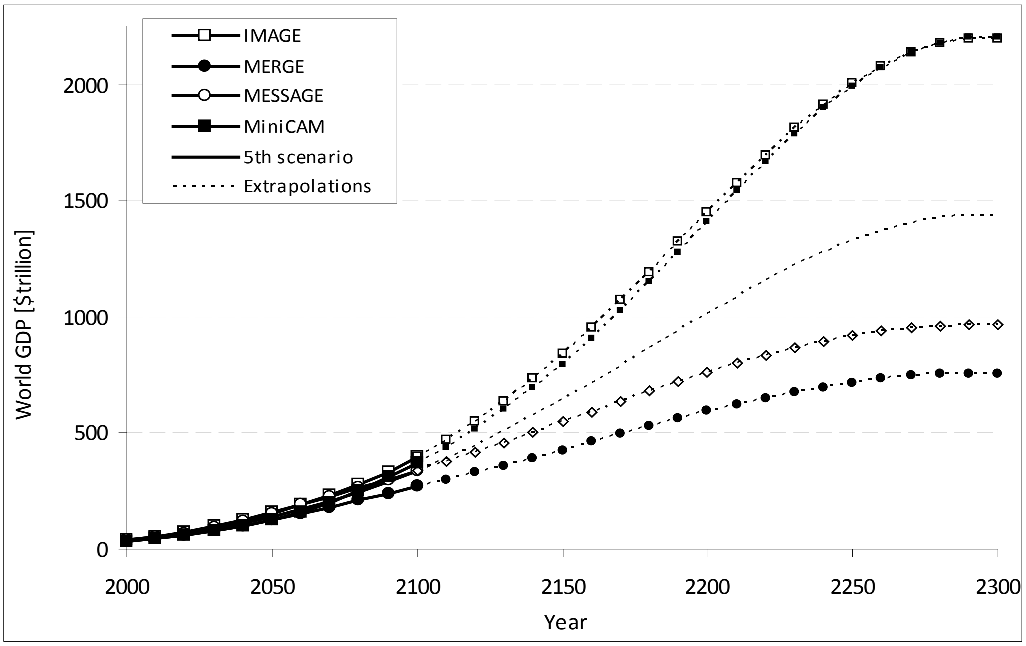

Figure 14-A.9.4 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)

Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

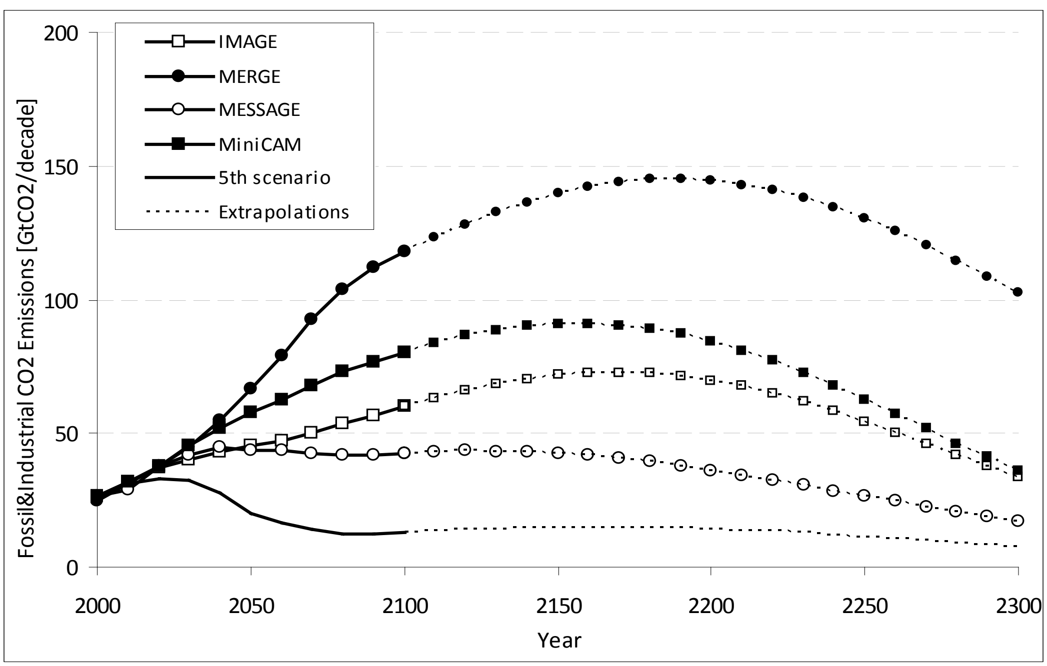

Figure 14-A.9.5 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

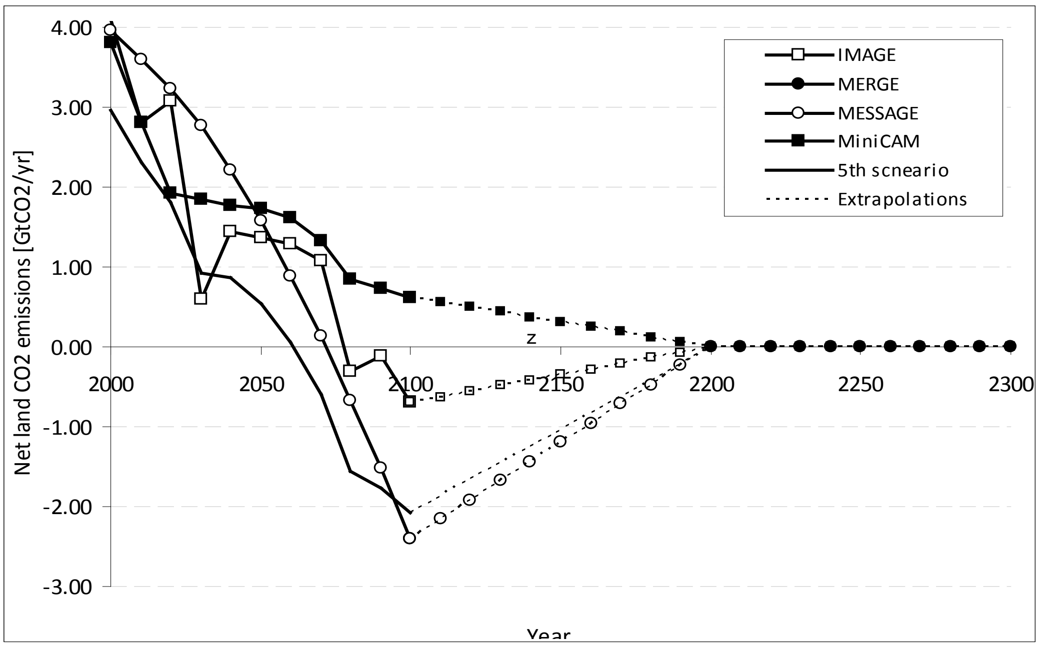

Figure 14-A.9.6 Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[kk]

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

[kk] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

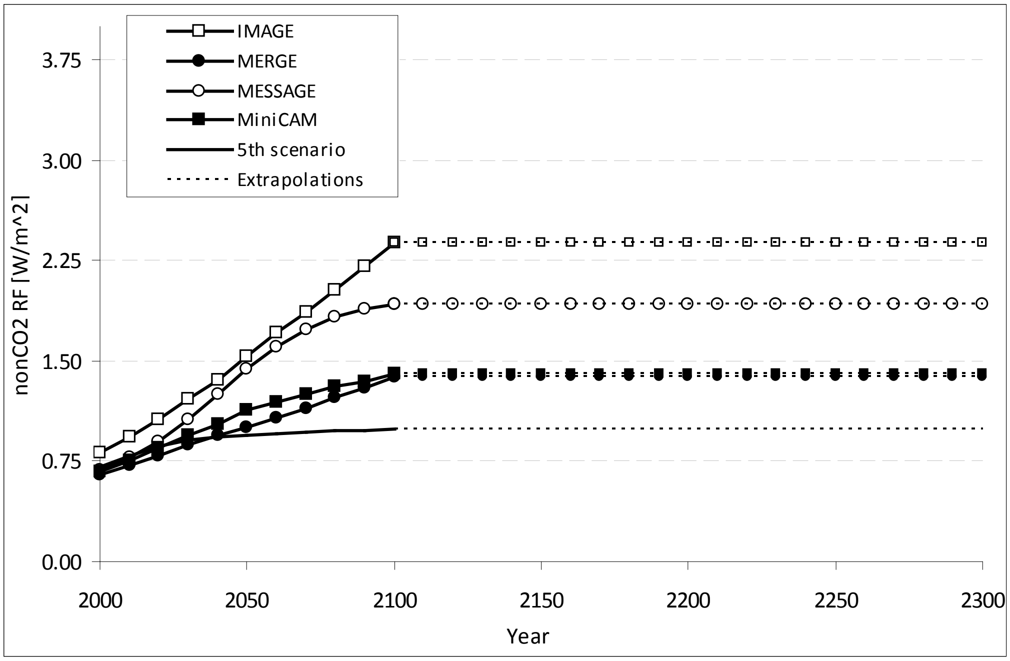

Figure 14-A.9.7 Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

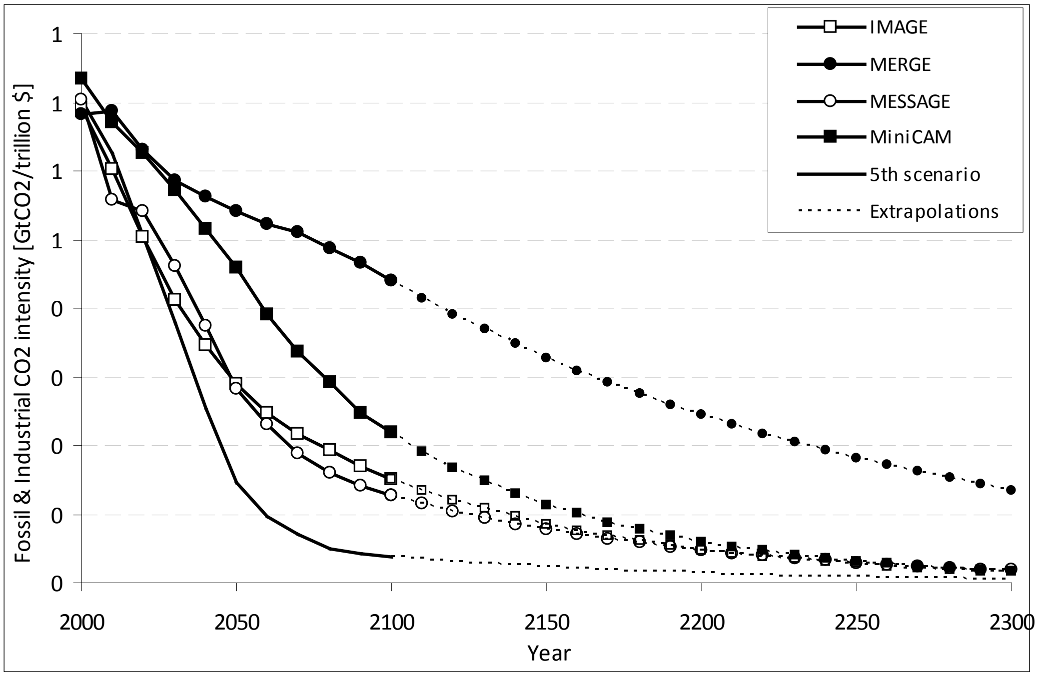

Figure 14-A.9.8 Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 14-A.9.2 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9

Scenario	**DICE**									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8

Scenario	**FUND**									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 14-A.9.3 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5
Scenario	**DICE**									
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6
Scenario	**FUND**									
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 14-A.9.4 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7
Scenario	**DICE**									
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0
Scenario	**FUND**									
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

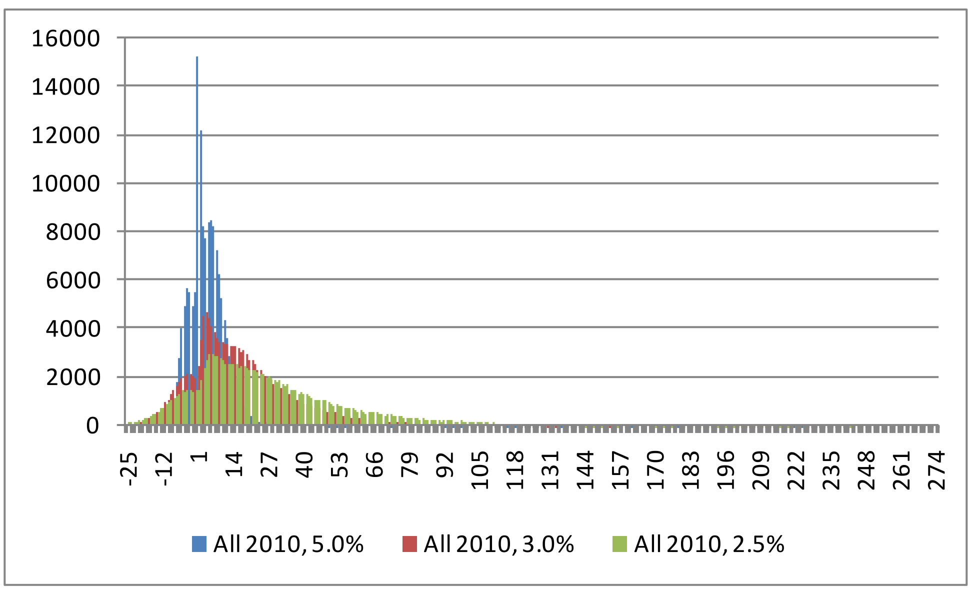

Figure 14-A.9.9 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate

* The distribution of SCC values ranges from -$5,192 to $66,116, but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 14-A.9.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate		Scenario		
		DICE	PAGE	FUND
5%	Mean	9	6.5	-1.3
	Variance	13.1	136	70.1
	Skewness	0.8	6.3	28.2
	Kurtosis	0.2	72.4	1,479.00
3%	Mean	28.3	29.8	6
	Variance	209.8	3,383.70	16,382.50
	Skewness	1.1	8.6	128
	Kurtosis	0.9	151	18,976.50
2.50%	Mean	42.2	49.3	13.6
	Variance	534.9	9,546.00	#######
	Skewness	1.2	8.7	149
	Kurtosis	1.1	143.8	23,558.30

APPENDIX 14-B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14-B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

14-B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report (revised November 2013) of the Interagency Working Group on the Social Cost of Carbon of the United States Government.[a] Minor changes were made to the working group's report to make it more consistent with the rest of this technical support document. Annex B describes the revisions that were made to the May 2013 report.

14-B.2 PURPOSE

The purpose of this document is to update the schedule of social cost of carbon (SCC)[b] estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).[1] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[c] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[d] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The Environmental Protection Agency (EPA), in collaboration with other Federal agencies such as the Department of Energy (DOE), continues to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

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[a] Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. Interagency Working Group on Social Cost of Carbon, United States Government. May 2013; revised November 2013. http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

[b] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67.

[c] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

[d] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).[1]

Section 3 summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section 4 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models. Section 5 provides a discussion of recent workshops to support improvements in SCC estimation.

14-B.3 SUMMARY OF MODEL UPDATES

This section briefly summarizes changes integrated into the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. In the most recent version of DICE, the model's simple carbon cycle has been updated to be more consistent with a relatively more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding climate sensitivity, discounting, and socioeconomic variables – are not discussed.

14-B.3.1 DICE

Changes in the DICE model relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008)[2] and on DICE2010 in Nordhaus (2010)[3] and the associated on-line appendix containing supplemental information.

14-B.3.1.1 Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the

Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008 p 44).[2e] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).[3] For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007, for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SCC estimates in DICE2010 relative to those from DICE2007.

14-B.3.1.2 Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[f] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report.[4] [g] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 ^{o}C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and

[e] MAGICC is a simple climate model initially developed within the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from much more sophisticated state of the art earth system simulation models (Randall et al. 2007).[4]
[f] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.
[g] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

14-B.3.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),[3] who notes that "…damages in the uncontrolled (baseline) [i.e., reference] case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 ^{o}C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 ^{o}C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly, all else equal.

14-B.3.2 FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 used in the interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.[h] Notable changes, due to their impact

[h] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013).[7] For the purpose of computing the SCC, the relevant changes are associated with improving consistency with IPCC AR4 by

on the estimates of expected SCC, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[i] We discuss each of these in turn.

14-B.3.2.1 Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave, meaning that for every simulation there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit as the temperature anomaly increases, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

14-B.3.2.2 Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a non-linear function of sea level rise, thereby assuming that the slope of the shore line is not constant moving inland, with a positive first derivative. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, therefore having an effect of lowering the expected SCC estimate. The model has also been updated to assume that the value of dry land at risk of inundation is not uniform across a region but will be a decreasing function of protection measure, thereby implicitly assuming that the most valuable land will be protected first.

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adjusting the atmospheric lifetimes of CH4 and N2O and incorporating the indirect forcing effects of CH4, along with making minor stability improvements in the sea wall construction algorithm.

[i] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not the subject of significant updates.

14-B.3.2.3 Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is made up of three additively separable components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the linear and quadratic coefficients are modeled as the ratio of two normal distributions. Within this specification, as draws from the distribution in the denominator approached zero the share of the sector's value "lost" approaches (+/-) infinity independent of the temperature anomaly itself. In FUND 3.8, the linear and quadratic coefficients are drawn directly from truncated normal distributions so that they remain in the range [0,¥) and (-¥,0], respectively, where the means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to increase the likelihood that increases in the temperature level will have either larger positive or negative effects on the agricultural sector relative to the previous version (through eliminating simulations in which the "lost" value approached (+/-) infinity). The net effect of this change on the SCC estimates is difficult to predict.

14-B.3.2.4 Temperature Response Model

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the cumulative temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

14-B.3.2.5 Methane

The IPCC notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007).[8] FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of CH_4 emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increase by 40% to account for its net impact on ozone production and increase in stratospheric water vapor. The general effect of this increased radiative forcing will be to increase the estimated SCC values, where the degree to which this occurs will be dependent upon the relative curvature of the damage functions with respect to the temperature anomaly.

14-B.3.3 PAGE

PAGE09 (Hope 2012)[9] includes a number of changes from PAGE2002, the version used in the 2009 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures. More details on PAGE2009 can be found in three working papers (Hope 2011a, 2011b, 2011c).[10, 11, 12] A description of PAGE2002 can be found in Hope (2006).[13]

14-B.3.3.1 Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts - PAGE2009 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. PAGE09 models damages from sea level rise as increasing less than linearly with sea level based on the assumption that low-lying shoreline areas will be associated with higher damages than current inland areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

14-B.3.3.2 Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience positive economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

14-B.3.3.3 Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region's coastline relative to the EU (Hope 2011b).[11] Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developing countries, and higher damages in developing countries.

14-B.3.3.4 Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" were modeled as an expected value. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of "discontinuity" is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

14-B.3.3.5 Adaptation

As in PAGE2002, adaptation is available to increase the tolerable level of temperature change and can help mitigate any climate change impacts that still occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by modifying the temperature change and sea level rise used in the damage function or by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 3°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 3°C by 50-90 percent after 20 years. Beyond 3°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c)[12] estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

14-B.3.3.6 Other Noteworthy Changes

Two other changes in the model are worth noting. A revised carbon cycle feedback is introduced to simulate decreased CO_2 absorption by the terrestrial biosphere and ocean as the temperature rises. This feedback is linear in the average global and annual temperature anomaly but is capped at a maximum value. In the previous version of PAGE, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In the previous version of PAGE, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass.

14-B.4 REVISED SCC ESTIMATES

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD.[1] The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the Fourth Assessment Report of the IPCC, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the SCC. The approach laid out in the TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination is available in the Annex.) As noted in the original TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (TSD, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

Table 14-B.4.1 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all

outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using basic linear interpolation. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14-B.4.1 Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	32	51	89
2015	11	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

The SCC estimates using the updated versions of the models are higher than those reported in the TSD due to the changes to the models outlined in the previous section. Figure 14-B.4.2 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

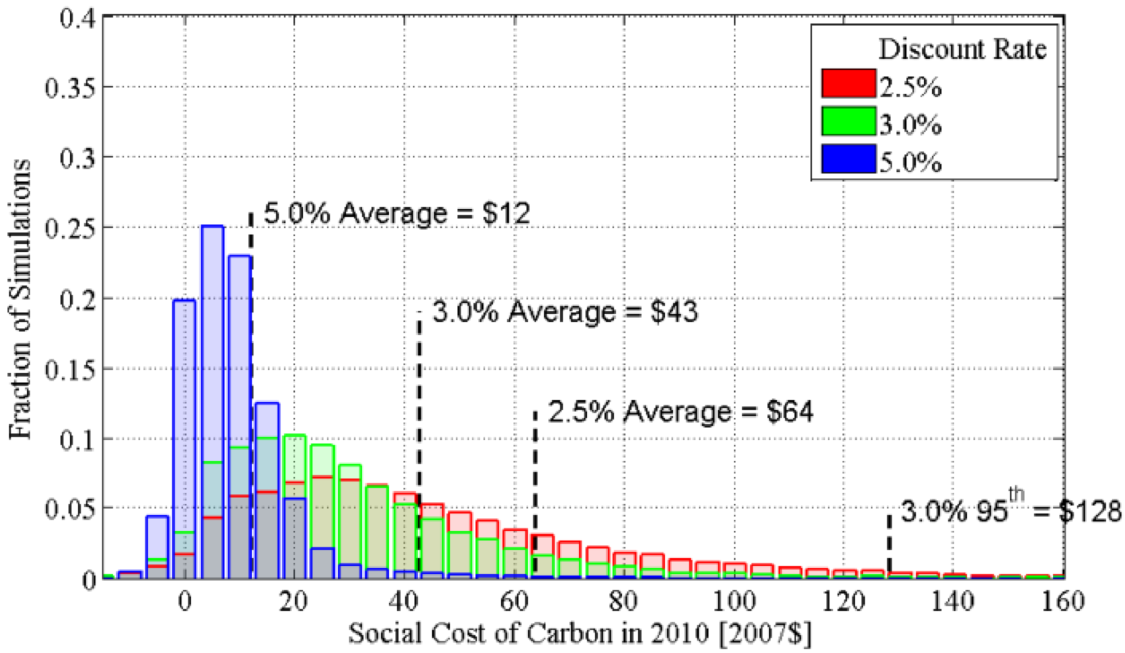

Figure 14-B.4.2 Distribution of SCC Estimates for 2020 (in 2007$ per ton CO_2)

As was the case in the original TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to allow the growth rate to be determined endogenously by the models through running them for a set of perturbation years out to 2050. Table 14-B.4.2 illustrates how the growth rate for these four SCC estimates varies over time.

Table 14-B.4.2 Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.3%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.4%
2030-2040	3.0%	1.9%	1.5%	2.1%
2040-2050	2.6%	1.6%	1.3%	1.5%

The future monetized value of emission reductions in each year (the SCC in year t multiplied by the change in emissions in year t) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the original TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

14-B.5 OTHER MODEL LIMITATIONS OR RESEARCH GAPS

The 2010 interagency SCC technical support report discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. It also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in long-term research work on modeling and valuation of climate impacts that we expect will inform improvements in SCC estimation in the future.

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ANNEX A

Table A1. Annual SCC Values: 2010-2050 (2007$/ton CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	32	51	89
2011	11	33	52	93
2012	11	34	54	97
2013	11	35	55	101
2014	11	36	56	105
2015	11	37	57	109
2016	12	38	59	112
2017	12	39	60	116
2018	12	40	61	120
2019	12	42	62	124
2020	12	43	64	128
2021	12	43	65	131
2022	13	44	66	134
2023	13	45	67	137
2024	14	46	68	140
2025	14	47	69	143
2026	15	48	70	146
2027	15	49	71	149
2028	15	50	72	152
2029	16	51	73	155
2030	16	52	75	159
2031	17	52	76	162
2032	17	53	77	165
2033	18	54	78	168
2034	18	55	79	172
2035	19	56	80	175
2036	19	57	81	178
2037	20	58	83	181
2038	20	59	84	185
2039	21	60	85	188
2040	21	61	86	191
2041	22	62	87	194
2042	22	63	88	197
2043	23	64	89	200
2044	23	65	90	203
2045	24	66	92	206
2046	24	67	93	209
2047	25	68	94	211
2048	25	69	95	214
2049	26	70	96	217
2050	26	71	97	220

Table A2. 2020 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	6	11	15	27	58	129	139	327	515	991
MERGE	4	6	9	16	34	78	82	196	317	649
MESSAGE	4	8	11	20	42	108	107	278	483	918
MiniCAM Base	5	9	12	22	47	107	113	266	431	872
5th Scenario	2	4	6	11	25	85	68	200	387	955

Scenario	DICE									
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126

Scenario	FUND									
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table A3. 2020 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	4	7	10	18	38	91	95	238	385	727
MERGE	2	4	6	11	23	56	58	142	232	481
MESSAGE	3	5	7	13	29	75	74	197	330	641
MiniCAM Base	3	5	8	14	30	73	75	184	300	623
5th Scenario	1	3	4	7	17	58	48	136	264	660

Scenario	DICE									
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79

Scenario	FUND									
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

Table A4. 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	5	10	28	27	71	123	244
MERGE	1	1	2	3	7	17	17	45	75	153
MESSAGE	1	1	2	4	9	24	22	60	106	216
MiniCAM Base	1	1	2	3	8	21	21	54	94	190
5th Scenario	0	1	1	2	5	18	14	41	78	208
Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario	FUND									
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

ANNEX B

The November 2013 revision of this technical support document is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013) published in the same journal (*Climatic Change*) in October 2013.[14] Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The differences between the original estimates reported in the May 2013 version of this technical support document and this revision are all one dollar or less.

APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

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APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

17-A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- Projections of annual market share increases for the alternative policies;
- NIA-RIA Integrated Model;
- XENERGY penetration curves used to analyze consumer rebates, including:
    - Background material,
    - DOE's adjustment of these curves for this analysis, and
    - Method for interpolating the curves;
- Detailed tables of rebates offered for the considered products; and
- Background material on Federal and state tax credits for appliances.

17-A.2 MARKET SHARE ANNUAL INCREASES BY POLICY

Table 17-A.2.1 to 17-A.2.13 show the annual increases in market shares of NEMA Premium motors, by horsepower range and sector, for the alternative policies analyzed in this RIA. DOE used these market share increases to calculate the market penetration of NEMA Premium motors in each of the analyzed alternative policies. The market penetrations of the alternative policies are ultimately the inputs DOE use to the NIA-RIA spreadsheet model.

Table 17-A.2.1 Annual Increases in Market Share of NEMA Premium Motors in Industry Attributable to Consumer Rebates

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2017	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2018	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2019	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2020	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2021	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2022	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2023	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2024	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2025	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2026	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2027	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2028	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2029	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2030	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2031	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2032	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2033	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2034	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2035	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2036	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2037	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2038	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2039	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2040	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2041	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2042	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2043	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2044	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%
2045	31.0%	17.7%	8.6%	8.6%	11.5%	17.4%

Table 17-A.2.2 Annual Increases in Market Share of NEMA Premium Motors in Industry Attributable to Consumer Tax Credits

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2017	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2018	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2019	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2020	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2021	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2022	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2023	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2024	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2025	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2026	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2027	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2028	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2029	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2030	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2031	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2032	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2033	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2034	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2035	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2036	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2037	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2038	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2039	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2040	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2041	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2042	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2043	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2044	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%
2045	18.6%	23.7%	17.0%	18.8%	25.1%	29.3%

Table 17-A.2.3 Annual Increases in Market Share of NEMA Premium Motors in Industry Attributable to Manufacturer Tax Credits

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2017	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2018	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2019	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2020	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2021	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2022	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2023	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2024	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2025	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2026	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2027	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2028	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2029	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2030	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2031	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2032	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2033	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2034	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2035	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2036	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2037	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2038	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2039	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2040	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2041	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2042	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2043	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2044	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%
2045	9.3%	11.8%	8.5%	9.4%	12.6%	14.6%

Table 17-A.2.4 Annual Increases in Market Share of NEMA Premium Motors in Industry Attributable to Early Replacement

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	1.2%	0.0%	8.8%	4.6%	15.0%	1.6%
2017	0.7%	0.0%	6.1%	2.8%	11.0%	0.6%
2018	0.4%	0.0%	4.0%	1.6%	6.8%	0.0%
2019	0.1%	0.0%	2.2%	0.7%	1.4%	0.0%
2020	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
2021	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2022	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2023	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2024	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2025	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2026	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2027	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2028	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2029	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2030	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2031	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2032	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2033	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2034	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2035	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2036	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2037	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2038	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2039	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2041	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2042	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2043	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2044	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2045	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 17-A.2.5 Annual Increases in Market Share of NEMA Premium Motors in Commercial Sector Attributable to Consumer Rebates

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2017	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2018	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2019	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2020	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2021	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2022	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2023	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2024	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2025	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2026	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2027	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2028	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2029	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2030	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2031	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2032	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2033	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2034	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2035	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2036	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2037	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2038	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2039	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2040	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2041	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2042	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2043	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2044	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%
2045	34.6%	17.6%	10.2%	10.6%	11.6%	19.7%

Table 17-A.2.6 Annual Increases in Market Share of NEMA Premium Motors in Commercial Sector Attributable to Consumer Tax Credits

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2017	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2018	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2019	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2020	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2021	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2022	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2023	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2024	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2025	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2026	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2027	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2028	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2029	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2030	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2031	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2032	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2033	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2034	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2035	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2036	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2037	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2038	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2039	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2040	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2041	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2042	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2043	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2044	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%
2045	20.7%	23.7%	18.2%	19.7%	25.9%	31.3%

Table 17-A.2.7 Annual Increases in Market Share of NEMA Premium Motors in Commercial Sector Attributable to Manufacturer Tax Credits

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2017	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2018	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2019	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2020	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2021	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2022	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2023	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2024	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2025	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2026	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2027	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2028	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2029	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2030	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2031	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2032	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2033	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2034	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2035	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2036	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2037	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2038	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2039	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2040	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2041	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2042	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2043	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2044	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%
2045	10.4%	11.9%	9.1%	9.9%	12.9%	15.6%

Table 17-A.2.8 Annual Increases in Market Share of NEMA Premium Motors in Commercial Sector Attributable to Early Replacement

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
2017	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
2018	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2019	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2020	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2021	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2022	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2023	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2024	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2025	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2026	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2027	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2028	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2029	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2030	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2031	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2032	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2033	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2034	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2035	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2036	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2037	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2038	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2039	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2041	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2042	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2043	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2044	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2045	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 17-A.2.9 Annual Increases in Market Share of NEMA Premium Motors in Commercial Sector Attributable to Bulk Government Purchases

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	0.9%	1.1%	0.8%	0.8%	1.1%	1.2%
2017	1.7%	2.0%	1.4%	1.5%	2.1%	2.3%
2018	2.6%	2.9%	2.1%	2.2%	3.1%	3.4%
2019	3.4%	3.9%	2.8%	3.0%	4.1%	4.5%
2020	4.2%	4.8%	3.4%	3.7%	5.1%	5.6%
2021	5.1%	5.8%	4.1%	4.4%	6.1%	6.7%
2022	5.9%	6.8%	4.8%	5.2%	7.1%	7.8%
2023	6.8%	7.7%	5.5%	5.9%	8.1%	9.0%
2024	7.6%	8.7%	6.2%	6.6%	9.2%	10.1%
2025	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2026	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2027	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2028	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2029	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2030	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2031	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2032	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2033	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2034	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2035	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2036	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2037	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2038	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2039	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2040	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2041	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2042	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2043	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2044	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%
2045	8.5%	9.7%	6.9%	7.4%	10.2%	11.2%

Table 17-A.2.10 Annual Increases in Market Share of NEMA Premium Motors in Agriculture Attributable to Consumer Rebates

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2017	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2018	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2019	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2020	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2021	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2022	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2023	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2024	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2025	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2026	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2027	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2028	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2029	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2030	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2031	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2032	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2033	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2034	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2035	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2036	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2037	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2038	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2039	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2040	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2041	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2042	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2043	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2044	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%
2045	21.3%	12.4%	13.0%	14.1%	14.1%	30.1%

Table 17-A.2.11 Annual Increases in Market Share of NEMA Premium Motors in Agriculture Attributable to Consumer Tax Credits

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2017	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2018	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2019	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2020	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2021	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2022	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2023	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2024	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2025	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2026	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2027	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2028	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2029	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2030	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2031	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2032	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2033	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2034	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2035	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2036	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2037	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2038	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2039	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2040	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2041	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2042	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2043	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2044	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%
2045	11.1%	28.4%	26.9%	31.5%	34.4%	45.7%

Table 17-A.2.12 Annual Increases in Market Share of NEMA Premium Motors in Agriculture Attributable to Manufacturer Tax Credits

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2017	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2018	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2019	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2020	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2021	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2022	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2023	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2024	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2025	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2026	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2027	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2028	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2029	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2030	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2031	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2032	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2033	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2034	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2035	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2036	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2037	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2038	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2039	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2040	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2041	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2042	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2043	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2044	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%
2045	5.5%	14.2%	13.4%	15.7%	17.2%	22.9%

Table 17-A.2.13 Annual Increases in Market Share of NEMA Premium Motors in Agriculture Attributable to Early Replacement

Year	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
2016	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2017	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2018	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2019	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2020	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2021	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2022	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2023	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2024	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2025	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2026	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2027	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2028	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2029	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2030	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2031	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2032	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2033	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2034	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2035	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2036	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2037	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2038	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2039	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2041	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2042	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2043	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2044	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2045	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

17-A.3 NIA-RIA INTEGRATED MODEL

For this analysis, DOE used its integrated NIA-RIA[a] model approach that built on the NIA model discussed in Chapter 10 and documented in Appendix 10-A.The resulting integrated NIA-RIA model featured both the NIA analysis inputs and results and the RIA inputs and had the capability to generate results for each of the RIA policies. For the RIA methodology documentation in Chapter 17, Section 17.3, the model created summaries of parameters calculated by the model for the consumer rebates and tax credit policies, generated their penetration curves (discussed in Section 17-A.4.3 below) and reported market share impacts for these policies by sector and horsepower range. For the RIA results reported in Chapter 17, Section 17.4, the model produced graphs of the market share increases by sector resulting from each of the policies analyzed and created summary tables for the national energy savings and net present value results. The model also generated tables of market share increases for each policy reported in Section 17-A.2 of this Appendix.

17-A.4 CONSUMER REBATE POLICY MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates, as well as the Consumer Tax Credits and Manufacturer Tax Credits policies. Next it discusses the adjustments it made to the maximum penetration rates. The adjusted penetration curves set the framework for the development of interpolated market penetration curves. For the method DOE used to develop interpolated market penetration curves please refer to Blum *et al* (2011, Appendix A).[25] The resulting interpolated market penetration curves for NEMA Premium motors by sector and horsepower range are presented in Chapter 17, Section 17.3.1.2.

17-A.4.1 Introduction

XENERGY, Inc.[b], developed a re-parameterized, mixed-source information diffusion model to estimate market impacts induced by financial incentives for purchasing energy efficient appliances.[1] The basic premise of the mixed-source model is that information diffusion drives the adoption of technology.

Extensive economic literature describes the diffusion of new products as technologies evolve. Some research focuses primarily on developing analytical models of diffusion patterns applicable to individual consumers or to technologies from competing firms.[2, 3, 4] One study records researchers' attempts to investigate the factors that drive diffusion processes.[5] Because a new product generally has its own distinct characteristics, few studies have been able conclusively to conclusively develop a universally applicable model. Some key findings, however, generally are accepted in academia and industry.

[a] NIA = national impact analysis; RIA = regulatory impact analysis
[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

One accepted finding is that, regardless of their economic benefits and technological merits, new technologies are unlikely to be adopted by all potential users. For many products, a ceiling must be placed on the adoption rate. A second conclusion is that not all adopters purchase new products at the same time: some act quickly after a new product is introduced; others wait for the product to mature. Third, diffusion processes can be characterized approximately by asymmetric S-curves that depict three stages of diffusion: starting, accelerating, and decreasing (as the adoption ceiling is approached).

A so-called epidemic model of diffusion is used widely in marketing and social studies. The epidemic model assumes that (1) all consumers place identical value on the benefits of a new product, and (2) the cost of a new product is constant or declines monotonically over time. What induces a consumer to purchase a new product is information about the availability and benefits of the product. In other words, information diffusion drives consumers' adoption of a new product.[3] The model incorporates information diffusion from both internal sources (spread by word of mouth from early adopters to prospective adopters) and external sources (the "announcement effect" produced by government agencies, institutions, or commercial advertising). The model incorporates both internal and external sources by combining a logistic function with an exponential function.[4,5]

The relative degree of influence from the internal and external sources determines the general shape of the diffusion curve for a specific product.[4,5] If adoption of a product is influenced primarily by external sources of information (the announcement effect), for instance, a high rate of diffusion occurs at the beginning of the process. In this scenario, external sources provide immediate information exposure to a significant number of prospective adopters. In contrast, internal sources (such as a network of prospective adopters) are relatively small in size and reach, producing a more gradual exposure to prospective adopters. Graphically speaking, information diffusion dominated by external sources is represented by a concave curve (the exponential curve in Figure 17-A.4.1). If adoption of a new product is influenced most strongly by internal sources of information, the number of adopters increases gradually, forming a convex curve (the logistic curve in Figure 17-A.4.1).

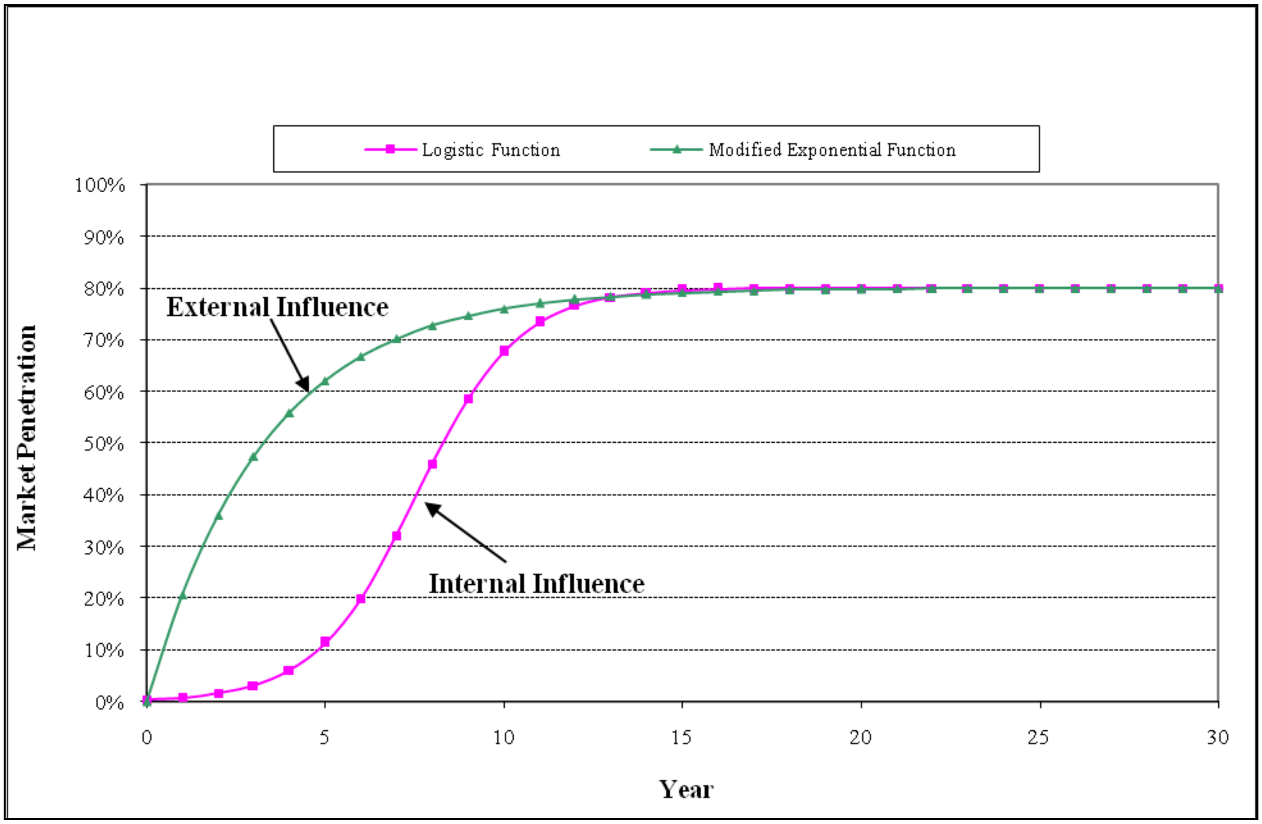

Figure 17-A.4.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies

17-A.4.2 Adjustment of XENERGY Penetration Curves

In consultation with the primary authors of the 2002 XENERGY study who later conducted similar California studies, DOE made some adjustments to XENERGY's original implementation (penetration) curves.[6] The experiences with utility programs since the XENERGY study indicate that incentive programs have difficulty achieving penetration rates as high as 80 percent. Consumer response is limited by barriers created by consumer utility issues and other non-economic factors. DOE therefore adjusted the maximum penetration parameters for some of the curves from 80 percent to the following levels:

Moderate Barriers:	70%
High Barriers:	60%
Extremely High Barriers:	50%

The *low barriers* and *no barriers* curves (the latter used only when a product has a very high base-case-market share) remained, respectively, with 80 percent and 100 percent as their maximum penetration rates. For the interpolated penetration curves (discussed below), DOE set the *no barriers* and *extremely high barriers* curves as the upper and lower bounds, respectively, for any benefit/cost ratio points higher or lower than the curves. It set another constraint such that the policy case market share cannot be great than 100 percent, as might occur for products with high base case market shares of the target-level technology.

17-A.4.3 Interpolation of Penetration Curves

As discussed above, the XENERGY penetration (implementation) curves followed a functional form to estimate the market implementation rate caused by energy efficiency measures such as consumer rebates.[c] The XENERGY report presents five reference market implementation curves that vary according to the level of market barriers to technology penetration.[1] Such curves have been used by DOE in the Regulatory Impact Analyses for rulemakings for appliance energy efficiency standards to estimate market share increases in response to rebate programs.[d] They provide a framework for evaluating technology penetration, yet require matching the studied market to the curve that best represents it. This approximate matching can introduce some inaccuracy to the analysis.

Blum et al (2011, Appendix A)[25] presents an alternative approach to such evaluation: a method to estimate market implementation rates more accurately by performing interpolations of the reference curves. The referred report describes the market implementation rate function and the reference curves, the method to calibrate the function to a given market, and the limitations of the method.

17-A.5 CONSUMER REBATE PROGRAMS

DOE performed a search for rebate programs that offered incentives for medium electric motors. Some organizations nationwide, comprising electric utilities and regional agencies, offer rebate programs for medium electric motors. DOE calculated the average rebate amount per horsepower for each horsepower range from a sample of 37 rebates from 27 organizations. For those programs offering fixed rebate amounts DOE first converted these amounts into their corresponding values of dollar per horsepower. DOE then calculated the average rebate value per horsepower for each horsepower, enclosure and number of poles across all programs, and used shipments weighted average to calculate a rebate value per horsepower for each horsepower range, which DOE eventually used in the analysis described in Chapter 17. Table 17-A.5.1 and 17-A.5.2 provide the organizations' name and state, shipments weighted average rebate amounts that DOE summarized for each program, and program websites. When there is more than one entry for an organization, it offers different rebates in different states. The final rebate amounts per horsepower for each horsepower range are presented in 2012$ at the end of the table.[e]

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[c] The RIA chapter refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.

[d] DOE has also used this method to estimate market share increases resulting from consumer tax credit and manufacturer tax credit programs, since the effects of tax credits on markets can be considered proportional to the rebate impacts.

[e] DOE gathered rebate data for medium electric motors during June, 2013. In the analysis, which assumes 2012$, it used the same rebate values, in the absence of a conversion factor for 2012$.

Table 17-A.5.1 Rebate Amounts for Medium Electric Motors (2012$/hp)

Utility	State	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
AEP Ohio	OH	6.26	4.47	2.80	1.96	1.90	0.71
Alliant Energy	IA	19.06	11.86	5.97	5.21	3.33	4.24
Alliant Energy	MN	3.98	1.95	1.10	0.23	0.32	
Arizona Public Service	AZ	2.65	1.56	0.47	0.33	0.16	
Avista	ID	14.45	8.16	6.34	5.01	3.84	
Burbank Water & power	CA	17.27	6.42	6.71	6.84	7.46	
Cedar Falls Utilities	IA	29.03	16.64	11.33			
Consolidated Edison (ConEd)	NY	20.97	7.62	4.37	4.03	3.95	
Dayton Power and Light	OH	25.00	15.00	10.00	10.00	10.00	3.73
Empire District Electric	AR	8.58	5.90	5.00	4.70	3.55	
Empire District Electric	MO	24.95	9.31	1.45			
Groton Utilities	CT	23.16	8.60	4.41	3.76	3.94	
Gulf Power	FL	25.00	8.00	8.00	3.00	3.00	2.57
Hawaii Energy Efficiency	HI	10.00	10.00	9.44	10.00	10.00	
Imperial Irrigation District	CA	17.27	6.42	6.71	6.84	7.46	
Kentucky Utilties Company	KY	6.00	6.00	6.00	6.00	6.00	2.24
Mass Save	MA	23.16	8.60	4.41	3.76	3.94	
MidAmerican Energy Company	IA	18.36	9.90	9.83	7.30	8.25	
MidAmerican Energy Company	IL	18.36	9.90	9.83	7.30	8.25	
Montana Dakota Utilities	MT	4.00	4.00	4.00	4.00	4.00	
New York State Energy Research and Development Authority (NYSERDA)	NY	0.99				0.01	
Otter Tail Power Company	SD	17.14	15.09	10.98	8.33	7.67	6.64
PECO Energy	PA	6.26	4.47	2.80	1.96	1.90	0.71
PPL Electric Utilities	PA	11.12	7.74	4.52	3.56	3.29	
Progress Energy	FL	2.82	2.28	1.39	1.25	0.89	0.41
Sacramento Municipal Utility District	CA		0.42	0.31			
Tampa Electric	FL	6.00	6.00	6.00	6.00	6.00	6.00

Utility	State	1-5 hp	6-20 hp	21-50 hp	51-100 hp	101-200 hp	201-500 hp
Tennessee Valley Authority	AL	5.23	2.99	3.12	1.86	1.47	
Tennessee Valley Authority	GA	5.23	2.99	3.12	1.86	1.47	
Tennessee Valley Authority	KY	5.23	2.99	3.12	1.86	1.47	
Tennessee Valley Authority	MS	5.23	2.99	3.12	1.86	1.47	
Tennessee Valley Authority	NC	5.23	2.99	3.12	1.86	1.47	
Tennessee Valley Authority	TN	5.23	2.99	3.12	1.86	1.47	
Tucson Electric Power	AZ	3.07	1.74	1.19	0.82	0.75	
Xcel Energy	CO	30.04	13.70	11.53	10.19	9.67	9.00
Xcel Energy	MN	15.02	6.85	5.77	5.09	4.84	4.50
Xcel Energy	NM	30.04	13.70	11.53	10.19	9.67	9.00

Table 17-A.5.2 References for Rebate Programs for Medium Electric Motors

Utility	State	Websites
AEP Ohio	OH	https://www.aepohio.com/account/
Alliant Energy	IA	http://www.alliantenergy.com/SaveEnergyAndMoney/Rebates/BusIA/031057
Alliant Energy	MN	http://www.alliantenergy.com/SaveEnergyAndMoney/Rebates/BusMN/032412
Arizona Public Service	AZ	http://www.aps.com/en/business/Pages/home.aspx
Avista	ID	https://www.avistautilities.com/business/rebates/washington/Pages/incentive_12.aspx
Burbank Water & power	CA	http://www.burbankwaterandpower.com/index.php/incentives-for-businesses/energy-solutions-business-rebate-programs
Cedar Falls Utilities	IA	http://www.cfu.net/save-energy/business-rebates.aspx
Consolidated Edison (ConEd)	NY	https://www.conedci.com/Motors.aspx
Dayton Power and Light	OH	http://www.dpandl.com/save-money/business-government/rapid-rebates/motors-drives-and-compressed-air-rebates/
Empire District Electric	AR	http://empirearkansas.programprocessing.com/content/prescriptiverebates
Empire District Electric	MO	http://empire.programprocessing.com/content/Home
Groton Utilities	CT	http://www.grotonutilities.com/conserv.asp?l=2
Gulf Power	FL	http://www.gulfpower.com/commercial/motors.asp

Utility	State	Websites
Hawaii Energy Efficiency	HI	http://www.hawaiienergyefficiency.com/59/for-your-business
Imperial Irrigation District	CA	http://www.iid.com/index.aspx?page=293
Kentucky Utilties Company	KY	http://www.lge-ku.com/rebate/commercial/download_application.asp
Mass Save	MA	http://www.masssave.com/business/new-construction-and-equipment/find-incentives/incentive-details-business-motor-up-nstar?p=77d80d5d-ff4e-4423-b226-5619a7729641
MidAmerican Energy Company	IA	http://www.midamericanenergy.com/ee/ia_bus_rebates_motors.aspx
MidAmerican Energy Company	IL	http://www.midamericanenergy.com/ee/il_bus_rebates_motors.aspx
Montana Dakota Utilities	MT	http://www.montana-dakota.com/conservation/savings-for-your-business
New York State Energy Research and Development Authority (NYSERDA)	NY	http://www.nyserda.ny.gov/Energy-Efficiency-and-Renewable-Programs/Commercial-and-Industrial/Business-Partners/Motors-Systems/Motor-Purchasers/Purchasers-Information.aspx
Otter Tail Power Company	SD	https://www.otpco.com/SaveEnergyMoney/SD%20-EEP/Pages/commercialMotorsEEP_SD.aspx
PECO Energy	PA	https://www.peco.com/Savings/ProgramsandRebates/Business/Pages/PECOSmartEquipmentIncentives.aspx
PPL Electric Utilities	PA	https://www.pplelectric.com/save-energy-and-money/rebate-and-incentive-programs/customer-rebates-applications.aspx
Progress Energy	FL	https://www.progress-energy.com/florida/business/save-energy-money/energy-efficiency-for-business.page?
Sacramento Municipal Utility District	CA	https://www.smud.org/en/business/save-energy/rebates-incentives-financing/industrial-process-improvement/express-incentives.htm
Tampa Electric	FL	http://www.tampaelectric.com/business/saveenergy/energyefficiencientmotors/
Tennessee Valley Authority	AL	http://www.energyright.com/industrial/lessthan_how.html
Tennessee Valley Authority	GA	http://www.energyright.com/industrial/lessthan_how.html
Tennessee Valley Authority	KY	http://www.energyright.com/industrial/lessthan_how.html
Tennessee Valley Authority	MS	http://www.energyright.com/industrial/lessthan_how.html
Tennessee Valley Authority	NC	http://www.energyright.com/industrial/lessthan_how.html
Tennessee Valley Authority	TN	http://www.energyright.com/industrial/lessthan_how.html
Tucson Electric Power	AZ	http://websafe.kemainc.com/Projects/Default.aspx?tabid=1030

Utility	State	Websites
Xcel Energy	CO	http://www.xcelenergy.com/Save_Money_&_Energy/For_Your_Business/Equipment_Efficiency/Motor_and_Drive_Efficiency_-_CO
Xcel Energy	MN	http://www.xcelenergy.com/Save_Money_&_Energy/For_Your_Business/Equipment_Efficiency/Motor_and_Drive_Efficiency_-_MN
Xcel Energy	NM	http://www.xcelenergy.com/Save_Money_&_Energy/For_Your_Business/Equipment_Efficiency/Motor_and_Drive_Efficiency_-_NM

17-A.6 FEDERAL AND STATE TAX CREDITS

This section summarizes the Federal and State tax credits available to consumers who purchase energy efficient appliances. This section also describes tax credits available to manufacturers who produce certain energy efficient appliances.

17-A.6.1 Federal Tax Credits for Consumers of Residential Appliances

EPACT 2005 included Federal tax credits for consumers who installed efficient air conditioners or heat pumps; gas, oil and propane furnaces and boilers; furnace fans; and/or gas, oil, or electric heat pump water heaters in new or existing homes.[7, 8] These tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by the American Recovery and Reinvestment Act (ARRA).[9] There was a $1,500 cap on the credit per home, including the amount received for insulation, windows, and air and duct sealing. Congress extended this provision for 2011, with some modifications to eligibility requirements, and reductions in the cap to $500 per home. The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[7, 10]
The tax credit for furnace fans was $50 in 2011, after which it expired.

The importance of the Federal tax credits has been emphasized in research in the residential heating industry on the impacts of the relatively large credits that were available for HVAC (heating, ventilating, and air conditioning) equipment. In a survey of HVAC distributors conducted by Vermont Energy Investment Corporation, respondents indicated that the ample credit had had a notable impact on sales of higher-efficiency heating and cooling equipment. Some distributors combined the Federal tax credits with manufacturer rebates and utility program rebates for a greater consumer incentive. However, when the amount of the Federal tax credit was reduced, smaller utility rebate incentives had not induced the same levels of equipment sales increases. The decrease in incentive size from a $1,500 cap in 2009-2010 to a $500 cap in 2011, during a period when the economy continued to be sluggish, resulted in a decline in total sales of residential HVAC products. Distributors stated that an incentive needed to cover 25 to 75 percent of the incremental cost of the efficient equipment to influence consumer choice. The industry publication “2011 HVAC Review and Outlook” noted a decline in sales of air conditioning units with >14 SEER in 2011 and a return in sales of units with >16 SEER to 2009 levels (after an increase in 2010). The large majority of distributor observed no impacts from the utility programs with their lower rebate amounts available in 2011. Distributors also commented on the advantages of the Federal tax credit being nationwide in contrast to utility rebate programs that target regional markets.[11, 12]

In an effort to evaluate the potential impact of a Federal appliance tax credit program, DOE reviewed Internal Revenue Service (IRS) data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. It estimated the percentage of taxpayers who filed Form 5695, *Residential Energy Credits.*[13] It also estimated the percentage of taxpayers with entries under Form 5695’s section 3, *Residential energy property costs*, line 3b, *qualified natural gas, propane, or oil furnace or hot water boiler*. DOE reasoned that the percentage of taxpayers with an entry on Line 3b could serve as a rough indication of the potential of taxpayer participation in a Federal tax credit program for furnaces during the initial program years. DOE found that of all residential taxpayers filing tax returns, 0.8 percent in 2006 and 0.6 percent in 2007, claimed a credit for a furnace or boiler. DOE further found that the percentages of those filing Form 5695 for any qualifying energy property expenditure (which also included installation of efficient windows, doors and roofs) were 3.1 and 3.2 percent in 2006 and 2007 respectively.

DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. While this tax credit was available from 1979 through 1985, DOE located data for only the first three years of the program.[14, 15, 16] For those three years - 1979, 1980, and 1981 - the percentages of taxpayers filing Form 5695 were 6.4 percent, 5.2 percent, and 4.9 percent. Given that the data from this earlier tax credit program were not disaggregated by type of energy property, this data series served only to indicate a possible trend of greater participation in the initial program year, followed by slightly smaller participation in subsequent years. However, DOE did not find detailed analysis of this program to indicate the possible reasons for such a trend. Also, this trend varies from the more stable trend shown in the EPAct 2005 energy tax credit program data for its first two program years.

As discussed in Chapter 17, Section 17.3.3, DOE analyzed the percentage of participation in consumer tax credit programs using its estimates of consumer participation in rebate programs that was based on benefit/cost data specific to each product class. Hence it was difficult to compare these detailed estimates to the more general data analysis described above from the existing Federal tax credit program, or to use the IRS data analysis in its consumer tax credit analysis.

17-A.6.2 Federal Tax Credits for Manufacturers

EPACT 2005 provided Federal Energy Efficient Appliance Credits to manufacturers that produced high-efficiency refrigerators, clothes washers, and dishwashers in 2006 and 2007.[17] The Emergency Economic Stabilization Act of 2008[18] amended the credits and extended them through 2010. The credits were extended again to 2011 with modifications in the eligibility requirements. Manufacturer tax credits were extended again, by the American Taxpayer Relief Act of 2012, for clothes washers, refrigerators, and dishwashers manufactured between January 1, 2012 and December 31, 2013.[19]

Manufacturers who produce these appliances receive the credits for increasing their production of qualifying appliances. These credits had several efficiency tiers in 2011. For 2012-2013, credits for the higher tiers remain but were eliminated for the lowest (least efficient) tiers for clothes washers and dishwashers.[10] The credit amounts applied to each unit manufactured. The credit to manufacturers of qualifying clothes washers, refrigerators and dishwashers was capped at $75 million for the period of 2008-2010. However, the most efficient refrigerator (30%) and clothes washer (2.2 MEF/4.5 wcf) models was not subject to the cap. The credit to manufacturers was capped at $25 million for 2011, with the most efficient refrigerators (35%) and clothes washers (2.8 MEF/3.5 WCF) exempted from this cap.[20]

17-A.6.3 State Tax Credits

The States of Oregon and Montana have offered consumer tax credits for efficient appliances for several years, and the States of Kentucky, Michigan and Indiana began offering such credits in 2009. The Oregon Department of Energy (ODOE) has disaggregated data on taxpayer participation in credits for eligible products. (See the discussion in chapter 17, section 17.3.3, on tax credit data for clothes washers.) Montana's Department of Revenue does not disaggregate participation data by appliance, although DOE reviewed Montana's overall participation trends and found them congruent with its analysis of Oregon's clothes washer tax credits.

Oregon's Residential Energy Tax Credit (RETC) was created in 1977. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers, which significantly increased participation in the program. The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001); furnaces and boilers (2002); and duct/air sealing, fuel cells, heat recovery, and renewable energy equipment. Beginning in 2012 a Tax Credit Extension Bill (HB3672) eliminated refrigerators, clothes washers, dishwashers, air conditioners, and boilers from the RETC program, leaving credits for water heaters, furnaces, heat pumps, tankless water heaters, and heat pump water heaters.[21, 22] Those technologies recognized by the Oregon Department of Energy as "premium efficiency" are eligible for tax credit of $0.60 per kWh saved in the first year (up to $1,500).[21, 23]

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.[24] The tax credit covers various residential energy and water efficient products, including split system central air conditioning; package system central air conditioning; split system air source heat pumps; package system heat pumps; natural gas, propane, or oil furnaces; hot water boilers; advanced main air circulating fans; heat recovery ventilators; gas, oil, or propane water heaters; electric heat pump water heaters; low-flow showerheads and faucets; light fixtures; and controls. In 2002 the amount of the credit was increased from 5 percent of product costs (up to $150) to 25 percent (up to $500) per taxpayer. The credit can be used for products installed in new construction or remodeling projects. The tax credit covers only that part of the cost and materials that exceed established standards of construction.

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