Chapter 2: Technologies, Cost, and Effectiveness

2.1 Overview of Technologies

In discussing the potential for CO_2 emission and fuel consumption reductions, it can be helpful to think of the work flow through the system. The initial work input is fuel. Each gallon of fuel has the potential to produce some amount of work and will produce a set amount of CO_2 (about 22 pounds of CO_2 per gallon of diesel fuel). The engine converts the chemical energy in the fuel to useable work to move the truck. Any reductions in work demanded of the engine by the vehicle or improvements in engine fuel conversion efficiency will lead directly to CO_2 emission and fuel consumption reductions.

Current diesel engines are 35-38 percent efficient over a range of operating conditions with peak efficiency levels between 40 and 45 percent depending on engine sizes and applications, while gasoline engines are approximately 30 percent efficient overall. This means that approximately one-third of the fuel's chemical energy is converted to useful work and two-thirds is lost to friction, gas exchange, and waste heat in the coolant and exhaust. In turn, the truck uses this work delivered by the engine to overcome overall vehicle-related losses such as aerodynamic drag, tire rolling resistance, friction in the vehicle driveline, and to provide auxiliary power for components such as air conditioning and lights. Lastly, the vehicle's operation, such as vehicle speed and idle time, affects the amount of total energy required to complete its activity. While it may be intuitive to look first to the engine for CO_2 reductions given that only about one-third of the fuel is converted to useable work, it is important to realize that any improvement in vehicle efficiency reduces both the work demanded and also the waste energy in proportion.

Technology is one pathway to improve heavy-duty truck GHG emissions and fuel consumption. Near-term solutions exist, such as those being deployed by SmartWay partners in heavy duty truck long haul applications. Other solutions are currently underway in the Light Duty vehicle segment, especially in the Large Pickup sector where many of the technologies can apply to the heavy duty pickup trucks covered under this proposal. Long-term solutions are currently under development to improve efficiencies and cost-effectiveness. While there is not a "silver bullet" that will significantly eliminate GHG emissions from heavy-duty trucks like the catalytic converter has for criteria pollutant emissions, significant GHG and fuel consumption reductions can be achieved through a combination of engine, vehicle system, and operational technologies.

The following sections will discuss technologies in relation to each of the proposed regulatory classes – Heavy Duty Pickup Trucks and Vans, Heavy Duty Engines, Class 7/8 Sleeper and Day Cabs, Class 2b-8 Vocational Trucks, and Trailers.

EPA and NHTSA collected information on the cost and effectiveness of fuel consumption and CO_2 emission reducing technologies from several sources. The primary sources of information were the National Academy of Sciences report of Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles (NAS)[1], TIAX's assessment of technologies to support the NAS panel report (TIAX)[2], EPA's

Heavy Duty Lumped Parameter Model[3], the analysis conducted by NESCCAF, ICCT, Southwest Research Institute and TIAX for reducing fuel consumption of heavy-duty long haul combination trucks (NESCCAF/ICCT)[4], and the technology cost analysis conducted by ICF for EPA (ICF).[5] In addition, EPA's simplified vehicle simulation model plays a key role in quantifying the effectiveness of various technologies on CO_2 emission and fuel consumption reductions in terms of vehicle performance. The simulation tool is described in DRIA Chapter 3 in more details.

2.2 Overview of Technology Cost Methodology

Section 2.2.1 presents the methods used to address indirect costs in this analysis. Section 2.2.2 presents the learning effects applied throughout this analysis. Section 2.10 presents a summary in tabular form of all the technology costs expected to be implemented in response to the proposed standards.

2.2.1 Markups to Address Indirect Costs

To produce a unit of output, engine and truck manufacturers incur direct and indirect costs. Direct costs include cost of materials and labor costs. Indirect costs may be related to production (such as research and development [R&D]), corporate operations (such as salaries, pensions, and health care costs for corporate staff), or selling (such as transportation, dealer support, and marketing). Similarly to direct costs, indirect costs are generally recovered by allocating a share of the costs to each unit of good sold. Although it is possible to account for direct costs allocated to each unit of good sold, it is more challenging to account for indirect costs allocated to a unit of good sold. To make a cost analysis process more feasible, markup factors, which relate indirect costs to the changes in direct costs, have been developed. These factors are often referred to as retail price equivalent (RPE) multipliers.

Cost analysts and regulatory agencies including the EPA have frequently used these multipliers to predict the resultant impact on costs associated with manufacturers' responses to regulatory requirements. Clearly the best approach to determining the impact of changes in direct manufacturing costs on a manufacturer's indirect costs would be to actually estimate the cost impact on each indirect cost element. However, doing this within the constraints of an agency's time or budget is not always feasible, or the technical, financial, and accounting information to carry out such an analysis may simply be unavailable.

RPE multipliers provide, at an aggregate level, the relative shares of revenues[6] to direct manufacturing costs. Using RPE multipliers implicitly assumes that incremental changes in direct manufacturing costs produce common incremental changes in all indirect cost contributors as well as net income. A concern in using the RPE multiplier in cost analysis for new technologies (which result from regulations requiring reductions in emissions) is that the indirect costs of vehicle modifications are not likely to be the same for different technologies. For example, less complex technologies could require fewer R&D efforts or less warranty coverage than more complex technologies. In addition, some simple technological adjustments may, for example, have no effect on the number of corporate personnel.

To address this concern, modified multipliers have been developed. These multipliers are referred to as indirect cost multipliers (or IC multipliers). In contrast to RPE multipliers, IC multipliers assign unique incremental changes to each indirect cost contributor as well as net income.

IC multiplier = (direct cost + adjusted indirect cost)/(direct cost)

Developing the IC multipliers from the RPE multipliers requires developing adjustment factors based on the complexity of the technology and the time frame under consideration. This methodology was used in the cost estimation for the recent Light Duty GHG rule. The agency has used ICM adjustment factors developed for light duty vehicles (with the exception that here return on capital has been incorporated into the ICMs, where it had not been in the light-duty rule) for the heavy duty pickup truck and van cost projections in this proposal primarily because the manufacturers involved in this segment of the heavy duty market are the same manufacturers which build light duty trucks.

For the Class 7/8 tractor, vocational trucks, and heavy duty engine cost projections in this proposal, EPA contracted with RTI International to update EPA's methodology for accounting for indirect costs associated with changes in direct manufacturing costs for heavy duty engine and truck manufacturers.[7] In addition to the indirect cost contributors varying by complexity and time frame, there is no reason to expect that the contributors would be the same for engine manufacturers as for truck manufacturers. The resulting report from RTI provides a description of the methodology, as well as calculations of new indirect cost multipliers. These indirect cost multipliers are intended to be used, along with calculations of direct manufacturing costs, to provide improved estimates of the full additional costs associated with new technologies.

To account for the indirect costs on class 2b and 3 trucks and on light heavy-duty engines, the agencies have applied an indirect cost multiplier (ICM) factor to all of the direct costs to arrive at the estimated technology cost. The ICM factors used are shown in Table 2-1. Near term values (2014 through 2021 in this analysis) account for differences in the levels of R&D, tooling, and other indirect costs that will be incurred. Once the program has been fully implemented, some of the indirect costs will no longer be attributable to the proposed standards and, as such, a lower ICM factor is applied to direct costs in 2022 and later.

Table 2-1 Indirect Cost Multipliers Used in this Analysis[a]

Class	Complexity	Near term	Long term
2b&3 Trucks and Vans	Low	1.17	1.13
	Medium	1.31	1.19
	High1	1.51	1.32
	High2	1.70	1.45
Loose diesel engines	Low	1.11	1.09
	Medium	1.18	1.13
	High1	1.28	1.19

	High2	1.43	1.29
Loose gasoline engines	Low	1.17	1.13
	Medium	1.31	1.19
	High1	1.51	1.32
	High2	1.70	1.45
Vocational/Combination Trucks	Low	1.14	1.10
	Medium	1.26	1.16
	High1	1.42	1.27
	High2	1.57	1.36

[a] Reference RTI LD report; Helfand update memo; RTI LD report

The agencies have also applied ICM factors to class 2b through 8 vocational truck and tractor technologies along with both medium and heavy heavy-duty engine technologies. The ICMs used in this analysis include a factor for profit that is a 0.05 share of direct costs, as calculated in the RTI report, for the class 7/8 tractor, vocational trucks, and heavy duty engine cost projections; for the heavy duty pickup truck and van cost projections, this analysis used a profit factor of 0.06 from the RTI LD report. In the long run in a competitive industry, profits should equal the return on capital investments necessary to sustain the industry. These capital investments represent the fixed costs of the industry. Note that, for the medium and heavy duty diesel engines, the agencies have applied these markups to ensure that our estimates are conservative since we have estimated fixed costs separately for technologies applied to these categories, effectively making the use of markups a double counting of some of the indirect costs.

For most of the segments in this analysis, the indirect costs are estimated by applying indirect cost multipliers (ICM) to direct cost estimates. ICMs were calculated by EPA as a basis for estimating the impact on indirect costs of individual vehicle technology changes that would result from regulatory actions. Separate ICMs were derived for low, medium, and high complexity technologies, thus enabling estimates of indirect costs that reflect the variation in research, overhead, and other indirect costs that can occur among different technologies. ICMs were also applied in the MY 2012-2016 CAFE rulemaking.

Previous CAFE rulemakings applied a retail price equivalent (RPE) factor to estimate indirect costs and mark up direct costs to the retail level. Retail Price Equivalents are estimated by dividing the total revenue of a manufacturer by the direct manufacturing costs. As such, it includes all forms of indirect costs for a manufacturer and assumes that the ratio applies equivalently for all technologies. ICMs are based on RPE estimates that are then modified to reflect only those elements of indirect costs that would be expected to change in response to a technology change. For example, warranty costs would be reflected in both RPE and ICM estimates, while marketing costs might only be reflected in an RPE estimate but not an ICM estimate for a particular technology, if the new technology is not one expected to be marketed to consumers. Because ICMs calculated by EPA are for individual technologies, many of which are small in scale, they often reflect a subset of RPE costs; as a result, the RPE is typically higher than an ICM. This is not always the case, as ICM estimates for complex technologies may reflect higher than average indirect costs, with the resulting ICM larger than the averaged RPE for the industry.

Precise association of ICM elements with individual technologies based on the varied accounting categories in company annual reports is not possible. Hence, there is a degree of uncertainty in the ICM estimates. If all indirect costs moved in proportion to changes in direct costs the ICM and RPE would be the same. Because most individual technologies are smaller scale than many of the activities of auto companies (such as designing and developing entirely new vehicles), it would be expected that the RPE estimate would reflect an upper bound on the average ICM estimate. The agencies are continuing to study ICMs and the most appropriate way to apply them, and it is possible revised ICM values may be used in our final rulemaking. With this in mind, the agencies are presenting a sensitivity analysis reflecting costs measured using the RPE in place of the ICM and indirect costs estimated independently in our primary analysis to examine the potential impact of these two approaches on estimated costs.

While this analysis relies on ICMs to estimate indirect costs, an alternative method of estimating indirect costs is the retail price equivalent factor (RPE). The RPE has been used by NHTSA, EPA and other agencies to account for cost factors not included in available direct cost estimates, which are derived from cost teardown studies or sometimes provided by manufacturers. The RPE is the basis for these markups in all DOT safety regulations and in most previous fuel economy rules. The RPE includes all variable and fixed elements of overhead costs, as well as selling costs such as vehicle delivery expenses, manufacturer profit, and full dealer markup, and assumes that the ratio of indirect costs to direct costs is constant for all vehicle changes. Historically, NHTSA has estimated that the RPE has averaged about 1.5 for the light-duty motor vehicle industry. The implication of an RPE of 1.5 is that each added $1.00 of variable cost in materials, labor, and other direct manufacturing costs results in an increase in consumer prices of $1.50 for any change in vehicles.

NHTSA has estimated the RPE from light-duty vehicle manufacturers' financial statements over nearly 3 decades, and although its estimated value has varied somewhat year-to-year, it has generally hovered around a level of 1.5 throughout most of this period. The NAS report as well as a study by RTI International found that other estimates of the RPE varied from 1.26 to over 2. In a recent report, The National Academy of Sciences (NAS) acknowledged that an ICM approach was preferable but recommended continued use of the RPE over ICMs until such time as empirical data derived from rigorous estimation methods is available. The NAS report recommended using an RPE of 1.5 for outsourced (supplier manufactured) and 2.0 for in-house (OEM manufactured) technologies and an RPE of 1.33 for advanced hybrid and electric vehicle technologies.

ICMs typically are significantly lower than RPEs, because they measure changes in only those elements of overhead and selling-related costs that are directly influenced by specific technology changes to vehicles. For example, the number of managers might not be directly proportional to the value of direct costs contained in a vehicle, so that if a regulation increases the direct costs of manufacturing vehicles, there might be little or no change in the number of managers. ICMs would thus assume little or no change in that portion of indirect costs associated with the number of managers – these costs would be allocated only to the existing base vehicle. By contrast, the RPE reflects the historical overall relationship between the direct costs to manufacture vehicles and the prices charged for vehicles, which must compensate manufacturers for both their direct and indirect costs for producing and selling vehicles. The assumption behind the RPE is that changes in the long-term price of the final product that accompany increases in direct costs of vehicle manufacturing will continue to reflect this historical relationship.

Another difference between the RPE and ICM is that ICMs have been derived separately for different categories of technologies. A relatively simple technology change, such as switching to a different tire with lower rolling resistance characteristics, would not influence indirect costs in the same proportion as a more complex change, such as development of a full hybrid design. ICMs were developed for 3 broad categories of technology complexities, and are applied separately to fuel economy technologies judged to fit into each of these categories. This requires determining which of these complexity categories each technology should be assigned.

There is some level of uncertainty surrounding both the ICM and RPE markup factors. The ICM estimates used in this proposal group all technologies into three broad categories and treat them as if individual technologies within each of the three categories (low, medium, and high complexity) would have the same ratio of indirect costs to direct costs. This simplification means it is likely that the direct cost for some technologies within a category will be higher and some lower than the estimate for the category in general. More importantly, the ICM estimates have not been validated through a direct accounting of actual indirect costs for individual technologies. Rather, the ICM estimates were developed using adjustment factors developed in two separate occasions: the first, a consensus process, was reported in the RTI report; the second, a modified Delphi method, was conducted separately and reported in an EPA memo. Both these panels were composed of EPA staff members with previous background in the automobile industry; the memberships of the two panels overlapped but were not the same. The panels evaluated each element of the industry's RPE estimates and estimated the degree to which those elements would be expected to change in proportion to changes in direct manufacturing costs. The method and estimates in the RTI report were peer reviewed by three industry experts and subsequently by reviewers for the International Journal of Production Economics. RPEs themselves are inherently difficult to estimate because the accounting statements of manufacturers do not neatly categorize all cost elements as either direct or indirect costs. Hence, each researcher developing an RPE estimate must apply a certain amount of judgment to the allocation of the costs. Moreover, RPEs for heavy and medium duty trucks and for engine manufacturers are not as well studied as they are for the light-duty automobile industry. Since empirical estimates of ICMs are ultimately derived from the same data used to measure RPEs, this affects both measures. However, the value of RPE has not been measured for specific technologies, or for groups of specific technologies. Thus applying a single average RPE to any given technology by definition overstates costs for very simple technologies, or understates them for advanced technologies.

To highlight the potential differences between the use of ICMs and RPEs to estimate indirect costs, the agencies conducted an analysis based on the use of average RPEs for each industry in the place of the ICM and direct fixed cost estimates used in our proposal. Since most technologies involved in this proposal are low complexity level technologies, the estimate based on the use of an average RPE likely overstates the costs. The weighted average

RPEs for the truck and engine industries are 1.36 and 1.28 respectively. These values were substituted for the ICMs and directly estimate indirect costs used in the primary cost analysis referenced elsewhere in this document. Using the average RPEs, the five model year cost of $8.2B in the primary analysis increases to $9.5B, an increase of 16 percent. The agencies request comment accompanied by supporting data on the use of ICMs and RPE factors to estimate fixed costs.

2.2.2 Learning Effects on Technology Costs

For some of the technologies considered in this analysis, manufacturer learning effects would be expected to play a role in the actual end costs. The "learning curve" or "experience curve" describes the reduction in unit production costs as a function of accumulated production volume. In theory, the cost behavior it describes applies to cumulative production volume measured at the level of an individual manufacturer, although it is often assumed—as both agencies have done in past regulatory analyses—to apply at the industry-wide level, particularly in industries that utilize many common technologies and component supply sources. Both agencies believe there are indeed many factors that cause costs to decrease over time. Research in the costs of manufacturing has consistently shown that, as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts. All of these factors allow manufacturers to lower the per-unit cost of production (i.e., the manufacturing learning curve).

NHTSA and EPA have a detailed description of the learning effect in the 2012-2016 light-duty rule. Most studies of the effect of experience or learning on production costs appear to assume that cost reductions begin only after some initial volume threshold has been reached, but not all of these studies specify this threshold volume. The rate at which costs decline beyond the initial threshold is usually expressed as the percent reduction in average unit cost that results from each successive doubling of cumulative production volume, sometimes referred to as the learning rate. Many estimates of experience curves do not specify a cumulative production volume beyond which cost reductions would no longer occur, instead depending on the asymptotic behavior of the effect for learning rates below 100 percent to establish a floor on costs.

In past rulemaking analyses, as noted above, both agencies have used a learning curve factor of 20 percent for each doubling of production volume. NHTSA has used this approach in analyses supporting recent CAFE rules. In its analysis, EPA has simplified the approach by using an "every two years" based learning progression rather than a pure production volume progression (i.e., after two years of production it was assumed that production volumes would have doubled and, therefore, costs would be reduced by 20 percent).

In the 2012-2016 light-duty rule, the agencies considered not only this volume-based learning as described above, but also "time-based" learning. Time-based learning, estimated by NHTSA in the 2011 CAFE rule, at three percent per year, occurs in years following the volume-based learning steps and represents the smaller scale learning that occurs as manufacturers continue to innovate. The time-based learning is, in effect, represented by the flattened out, asymptotic portion of the learning curve.

For this analysis, the agencies have employed both volume-based and time-based learning effects. In the analysis, as noted above, volume-based learning is estimated to result in 20 percent lower costs after two full years of implementation (i.e., the 2016 MY costs are 20 percent lower than the 2014 and 2015 model year costs). Time-based learning is estimated to result in 3 percent lower costs in each year following first introduction of a given technology. Once two volume-based learning steps have occurred (for technologies having volume-based learning applied while time-based learning would begin in year 2 for technologies having time-based learning applied), time-based learning at 3 percent per year becomes effective for 5 years. Beyond 5 years of time-based learning at 3 percent per year, 5 years of time-based learning at 2 percent per year, then 5 at 1 percent per year become effective.

Learning effects are applied to most but not all technologies because some of the expected technologies are already used rather widely in the industry and, presumably, learning impacts have already occurred. Volume-based learning was considered for only a handful of technologies that are considered to be new or emerging technologies. Most technologies have been considered to be more established given their current use in the fleet and, hence, the lower time-based learning has been applied. The learning effects applied to each technology are summarized in Table 2-2.

2-2 Learning Effects Applied to Technologies Used in this Analysis

Technology	Applied to	Learning Effect
Cylinder head improvements	Engines	Time
Turbo efficiency improvements	Engines	Time
EGR cooler efficiency improvements	Engines	Time
Water pump improvements	Engines	Time
Oil pump improvements	Engines	Time
Fuel pump improvements	Engines	Time
Fuel rail improvements	Engines	Time
Fuel injector improvements	Engines	Time
Piston improvements	Engines	Time
Valve train friction reductions	Engines	Time
Turbo compounding	Engines	Time
Engine friction reduction	Engines	Time
Coupled cam phasing	Engines	Time
Stoichiometric gasoline direct injection	Engines	Time
Low rolling resistance tires	Vocational trucks	Volume
Low rolling resistance tires	Trucks	Time
Aero (except Aero SmartWay Advanced)	Trucks	Time
Aero SmartWay Advanced	Trucks	Volume
Weight reduction (via single wide tires and/or aluminum wheels)	Trucks	Time
Auxiliary power unit	Trucks	Time
Air conditioning leakage	Trucks	Time

The learning effects discussed here impact the technology costs considered here in that those technology costs for which learning effects are considered applicable are changing throughout the period of implementation and the period following implementation. For example, some of the technology costs considered in this analysis are taken from the 2012-2016 light-duty rule and scaled appropriately giving consideration to the heavier weights and loads in the heavy-duty segment. Many of the costs in the 2012-2016 light-duty rule were consider "valid" for the 2012 model year. If time based learning were applied to those technologies, the 2013 cost would be 3 percent lower than the 2012 cost, and the 2014 model year cost 3 percent lower than the 2013 cost, etc. As a result, the 2014 model year cost presented in, for example, Section 2.3 would reflect those two years of time based learning and would not be identical to the 2012 model year cost presented in the 2012-2016 light-duty rule.

2.3 Heavy Duty Pickup Truck and Van Technologies and Costs

2.3.1 Gasoline Engines

The spark ignited engines for class 2B and 3 vehicles are typically the same as offered in the light duty segment. These engines typically range in displacement between five and eight liters and are either V8 or V10 configurations.

The engine technologies proposed are based on the technologies described in the Light Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document.[8] Some of the references come from Technologies and Approaches to Reducing the Fuel Consumption of Medium and Heavy Duty Vehicles by The National Academies, March, 2010. These technologies include engine friction reduction, cam phasing, cylinder deactivation and stoichiometric gas direct injection.

2.3.1.1 Low Friction Lubricants

One of the most basic methods of reducing fuel consumption in both gasoline and diesel engines is the use of lower viscosity engine lubricants. More advanced multi-viscosity engine oils are available today with improved performance in a wider temperature band and with better lubricating properties. This can be accomplished by changes to the oil base stock (e.g., switching engine lubricants from a Group I base oils to lower-friction, lower viscosity Group III synthetic) and through changes to lubricant additive packages (e.g., friction modifiers and viscosity improvers). The use of 5W-30 motor oil is now widespread and auto manufacturers are introducing the use of even lower viscosity oils, such as 5W-20 and 0W-20, to improve cold-flow properties and reduce cold start friction. However, in some cases, changes to the crankshaft, rod and main bearings and changes to the mechanical tolerances of engine components may be required. In all cases, durability testing would be required to ensure that durability is not compromised. The shift to lower viscosity and lower friction lubricants will also improve the effectiveness of valvetrain technologies such as cylinder deactivation, which rely on a minimum oil temperature (viscosity) for operation.

Based on 2012-2016 Light-duty final rule, and previously-received confidential manufacturer data, NHTSA and EPA estimated the effectiveness of low friction lubricants to be between 0 to 1 percent.

In the 2012-2016 light-duty FRM, the agencies estimated the cost of moving to low friction lubricants at $3 per vehicle (2007$). That estimate included a markup of 1.11 for a low complexity technology. For class 2b and 3, we are using the same base estimate but have marked it up to 2008 dollars using the GDP price deflator and have used a markup of 1.17 for a low complexity technology to arrive at a value of $4 per vehicle. As in the light-duty rule, learning effects are not applied to costs for this technology and, as such, this estimate applies to all model years.[1,2]

2.3.1.2 Engine Friction Reduction

Manufacturers can reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Approximately 10 percent of the energy consumed by a vehicle is lost to friction, and just over half is due to frictional losses within the engine. Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. Additionally, as computer-aided modeling software continues to improve, more opportunities for evolutionary friction reductions may become available.

All reciprocating and rotating components in the engine are potential candidates for friction reduction, and minute improvements in several components can add up to a measurable fuel economy improvement. The 2012-2016 LD rule, 2010 NAS, NESCCAF and EEA reports as well as confidential manufacturer data suggested a range of effectiveness for engine friction reduction to be between 1 to 3 percent. NHTSA and EPA continue to believe that this range is accurate.

Consistent with the 2012-2016 light-duty FRM, the agencies estimate the cost of this technology at $14 per cylinder compliance cost (2008$), including the low complexity ICM markup value of 1.17. Learning impacts are not applied to the costs of this technology and, as such, this estimate applies to all model years. This cost is multiplied by the number of engine cylinders.

2.3.1.3 Coupled Cam Phasing (CCP)

Valvetrains with coupled (or coordinated) cam phasing can modify the timing of both the inlet valves and the exhaust valves an equal amount by phasing the camshaft of an

[1] Note that throughout the cost estimates for this HD analysis, the agencies have used slightly higher markups than those used in the 2010-2016 light-duty FRM. The new, slightly higher ICMs include return on capital of roughly 6 percent, a factor that was not included in the light-duty analysis.
[2] Note that the costs developed for low friction lubes for this analysis reflect the costs associated with any engine changes that would be required as well as any durability testing that may be required.

overhead valve (OHV) engine. For overhead valve (OHV) engines, which have only one camshaft to actuate both inlet and exhaust valves, CCP is the only VVT implementation option available and requires only one cam phaser.

Consistent with the 2012-2016 Light Duty final rule, NHTSA and EPA estimate the effectiveness of CCP to be between 1 to 4 percent.

Consistent with the 2012-2016 Light Duty final rule, NHTSA and EPA estimate the cost of a cam phaser at $46 (2008$) in the 2014MY. This estimate includes a low complexity ICM of 1.17 and time based learning. All engines in the Class 2b&3 category use over-head valve engines (OHV) and, as such, would require only one cam phaser for coupled cam phasing.

2.3.1.4 Cylinder Deactivation (DEAC)

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation (DEAC) can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this "part-cylinder" mode.

Cylinder deactivation control strategy relies on setting maximum manifold absolute pressures or predicted torque within which it can deactivate the cylinders. Noise and vibration issues reduce the operating range to which cylinder deactivation is allowed, although manufacturers are exploring vehicle changes that enable increasing the amount of time that cylinder deactivation might be suitable. Some manufacturers may choose to adopt active engine mounts and/or active noise cancellations systems to address NVH concerns and to allow a greater operating range of activation.

Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently.

NHTSA and EPA adjusted the 2012-2016 Light Duty final rule estimates using updated power to weight ratings of heavy-duty trucks and confidential business information and confirmed a range of 3 to 4 percent for these vehicles.

Consistent with the 2012-2016 light-duty FRM, NHTSA and EPA have estimated the cost of cylinder deactivation at $193 for the 2014MY (2008$). This estimate includes a low complexity ICM of 1.17 and time based learning.

2.3.1.5 Stoichiometric Gasoline Direct Injection (SGDI)

Stoichiometric gasoline direct injection (SGDI) engines inject fuel at high pressure directly into the combustion chamber (rather than the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Several manufacturers have recently introduced vehicles with SGDI engines, including GM and Ford and have announced their plans to increase dramatically the number of SGDI engines in their portfolios.

The 2012-2016 Light Duty rule estimate the range of effectiveness to be from 1 to 2 percent for SGDI. NHTSA and EPA reviewed this estimate for purposes of the NPRM, and continue to find it accurate.

The NHTSA and EPA cost estimates for SGDI take into account the changes required to the engine hardware, engine electronic controls, ancillary and Noise Vibration and Harshness (NVH) mitigation systems. Through contacts with industry NVH suppliers, and manufacturer press releases, the agencies believe that the NVH treatments will be limited to the mitigation of fuel system noise, specifically from the injectors and the fuel lines. Consistent with the 2012-2016 light-duty rule, the agencies estimate the cost of conversion to SGDI on a V8 engine at $395 (2008$) for the 2014MY. This estimate includes a low complexity ICM of 1.17 and time based learning.

2.3.2 Diesel Engines

Diesel engines in this class of vehicle have emissions characteristics that present challenges to meeting federal Tier 2 NO_x emissions standards. It is a significant systems-engineering challenge to maintain the fuel consumption advantage of the diesel engine while meeting U.S. emissions regulations. Fuel consumption can be negatively impacted by emissions reduction strategies depending on the combination of strategies employed. Emission compliance strategies for diesel vehicles sold in the U.S. are expected to include a combination of improvements of combustion, air handling system, aftertreatment, and advanced system control optimization. These emission control strategies are being introduced on Tier 2 light-duty diesel vehicles today

The engine technologies proposed are based on the technologies described in the Light Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document.[9] Some of reference comes from Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy Duty Vehicles by The National Academies, March, 2010. Several key advances in diesel technology have made it possible to reduce missions coming from the engine prior to aftertreatment. These technologies include, engine friction and parasitic loss reduction, improved fuel systems (higher injection pressure and multiple-injection capability), advanced controls and sensors to optimize combustion and emissions performance, higher EGR levels and EGR cooling to reduce NOx, and advanced turbocharging systems.

2.3.2.1 Low Friction Lubricants

Consistent with the discussion above for gasoline engines (see Section 2.3.1.1), the agencies are expecting some engine changes to accommodate low friction lubricants. Based on 2012-2016 Light-duty final rule, and previously-received confidential manufacturer data, NHTSA and EPA estimated the effectiveness of low friction lubricants to be between 0 to 1 percent.

In the 2012-2016 light-duty FRM, the agencies estimated the cost of moving to low friction lubricants at $3 per vehicle (2007$). That estimate included a markup of 1.11 for a low complexity technology. For Class 2b and 3, we are using the same base estimate but have marked it up to 2008 dollars using the GDP price deflator and have used a markup of 1.17 for a low complexity technology to arrive at a value of $4 per vehicle. As in the light-duty rule, learning effects are not applied to costs for this technology and, as such, this estimate applies to all model years.[3,4]

2.3.2.2 Engine Friction Reduction

Engine Friction Reduction: Reduced friction in bearings, valve trains, and the piston-to-liner interface will improve efficiency. Friction reduction opportunities in the engine valve train and at its roller/tappet interfaces exist for several production engines. In virtually all production engines, the piston at its skirt/cylinder wall interface, wrist pin and oil ring/cylinder wall interface offer opportunities for friction reduction. Use of more advanced oil lubricant that could be available for production in the future can also play a key role in reducing friction. Any friction reduction must be carefully developed to avoid issues with durability or performance capability. Estimations of fuel consumption improvements due to reduced friction range from 0 percent to 2 percent. [TIAX, Assessment of Fuel Economy Technologies for Medium- and Heavy- Duty Vehicles, Final Report, Nov. 19, 2009, pg 4-15].

Consistent with the cost estimated for gasoline engines, the agencies estimate the cost of engine friction reduction at $14 per cylinder compliance cost (2008$), including the low

[3] Note that throughout the cost estimates for this HD analysis, the agencies have used slightly higher markups than those used in the 2010-2016 light-duty FRM. The new, slightly higher ICMs include return on capital of roughly 6 percent, a factor that was not included in the light-duty analysis.

[4] Note that the costs developed for low friction lubes for this analysis reflect the costs associated with any engine changes that would be required as well as any durability testing that may be required.

complexity ICM of 1.17, for a MY 2014 vehicle (learning effects are not applied to engine friction reduction). This cost is multiplied by the number of engine cylinders.

2.3.2.3 Combustion and Fuel Injection System Optimization

More flexible fuel injection capability with higher injection pressure provides more opportunities to improve engine fuel economy, while maintaining the same emission level. Combustion system optimization features system level integration and match, which includes piston bowl, injector tip and the number of holes, and intake swirl ratio. Cummins reports 9.1 percent improvement in fuel consumption as opposed to 2007 baseline while meeting Tier2 Bin 5 emissions when the combustion and fuel injection system are integrated with other technologies, such as advanced and integrated aftertreatment technology, and advanced air handling system (D. Stanton, Cummins, August, 2009 DEER Conference). Translating this improvement with 2010 baseline engine, this could result in 4-6 percent improvement assuming that 2010 baseline engine has 3-5 percent advantage in fuel economy over 2007 engine baseline.

The cost for this technology includes costs associated with low temperature exhaust gas recirculation (see Section 2.3.2.4) and improved turbochargers (see Section 2.3.2.5). These costs are considered collectively in our costing analysis and termed “diesel engine improvements.” The agencies have estimated the cost of diesel engine improvements based on the TIAX report which estimated the retail price equivalent at $500 using a 2 times multiplier. Dividing that value gives a direct manufacturing cost of $250. Applying a low complexity ICM of 1.17 and time based learning from 2012 forward results in the agencies’ estimate of $275 (2008$) in the 2014MY.

2.3.2.4 Low Temperature Exhaust Gas Recirculation

Low temperature exhaust gas recirculation could be one of options to improve engine performance. Most medium vehicle diesel engines sold in the U.S. market today use cooled EGR, in which part of the exhaust gas is routed through a cooler (rejecting energy to the engine coolant) before being returned to the engine intake manifold. EGR is a technology employed to reduce peak combustion temperatures and thus NO_x. Low-temperature EGR uses a larger or secondary EGR cooler to achieve lower intake charge temperatures, which tend to further reduce NO_x formation. Low-temperature EGR can allow changes such as more advanced injection timing that will increase engine efficiency slightly more than 1 percent (NESCCAF/ICCT, 2009, p. 62). Because low-temperature EGR reduces the engine’s exhaust temperature, it may not be compatible with exhaust energy recovery systems such as turbocompound or a bottoming cycle.

The agencies’ cost estimate for this technology is discussed in Section 2.3.2.3.

2.3.2.5 Turbocharger Technology

Compact two stage turbochargers can increase the boost level with wider operation range, thus improving engine thermal efficiency. Ford’s new developed 6.7L Scorpion engine features twin-compressor turbocharger. Cummins is also developing their own two stage turbochargers (D. Stanton, Cummins, August, 2009 DEER Conference). It is expected that this type of technology will continue to be improved by better matching with system and developing higher compressor and turbine efficiency.

The agencies' cost estimate for this technology is discussed in Section 2.3.2.3.

2.3.2.6 Reduction of Parasitic Loads

Accessories that are traditionally gear or belt driven by a vehicle's engine can be optimized and/or converted to electric power. Examples include the engine water pump, oil pump, fuel injection pump, air compressor, power-steering pump, cooling fans, and the vehicle's air-conditioning system. Optimization and improved pressure regulation may significantly reduce the parasitic load of the water, air and fuel pumps. Electrification may result in a reduction in power demand, because electrically powered accessories (such as the air compressor or power steering) operate only when needed if they are electrically powered, but they impose a parasitic demand all the time if they are engine driven. In other cases, such as cooling fans or an engine's water pump, electric power allows the accessory to run at speeds independent of engine speed, which can reduce power consumption. Electrification of accessories can individually improve fuel consumption, but as a package on a hybrid vehicle it is estimated that 3 to 5 percent fuel consumption reduction is possible.[8] The TIAX [2009, pg. 3-5] study used 2 to 4 percent fuel consumption improvement for accessory electrification, with the understanding that electrification of accessories will have more effect in short-haul/urban applications and less benefit in line-haul applications.

Consistent with the 2012-2016 light-duty rule (where this technology was referred to as improved accessories), the agencies estimate the cost for this technology at $88 (2008$) for a 2014MY vehicle. This estimate includes a low complexity ICM of 1.17 and time based learning.

2.3.2.7 Improved Aftertreatment Efficiency and Effectiveness

Improved SCR Conversion Efficiency: Selective Catalytic Reduction (SCR) systems are used by several manufacturers to control NO_x emissions. 2010 fuel consumption was reduced 3 to 4 percent when compared to 2009, depending upon the manufacturer [2009, TIAX]. Additional improvements of 4 percent relative to 2010 may be reasonably expected as system effectiveness increases and accumulated knowledge is applied in calibration. Additionally, as SCR system effectiveness is improved, Diesel particulate filters (DPF) may be better optimized to reduced particulate loading (ability to run at higher engine out NO_x), reducing the associated pressure drop associated with their presence in the exhaust system. Such DPF changes may result in a 1.0 – 1.5 percent fuel consumption reduction [TIAX, 2009, pg. 4-10].

The agencies have estimated the cost of this technology at $25 for each percentage improvement in fuel consumption. This estimate is based on the agencies' belief that this technology is, in fact, a very cost effective approach to improving fuel consumption. As such, $25 per percent improvement is considered a reasonable cost. This cost would cover the engineering and test cell related costs necessary to develop and implement the improved control strategies that would allow for the improvements in fuel consumption. Importantly, the engineering work involved would be expected to result in cost savings to the aftertreatment and control hardware (lower platinum group metal (PGM) loadings, lower reductant dosing rates, etc.). Those savings are considered to be included in the $25 per percent estimate described here. Given the 4 percent expected improvement in fuel consumption results in an estimated cost of $110 (2008$) for a 2014MY vehicle. This estimate includes a low complexity ICM of 1.17 and time based learning from 2012 forward.

2.3.3 Drive Train

NHTSA and EPA have also reviewed the transmission technology estimates used in the 2012-2016 light duty final rule. In doing so, NHTSA and EPA considered or reconsidered all available sources and updated the estimates as appropriate. The section below describes each of the transmission technologies considered for this rulemaking.

2.3.3.1 Improved Automatic Transmission Control (IATC) (Aggressive Shift Logic and Early Torque Converter Lockup)

Calibrating the transmission shift schedule to upshift earlier and quicker, and to lock-up or partially lock-up the torque converter under a broader range of operating conditions can reduce fuel consumption and CO_2 emissions. However, this operation can result in a perceptible degradation in noise, vibration, and harshness (NVH). The degree to which NVH can be degraded before it becomes noticeable to the driver is strongly influenced by characteristics of the vehicle, and although it is somewhat subjective, it always places a limit on how much fuel consumption can be improved by transmission control changes. Given that the Aggressive Shift Logic and Early Torque Converter Lockup are best optimized simultaneously due to the fact that adding both of them primarily requires only minor modifications to the transmission or calibration software, these two technologies are combined in the modeling.

2.3.3.2 Aggressive Shift Logic

During operation, an automatic transmission's controller manages the operation of the transmission by scheduling the upshift or downshift, and locking or allowing the torque converter to slip based on a preprogrammed shift schedule. The shift schedule contains a number of lookup table functions, which define the shift points and torque converter lockup based on vehicle speed and throttle position, and other parameters such as temperature. Aggressive shift logic (ASL) can be employed in such a way as to maximize fuel efficiency by modifying the shift schedule to upshift earlier and inhibit downshifts under some conditions, which reduces engine pumping losses and engine friction. The application of this technology does require a manufacturer to confirm that drivability, durability, and NVH are not significantly degraded.

We consider this technology to be present in the baseline, 6-speed automatic transmissions in the majority of class 2b and 3 trucks in the 2010 model year timeframe.

2.3.3.3 Early Torque Converter Lockup

A torque converter is a fluid coupling located between the engine and transmission in vehicles with automatic transmissions and continuously-variable transmissions (CVT). This fluid coupling allows for slip so the engine can run while the vehicle is idling in gear (as at a stop light), provides for smoothness of the powertrain, and also provides for torque multiplication during acceleration, and especially launch. During light acceleration and cruising, the inherent slip in a torque converter causes increased fuel consumption, so modern automatic transmissions utilize a clutch in the torque converter to lock it and prevent this slippage. Fuel consumption can be further reduced by locking up the torque converter at lower vehicle speeds, provided there is sufficient power to propel the vehicle, and noise and vibration are not excessive. If the torque converter cannot be fully locked up for maximum efficiency, a partial lockup strategy can be employed to reduce slippage. Early torque converter lockup is applicable to all vehicle types with automatic transmissions. Some torque converters will require upgraded clutch materials to withstand additional loading and the slipping conditions during partial lock-up. As with aggressive shift logic, confirmation of acceptable drivability, performance, durability and NVH characteristics is required to successfully implement this technology.

We consider this technology to be present in the baseline, 6-speed automatic transmissions in the majority of class 2b and 3 trucks in the 2010 model year timeframe.

2.3.3.4 Automatic 6- and 8-Speed Transmissions

Manufacturers can also choose to replace 4- and 5-speed transmission with 6- or 8-speed automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional planetary gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers need to develop strategies for smooth shifts. Some manufacturers are replacing 4- and 5-speed automatics with 6-speed automatics, and 7- and 8-speed automatics have also entered production, albeit in lower-volume applications in luxury and performance oriented cars.

As discussed in the 2012-2016 light duty final rule, confidential manufacturer data projected that 6-speed transmissions could incrementally reduce fuel consumption by 0 to 5 percent from a baseline 4-speed automatic transmission, while an 8-speed transmission could incrementally reduce fuel consumption by up to 6 percent from a baseline 4-speed automatic transmission. GM has publicly claimed a fuel economy improvement of up to 4 percent for its new 6-speed automatic transmissions.

NHTSA and EPA reviewed and revised these effectiveness estimates based on usage and testing methods for Class 2B and 3 vehicles along with confidential business information. When combined with IATC, the agencies estimate the effectiveness for a conversion from a 4 to a 6-speed transmission to be 5.3 percent and a conversion from a 6 to 8-speed transmission to be 1.7 percent for the NPRM.

As for costs, the agencies have considered the recent study conducted by NAS (NAS 2010) which showed an incremental cost of $210 for an 8 speed automatic transmission relative to a 6 speed automatic transmission (the baseline technology for 2010MY Class 2b & 3 pickups and vans). Considering this to be a valid cost for 2012MY and applying a low complexity ICM of 1.17 results in a cost of $246 in 2012. Considering time based learning to be appropriate for automatic transmissions and applying two years of time based learning results in a 2014MY cost of $231 (2008$). This technology is considered applicable to both gasoline and diesel trucks and vans.

2.3.3.5 Electric Power Steering/Electro-hydraulic Power Steering (EPS/EHPS)

Electric power steering (EPS) or Electrohydraulic power steering (EHPS) provides a potential reduction in CO2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles may require a higher voltage system which may add cost and complexity.

The 2010 light-duty final rule estimated a 1 to 2 percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer data. NHTSA and EPA reviewed these effectiveness estimates and found them to be accurate, thus they have been retained for this final rule.

NHTSA and EPA adjusted the EPS cost for the current rulemaking based on a review of the specification of the system. Adjustments were made to include potentially higher voltage or heavier duty system operation for class 2b and 3. Accordingly, higher costs were estimated for systems with higher capability. After accounting for the differences in system capability and applying the ICM markup of low complexity technology of 1.17, the estimated costs for this proposal are $108 for a MY 2014 truck or van (2008$). As EPS systems are in widespread usage today, time-based learning is deemed applicable. EHPS systems are considered to be of equal cost and both are considered applicable to gasoline and diesel engines.

2.3.4 Aerodynamics

Aerodynamic drag is an important aspect of the power requirements for Class 2b and 3 trucks. Because aerodynamic drag is a function of the cube of vehicle speed, small changes in the aerodynamics of a Class 2b and 3 can reduce drag, fuel consumption, and GHG emissions. Some of the opportunities to reduce aerodynamic drag in Class 2b and 3 vehicles are similar to those in Class 1 and 2 (i.e., light duty) vehicles. In general, these transferable features make the cab shape more aerodynamic by streamlining the airflow over the bumper, grill, windshield, sides, and roof. Class 2b and 3 vehicles may also borrow from light-duty vehicles certain drag reducing accessories (e.g., streamlined mirrors, operator steps, and sun visors). The great variety of applications for Class 2b and 3 trucks result in a wide range of operational speed profiles (i.e., in-use drive cycles) and functional requirements (e.g., shuttle buses that must be tall enough for standing passengers, trucks that must have racks for ladders). This variety makes it challenging to develop aerodynamic solutions that consider the entire vehicle.

Consistent with the 2012-2016 light-duty rule, the agencies have estimated the cost for this technology at $54 (2008$) including a low complexity ICM of 1.17. This cost is applicable in the 2014 model year to both gasoline and diesel trucks and vans.

2.3.5 Tires

Typically, tires used on Class 2b/3 vehicles are not designed specifically for the vehicle. These tires are designed for broader use and no single parameter is optimized. Similar to vocational vehicles, the market has not demanded tires with improved rolling resistance; therefore, manufacturers have not traditionally designed tires with low rolling resistance for Class 2b/3 vehicles. EPA believes that a regulatory program that incentivizes the optimization of tire rolling resistance, traction and durability can bring about GHG emission reductions from this segment.

Based on the 2012-2016 Light-duty final rule and the 2010 NAS report, the agencies have estimated the cost for low rolling resistance tires to be $6 per Class 2b truck or van, and $9 per Class 3 truck or van.[5] The higher cost for the Class 3 trucks and vans is due to the predominant use of dual rear tires and, thus, 6 tires per truck. Due to the commodity-based nature of this technology, cost learning is not applied. This technology is considered applicable to both gasoline and diesel.

2.4 Heavy Duty Engines

The proposed regulatory structure for heavy duty engines separates the compression ignition (or "diesel") engines into three regulatory classes and from spark ignition (or "gasoline") engines into a single regulatory class. Therefore, the subsequent discussion will assess each type of engine separately.

The Light Heavy Duty Diesel engines typically range between 4.7 and 6.7 liters displacement, the Medium Heavy Duty Diesel engines typically have some overlap in displacement with the Light Heavy Duty Diesel engines and range between 6.7 and 9.3 liters. The Heavy Duty Diesel engines typically are represented by engines between 10.8 and 16 liters. The heavy duty gasoline engines have ranged in the past between 4.8 and 8.1 liters.

2.4.1 Spark Ignition Engines

Spark ignition engines are certified for the heavy duty market. These engines typically range in displacement between five and eight liters and are either V8 or V10

[5] "Tires and Passenger Vehicle Fuel Economy," Transportation Research Board Special Report 286, National Research Council of the National Academies, 2006, Docket EPA-HQ-OAR-2009-0472-0146.

configurations. As found in the NAS study, most are either V8 or V10 engines with port fuel injection, naturally aspirated with fixed valves. In the recent past, the primary producers of the gasoline engines were limited to Ford and General Motors. The engines sold separately, which require an engine certificate in lieu of a chassis certificate, are the same as or very similar to the engines used in the pickup truck and vans. Therefore, NHTSA and EPA developed the baseline, list of engine technologies, and standards to reflect this commonality.

2.4.1.1 Baseline SI Engine CO_2 and Fuel Consumption

Similar to the gasoline engine used as the baseline in the Light Duty GHG rule (an assumption not questioned in the comments to that rulemaking), the agencies assumed the baseline engine in this segment to be a naturally aspirated, single overhead valve V8 engine. The following discussion of effectiveness is generally in comparison to 2010 baseline engine performance.

NHTSA and EPA developed the baseline fuel consumption and CO_2 emissions for the gasoline engines from manufacturer reported CO_2 values used in the certification of non-GHG pollutants. The baseline engine for the analysis was developed to represent a 2011 model year engine, because this is the most current information available. The average CO_2 performance of the heavy duty gasoline engines was 660 g/bhp-hour, which will be used as a baseline.

2.4.1.2 Gasoline Engine Technologies

The engine technologies projected for the gasoline heavy-duty engines are based on the technologies used in the Light Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document.[10] The effectiveness of the technology packages were evaluated using the EPA Lumped Parameter model HD Version 1.0.0.1.[11] The HD version of the Lumped Parameter model includes a subset of the technologies included in the Large Pickup Truck version of the Light Duty rulemaking to recognize that some technologies will have limited effectiveness due to the higher operating weights of these trucks. The HD Lumped Parameter model also has reduced the effectiveness of several of the individual technologies again to recognize the higher test weights used in regulatory programs.

2.4.1.2.1 Engine Friction Reduction

In addition to low friction lubricants, manufacturers can also reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. Additionally, as computer-aided modeling software continues to improve, more opportunities for evolutionary friction reductions may become available. All reciprocating and rotating components in the engine are potential candidates for friction reduction, and minute improvements in several components can add up to a measurable fuel economy improvement. The 2012-2016 light duty rule, 2010 NAS, NESCCAF and EEA reports as well as confidential manufacturer data suggested a range of effectiveness for engine friction reduction to be between 1 to 3 percent. NHTSA and EPA continue to believe that this range is accurate.

NHTSA and EPA believe that the cost estimate is closer to the lower end of the model year (MY) 2011 CAFE final rule range and thus for this rulemaking is proposing $9 per cylinder compliance cost (2008$), plus a low complexity Indirect Cost Multiplier (ICM) markup value of 1.17, for a MY 2016 engine (learning effects are not applied to engine friction reduction). This cost is multiplied by the eight cylinders resulting in a cost of $88 (2008$) per engine for this technology.

2.4.1.2.2 Coupled Cam Phasing

Valvetrains with coupled (or coordinated) cam phasing (CCP) can modify the timing of both the inlet valves and the exhaust valves an equal amount by phasing the camshaft of a single overhead cam (SOHC) engine or an overhead valve (OHV) engine. For overhead cam engines, this requires the addition of a cam phaser on each bank of the engine so SOHC V-engines have two cam phasers. For overhead valve (OHV) engines, which have only one camshaft to actuate both inlet and exhaust valves, CCP is the only variable valve timing (VVT) implementation option available and requires only one cam phaser. Based on 2010 Light Duty final rule, previously-received confidential manufacturer data, and the NESCCAF report, NHTSA and EPA estimated the effectiveness of CCP to be between 1 to 4 percent. NHTSA and EPA reviewed this estimate for purposes of the NPRM, and continue to find it accurate.

Consistent with the 2010 2012-2016 Light Duty final rule, NHTSA and EPA estimate the cost of a cam phaser at $46 (2008$) in the 2014MY. This estimate includes a low complexity ICM of 1.17. With two years of time based learning this cost becomes $43 (2008$) in the 2016MY. All heavy-duty gasoline loose engines are over-head valve engines (OHV) and, as such, would require only one cam phaser for coupled cam phasing.

2.4.1.2.3 Cylinder Deactivation

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation (DEAC) can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this "part cylinder" mode.

Cylinder deactivation control strategy relies on setting maximum manifold absolute pressures or predicted torque within which it can deactivate the cylinders. Noise vibration and harshness (NVH) issues reduce the operating range to which cylinder deactivation is allowed, although manufacturers are exploring vehicle changes that enable increasing the amount of time that cylinder deactivation might be suitable. Some manufacturers may choose to adopt active engine mounts and/or active noise cancellations systems to address NVH concerns and to allow a greater operating range of activation. Cylinder deactivation has seen a recent resurgence thanks to better valvetrain designs and engine controls. General Motors and Chrysler Group have incorporated cylinder deactivation across a substantial portion of their V8-powered lineups.

Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently. NHTSA and EPA adjusted the 2010 Light Duty final rule estimates using updated power to weight ratings of heavy-duty trucks and confidential business information and confirmed a range of 3 to 4 percent for these vehicles.

Consistent with the 2012-2016 light-duty FRM, NHTSA and EPA have estimated the cost of cylinder deactivation at $193 for the 2014MY (2008$). This estimate includes a low complexity ICM of 1.17. With two years of time based learning, this cost becomes $181 (2008$) in the 2016MY.

2.4.1.2.4 Stoichiometric gasoline direct injection

(SIDI), engines inject fuel at high pressure directly into the combustion chamber (rather than the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs. NHTSA and EPA estimate the range of 1 to 2 percent improvement for SGDI.

The NHTSA and EPA cost estimates for SGDI take into account the changes required to the engine hardware, engine electronic controls, ancillary and NVH mitigation systems. Through contacts with industry NVH suppliers, and manufacturer press releases, the agencies believe that the NVH treatments will be limited to the mitigation of fuel system noise, specifically from the injectors and the fuel lines.

The NHTSA and EPA cost estimates for SGDI take into account the changes required to the engine hardware, engine electronic controls, ancillary and Noise Vibration and Harshness (NVH) mitigation systems. Through contacts with industry NVH suppliers, and manufacturer press releases, the agencies believe that the NVH treatments will be limited to the mitigation of fuel system noise, specifically from the injectors and the fuel lines.

Consistent with the 2012-2016 light-duty rule, the agencies estimate the cost of conversion to SGDI on a V8 engine at $395 (2008$) for the 2014MY. This estimate includes a low complexity ICM of 1.17. With two years of time based learning, this cost becomes $372 (2008$) in the 2016MY.

2.4.1.3 Derivation of Gasoline Engine Standard

The average CO_2 performance of the two heavy duty gasoline engines certified for 2010 and 2011 model years was 660 g CO_2/bhp-hour. The HD Lumped Parameter model analysis projects that the package of the three technologies (friction reduction, closed couple cam phasing, and stoichiometric direct injection) could reduce CO_2 emissions and fuel consumption by 5 percent. Therefore, the agencies are proposing to set the standard in 2016 model year at 627 g CO_2/bhp-hr.

2.4.1.4 SI Engine Technology Cost

The overall projected engine package cost in for a 2016 model year engine is $474 (2008$).

Table 2-3

	2016
Engine Friction Reduction	$80
Coupled Cam Phasing	$41
Stoichiometric Gas Direct Injection	$353
Total	$474

2.4.2 Diesel Engines

2.4.2.1 Baseline Engines

The agencies developed the baseline diesel engine as a 2010 model year engine with an aftertreatment system which meets EPA's 0.2 grams of NOx/bhp-hr standard with a selective catalytic reduction (SCR) system along with EGR and meets the PM emissions standard with a diesel particulate filter (DPF) with active regeneration. The engine is turbocharged with a variable geometry turbocharger. The following discussion of technologies describes improvements over the 2010 model year baseline engine performance, unless otherwise noted.

The CO_2 performance over the FTP for the baseline engines were developed through manufacturer reporting of CO_2 in their non-GHG certification applications for 2010 model year. This data was carefully considered to insure that the baseline represented an engine meeting the 0.2 g/bhp-hr NOx standard. For those engines that were not at this NOx level or higher, then the agencies derived a CO_2 correction factor to bring them to a 0.2 g/bhp-hr NOx emissions. The CO_2 correction factor is derived based on available experimental data obtained from manufacturers and public literature. The agencies then sales-weighted the CO_2 performance to derive a baseline CO_2 performance for each engine class.

In order to establish baseline SET performance for the Heavy Heavy Duty and Medium Heavy Duty Diesel Engines, several sources were considered. Some engine manufacturers provided the agencies SET modal results or fuel consumption maps to represent their 2009 model year engine fuel consumption performance. As a supplement to this, complete engine map CO_2 data (including SET modes) acquired in EPA test cells were also considered. The pre-2010 maps are subsequently adjusted to represent 2010 model year engine maps by using predefined technologies including SCR and other advanced systems that are being used in current 2010 production.

In summary, the baseline CO2 performance for each diesel engine category is included in Table 2-4.

Table 2-4: Baseline CO_2 Performance (g/bhp-hr)

LHDD - FTP	MHDD - FTP	HHDD - FTP	HHDD - SET
630	630	584	490

The agencies used the baseline engine to assess the potential of each of the following technologies.

2.4.2.2 Combustion System Optimization

Continuous improvements on the fuel injection system allows more flexible fuel injection capability with higher injection pressure, which can provide more opportunities to improve engine fuel economy, while maintaining the same emission level. Combustion system optimization, featuring piston bowl, injector tip and the number of holes, in conjunction with the advanced fuel injection system, is able to further improve engine performance and fuel economy. At this point, all engine manufacturers spearhead substantial efforts into this direction in the hope that their development efforts would be translated into production in the near futures. The examples include the combustion development programs conducted by Cummins and Detroit Diesel (D. Stanton, Cummins, 2009 DOE Semi-Mega Merit Review, May 21, 2009, and H. Zhang, 2009 DOE Semi-Mega Merit Review, May 21, 2009) , funded by Department of Energy. They both claim that 10 percent thermal efficiency improvement at 2010 emission level is achievable. While their findings are still more towards research environment, their results do enhance the possibility that some of technologies they are developing could be applied to production in the time frame of 2017.

The cost for this technology includes costs associated with low temperature exhaust gas recirculation (see Section 2.3.2.4) and improved turbochargers (see Section 2.3.2.5). These costs are considered collectively in our costing analysis and termed “diesel engine improvements.” The agencies have estimated the cost of diesel engine improvements based on the TIAX report which estimated the retail price equivalent at $500 using a 2 times multiplier. Dividing that value gives a direct manufacturing cost of $250. Applying a low complexity ICM of 1.11 and time based learning from 2012 forward results in the agencies’ estimate of $217 (2008$) in the 2014MY. This cost is applicable only to light-heavy HD diesel engines.

2.4.2.3 Turbochargers

Many advanced turbocharger technologies can be potentially added into production in the time frame between 2014 and 2017, and some of them are already in production. Mechanical turbo-compound, two stages of turbochargers with intercooler, and high efficient low speed compressor are just names of a few.

Turbo-compound has been used in production by Detroit Diesel for their DD15 and DD16 engines. It is a system with a power turbine that is added to the downstream of the turbine to extract additional energy from the exhaust. The power turbine is connected to the crankshaft to supply additional power (NESCCAF/ICCT, 2009, p. 81). Typically, the attachment includes a fluid coupling (to allow for speed variation and to protect the power turbine from engine torsional vibration) and a gear set to match power turbine speed to crankshaft speed. Published information on the fuel consumption reduction from mechanical turbocompounding varies, as evidenced by the following: 3 -5 percent, according to the Detroit Diesel Corporation[5] which has a turbocompound engine in production; 2.5 to 3 percent (NESCCAF/ICCT, 2009, p. 54); 3 percent (K. G. Duleep of Energy and Environmental Analysis)[6]; 4 to 5 percent (R. Kruiswyk, 2008, pp. 212-214); and TIAX (2009, pp. 4-17) used 2.5 to 3 percent. Some of these differences may depend on the operating condition or duty cycle that was considered by the different researchers. The performance of a turbocompound system tends to be highest at full load and much less or even act as a energy sink to suck the energy at light loads. Because of that, a clutch that can separate the engine crankshaft from turbo-compound gear train could be proposed and put into production in order to overcome the drawbacks of turbo-compound at light loads, thus improving fuel economy over the entire speed and load ranges. Incremental cost increases associated with the addition of mechanical turbocompounding are significant, due to the complexity of the mechanical power transmission system required to connect the power turbine to the drivetrain. Such costs are estimated to be $1040 inclusive of an RPE factor of 1.28 (i.e., $813 in direct manufacturing costs).

Electric turbo-compound is another potential device, although it is still not as mature in terms of production as opposed to mechanical turbo-compound. This approach is similar in concept to mechanical turbocompound, except that the power turbine drives an electrical generator (NESCCAF/ICCT, 2009, p. 29). The electricity produced can be used to power an electrical motor supplementing the engine output, to power electrified accessories, or to charge a hybrid system battery. Electric turbocompound is a technology that fits particularly well with a hybrid electric powertrain for long-haul applications where regenerative braking opportunities are limited. The benefits of electric turbocompound and an electric hybrid powertrain can be additive. The NESCCAF/ICCT study (p. 54) modeled an electric turbocompound system and estimated benefits at 4.2 percent, including electrification of accessories. Caterpillar, Inc., as part of Department of Energy (DOE) funded work, modeled a system that showed 3 to 5 percent improvement, while John Deere investigated a system (off-highway) that offered 10 percent improvement (Vuk 2006; TIAX, 2009, p. A-10). None of these systems have been demonstrated commercially. TIAX (2009, pp. 3-5) used a range of 4 to 5 percent for its estimates, which included the benefits of electric accessories.

Two-stage turbocharger technology has been used in production by Navistar and other manufacturers. Ford's new developed 6.7L Scorpion engine features twin-compressor turbocharger. Higher boost with wider range of operations and higher efficiency can further enhance engine performance, thus fuel economy. It is expected that this type of technology will continue to be improved by better matching with system and developing higher compressor and turbine efficiency.

For this analysis, we have estimated the cost of turbo-compounding at $823 (2008$). This estimate includes a low complexity ICM of 1.11. This cost is applicable in the 2017MY when engines being placed in long-haul (i.e., sleeper cab) trucks are expected to add this technology. Time based learning is considered applicable to this technology. For the more basic technology of improving the turbo efficiency, the agencies have estimated a cost of $17 (2008$) including a low complexity ICM of 1.11. That estimate would be considered valid in the 2014MY and time based learning would be applied going forward.

2.4.2.4 Engine Parasitic and Friction Reduction

Engine parasitic and friction reduction is another key technical areas that can be further improved in production moving to 2014 and 2017 time frame. Reduced friction in bearings, valve trains, and the piston-to-liner interface will improve efficiency. Friction reduction opportunities in the engine valve train and at its roller/tappet interfaces exist for several production engines. The piston at its skirt/cylinder wall interface, wrist pin and oil ring/cylinder wall interface offers opportunities for friction reduction. Use of more advanced oil lubricant that could be available for production in the future can also play a key role in reducing friction. Any friction reduction must be carefully developed to avoid issues with durability or performance capability. Estimations of fuel consumption improvements due to reduced friction range from 0 percent to 2 percent. [TIAX, Assessment of Fuel Economy Technologies for Medium- and Heavy- Duty Vehicles, Final Report, Nov. 19, 2009, pg 4-15]. All fuel injection system manufacturers are working hard to reduce parasitic loss due to high pressure pumps and common rail flow loss in the hope that those development would add up further fuel economy improvement.

Incremental manufacturing costs increases associated with the reduction of parasitics and friction may include those associated with an optimized, electric water pump, replacing a mechanically driven water pump ($100). Additionally, an improved mechanical oil pump with more efficient relief mechanism and optimized hydrodynamic design may incur costs ($5). A fuel pump capable of delivering higher pressures and with efficient regulation may require improved materials and more elaborate regulating hardware ($5). Improved Pistons with less friction generated at the skirt may require incrementally more precision in finish machine operations ($3). Finally, a more efficient, reduced friction valve train will require more precise machining processes and an increased parts count ($90). All costs presented here are considered to include a retail price equivalent factor of 1.28.

Removing the 1.28 RPE factor from the above cost estimates and instead applying a low complexity ICM of 1.11 results in the following costs: electric water pump, $87; improved mechanical oil pump, $4, improved fuel pump, $4; improved pistons, $3; reduced friction valve train, \$78. All costs are in 2008 dollars. Time based learning is considered applicable to all of these costs.

2.4.2.5 Advanced Model Based Control

Significant progresses on advanced model based control have been made in the past few years. Detroit Diesel introduced the next generation model based control concept, achieving 4 percent thermal efficiency improvement while simultaneously reducing emissions in transient operations (H. Zhang etc., DEER conference, Dearborn, Michigan, August 6, 2008). Their model based concept features a series of real time optimizers with multiple inputs and multiple outputs. This controller contains many physical based models for engine and aftertreatment. It produces fully transient engine performance and emissions predictions in a real-time manner. Although this control concept may still not be mature in 2014 production, it would be a realistic estimate that this type of real time model control could be in production before 2017, thus significantly improving engine fuel economy.

2.4.2.6 Integrated Aftertreatment System

All manufacturers use diesel particulate filter (DPF) to reduce particulate matter (PM). All except Navistar rely on SCR to reduce NOx emissions. Periodic regeneration to remove loaded soot is required for all DPF. One way is to directly inject the fuel into exhaust stream, called active regeneration, and a diesel oxidation catalyst (DOC) or other device then oxidizes the fuel in the exhaust stream, providing the heat required for DPF regeneration and increasing the fuel consumption of the vehicle. The other method is to use NO_2, called passive regeneration, to directly react with soot at much lower exhaust temperature than active regeneration. Use of advanced thermal management could be made in production to eliminate active regeneration, thus significantly improve fuel economy. Volvo has announced in 2009 that their 2010 DPF+SCR system has eliminated active regeneration for on-highway vehicles. All other manufacturers are working in the same direction, minimizing or eliminating active regeneration, thus improving fuel economy at least by 1 percent.

Higher SCR NO_x conversion efficiency will allow higher engine-out NO_x emissions, and therefore, will give more room for engine system optimization, while maintaining the same or even less diesel engine fluid (DEF) consumption. Advanced model based control on DEF usage and slip can further improve DEF consumption, thus fuel economy. For those manufacturers that use SCR as their NO_x reduction devices, properly integrated DPF and SCR system is essential, which is not only able to improve emissions reductions, but also to improve fuel economy through more advancing canning design, thus minimizing pressure drop across the system. Improvements in aftertreatment system efficiency should be cost neutral, requiring no increases in precious metal loading or manufacturing expense.

The agencies have estimated the cost of this technology at \$25 for each percentage improvement in fuel consumption. This estimate is based on the agencies' belief that this technology is, in fact, a very cost effective approach to improving fuel consumption. As such, \$25 per percent improvement is considered a reasonable cost. This cost would cover the engineering and test cell related costs necessary to develop and implement the improved control strategies that would allow for the improvements in fuel consumption. Importantly, the engineering work involved would be expected to result in cost savings to the aftertreatment and control hardware (lower platinum group metal (PGM) loadings, lower reductant dosing rates, etc.). Those savings are considered to be included in the $25 per percent estimate described here. Given the 4 percent expected improvement in fuel consumption results in an estimated cost of $110 (2008$) for a 2014MY vehicle. This estimate includes a low complexity ICM of 1.11 and time based learning from 2012 forward. Note that this cost is applied only to light-heavy HD diesel engines. The cost for this technology is considered separately for medium and heavy HD diesel engines since the cost is considered largely one of research and development which probably results in lower actual part cost.

2.4.2.7 Electrification

Many accessories that are traditionally gear or belt driven by a vehicle's engine can be decoupled with the engine speed, so that those accessories can be tailored to a specific engine speed, thus better efficiency. Examples include the engine water pump, oil pump, fuel injection pump, air compressor, power-steering pump, cooling fans, and the vehicle's air-conditioning system. The most tangible development toward production in 2017 time frame would be electric water and oil pumps. It is expected that about 0.5 to 1.0 percent thermal efficiency improvement could be achieved with electrification of these two pumps.

Costs for electrification are considered as part of the costs for improved water and oil pumps discussed in Section 2.4.2.4.

2.4.2.8 Waste Heat Recovery

A bottoming cycle uses exhaust energy or other heat sources from the primary engine to develop additional power without using additional fuel. A typical bottoming cycle consists of the following components: a feed pump to drive the working fluid from the condenser to the evaporator (or boiler); the evaporator, which transfers waste heat energy from the primary engine to the working fluid; an expander, which takes energy from the working fluid to make mechanical power; and a condenser that rejects unused heat energy from the bottoming cycle working fluid before starting a new cycle. While it is still questionable whether this technology would be put into production before 2014 model year, significant progress has been made recently. Cummins, Inc. has shown a projected increase of thermal efficiency from 49.1 to 52.9 percent (7.2 percent decrease in fuel consumption) using an organic Rankine cycle. Cummins reports recovering 2.5 thermal efficiency points from the exhaust and 1.3 thermal efficiency points from the coolant and EGR stream.[16] The NESCCAF/ICCT report (2009, pp. 55-56) showed the effect of a steam bottoming cycle to reduce fuel consumption by up to 10 percent. The costs of implementing a Waste Heat Recovery system are significant, estimated at $1700. Such costs include necessary power extraction unit and gearbox, heat exchangers and compressor.

2.4.2.9 2014 Model Year HHDD Engine Package

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement in the 2014 model year. The agencies considered improvements in parasitic and friction losses through piston designs to reduce friction, improved lubrication, and improved water pump and oil pump designs to reduce parasitic losses. The aftertreatment improvements are available through lower backpressure of the systems and optimization of the engine-out NOx levels. Improvements to the EGR system and air flow through the intake and exhaust systems, along with turbochargers can also produce engine efficiency improvements. Lastly, an increase in combustion pressures and controls can reduce fuel consumption of the engine. The projected impact of each set of these technologies is included in Table 2-5. Based on the improvements listed in the table, the overall weighted reduction based on the SET mode weightings is projected at 3 percent

Table 2-5: Projected Percent CO2 Impact for SET Modes in 2014 Model Year

SET Mode	Speed, percentLoad	Parasitic, Friction	Aftertreatment Improvement	Air Handling	Combustion, Control
1	Idle	0.0	0.0	0.0	-0.4
2	A, 100	-0.9	-1.1	-1.1	-0.9
3	B, 50	-0.9	-1.1	-1.1	-1.1
4	B, 75	-1.1	-1.3	-1.3	-1.3
5	A, 50	-0.4	-0.7	-1.1	-0.9
6	A, 75	-0.7	-0.9	-1.3	-1.1
7	A, 25	-0.2	-0.4	-0.9	-0.4
8	B, 100	-1.3	-1.3	-1.3	-0.9
9	B, 25	-0.7	-0.9	-0.9	-0.4
10	C, 100	-1.7	-1.5	-1.3	-0.9
11	C, 25	-0.9	-0.9	-0.9	-0.2
12	C, 75	-1.3	-1.3	-1.1	-0.4
13	C, 50	-1.1	-1.1	-0.9	-0.7

The agencies derived the HHDD FTP technology effectiveness for the 2014 model year based on a similar approach. Using the same technologies as discussed for the HHDD SET above, the agencies project the reductions at 3 percent. It should be pointed out that individual technology improvement is not additive to each other due to the interaction of technology to technology.

The cost estimates for the complete heavy-HD diesel engine packages are shown in [need help with this cross ref to table just below – cannot fix until accept all track changes].

Table 2-6 Technology and Package Costs for Heavy-HDD Engines (2008$)

Technology	2014	2015	2016	2017
Cylinder Head	$6	$6	$6	$6
Turbo efficiency	$17	$17	$16	$16

EGR cooler	$3	$3	$3	$3
Water pump	$87	$84	$82	$79
Oil pump	$4	$4	$4	$4
Fuel pump	$4	$4	$4	$4
Fuel rail	$10	$9	$9	$9
Fuel injector	$10	$10	$10	$9
Piston	$3	$3	$2	$2
Turbo-compounding (engines placed in sleeper cabs only)	$0	$0	$0	$823
HHDD Total	$145	$140	$136	$132
HHDD Total (sleeper cab)	$145	$140	$136	$955

2.4.2.10 2014 Model Year LHDD/MHDD Engine Package

The agencies considered the same 2014 model year technology package developed for the HHDD engines for the LHDD and MHDD engines. The package includes parasitic and friction reduction, improved lubrication, aftertreatment improvements, EGR system and air flow improvements, and combustion pressure increase and controls to reduce fuel consumption of the engine. The agencies project that these improvements will produce a 5 percent reduction in fuel consumption and CO_2.

The cost estimates for the complete medium-HD diesel engines are shown in **Table 2-7**. The cost estimates for the complete light-HD diesel engines are shown in Table 2-8.

Table 2-7 Technology and Package Costs for Medium-HDD Engines (2008$)

Technology	2014	2015	2016	2017
Cylinder Head	$6	$6	$6	$6
Turbo efficiency	$17	$17	$16	$16
EGR cooler	$3	$3	$3	$3
Water pump	$87	$84	$82	$79
Oil pump	$4	$4	$4	$4
Fuel pump	$4	$4	$4	$4
Fuel rail	$10	$9	$9	$9
Fuel injector	$10	$10	$10	$9
Piston	$3	$3	$2	$2
Valve train friction	$78	$76	$73	$71

reduction				
MHDD Total	$223	$216	$210	$203

Table 2-8 Technology and Package Costs for Light-HDD Engines (2008$)

Technology	2014	2015	2016	2017
Aftertreatment improvements	$111	$108	$104	$101
Engine improvements	$217	$210	$204	$198
LHDD Total	$328	$318	$308	$299

2.4.2.11 2014 Model Year Diesel Engine Standards

The agencies applied the 5 percent reduction for the LHDD/MHDD engines and the 3 percent reduction for the HHDD engines based on the projected technology package improvements in 2014 model year to the 2010 model year baseline performance included in Table 2-4. The results are the proposed 2014 model year standards, as shown in Table 2-9.

Table 2-9: 2014 Model Year Proposed Standards (g CO_2/bhp-hr)

LHDD - FTP	MHDD - FTP	HHDD - FTP	MHDD_- SET	HHDD - SET
600	600	567	502	475

2.4.2.12 2017 Model Year HHDD Engine Package

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement in the 2017 model year. The agencies considered additional improvements in the technologies included in the 2014 model year package in addition to turbocompounding. The projected impact of each set of these technologies is included in Table 2-10: . Based on the improvements listed in the table, the overall weighted reduction based on the SET mode weightings is projected at 6 percent.

Costs for 2017 are shown in [help with Cross Ref to table on Heavy-HD diesel costs.

Table 2-10: Projected CO_2 Improvements for SET Modes in 2017 Model Year

SET Mode	Speed, Percent tLoad	Turbo-compounding	Parasitic, Friction	Aftertreatment Improvement	Air handling	Combustion, Control
1	Idle	0.2	0.00	0.00	0.00	-0.50
2	A, 100	-4.50	-1.00	-1.25	-1.25	-1.00
3	B, 50	-2.50	-1.00	-1.25	-1.25	-1.25

4	B, 75	-4.50	-1.25	-1.50	-1.50	-1.50
5	A, 50	-1.50	-0.50	-0.75	-1.25	-1.00
6	A, 75	-4.00	-0.75	-1.00	-1.50	-1.25
7	A, 25	0.20	-0.25	-0.50	-1.00	-0.50
8	B, 100	-5.50	-1.50	-1.50	-1.50	-1.00
9	B, 25	0.30	-0.75	-1.00	-1.00	-0.50
10	C, 100	-5.00	-2.00	-1.75	-1.50	-1.00
11	C, 25	0.50	-1.00	-1.00	-1.00	-0.25
12	C, 75	-3.50	-1.50	-1.50	-1.25	-0.50
13	C, 50	-2.00	-1.25	-1.25	-1.00	-0.75

The agencies derived the HHDD FTP technology package effectiveness for the 2017 model year based on a similar approach. However, the addition of turbocompounding shows a greater effectiveness on the SET cycle than the FTP cycle because of the steady state nature and amount of time spent at higher speeds and loads during the SET. Using the same technologies as discussed for the HHDD SET above, the agencies project the reductions at 5 percent for the FTP. It is noticed that there is a small penalty on CO_2 using turbocomponding at low loads from Table 2-5, since no mechanism to disengage turbocompounding and engine crankshaft is proposed in this table. This means that an introduction of a clutch to disengage turbocompound and engine whenever the turbocompounding does not provide positive work will further improve CO_2 reduction. Similar to Table 2-3, individual technology in Table 2-5 is not additive to each other due to the interaction of technology to technology.

2.4.2.13 2017 Model Year LHDD/MHDD Engine Package

The agencies developed the 2017 model year LHDD/MHDD engine package based on additional improvements in the technologies included in the 2014 model year package. The projected impact of these technologies provides an overall reduction of 9 percent over the 2010 model year baseline.

Costs for the 2017 model year are shown in **Table 2-7** (medium-HD) and Table 2-8 (light-HD).

2.4.2.14 2017 Model Year Diesel Engine Standards

The agencies applied the 8.6 percent reduction for the LHDD/MHDD engines and the 5 percent reduction for the HHDD engines using the FTP and a 6.1 percent reduction for HHDD engines using the SET based on the projected technology package improvements in 2017 model year to the 2010 model year baseline performance included in Table 2-4. The results are the proposed 2014 model year standards, as shown in Table 2-11.

Table 2-11 2017 Model Year Proposed Standards (g CO_2/bhp-hr)

LHDD - FTP	MHDD - FTP	HHDD - FTP	MHDD - SET	HHDD - SET
576	576	555	487	460

2.5 Class 7/8 Day Cabs and Sleeper Cabs

The proposed regulatory classifications for Class 7 and 8 day and sleeper cabs involves seven regulatory classes.

Class 7 Day Cab with Low Roof

Class 7 Day Cab with High Roof

Class 8 Day Cab with Low Roof

Class 8 Day Cab with High Roof

Class 8 Sleeper Cab with Low Roof

Class 8 Sleeper Cab with Mid Roof

Class 8 Sleeper Cab with High Roof

The regulatory classes are being proposed to differentiate between tractor usages through using characteristics of the truck. The technologies being proposed to reduce fuel consumption and CO_2 emissions from tractors can be developed for all seven classes. However, the typical usage pattern may limit the penetration rate of the technology. For example, aerodynamic improvements can reduce the fuel consumption and CO_2 emissions of a tractor at high speeds. However, this technology could be a detriment to fuel consumption if applied to a tractor travelling at low speeds. The agencies discuss technologies, penetration rates, and costs for each regulatory class in the sections below.

2.5.1 Aerodynamics

Up to 25 percent of the fuel consumed by a line-haul truck traveling at highway speeds is used to overcome aerodynamic drag forces, making aerodynamic drag a significant contributor to a Class 7 or 8 tractor's GHG emissions and fuel consumption.[12] Because aerodynamic drag varies by the square of the vehicle speed, small changes in the tractor aerodynamics can have significant impacts on GHG emissions and fuel efficiency of that vehicle. With much of their driving at highway speed, the benefits of reduced aerodynamic drag for Class 7 or 8 tractors are significant.[13]

The common measure of aerodynamic efficiency is the coefficient of drag (Cd). The aerodynamic drag force (i.e., the force the vehicle must overcome due to air) is a function the Cd, the area presented to the wind (i.e., the projected area perpendicular to the direction of travel or frontal area), and the cube of the vehicle speed. Cds for today's fleet typically range from greater than 0.80 for a "classic" body tractor to approximately 0.58 for tractors that incorporate a full package of widely, commercially available aerodynamic features.

2.5.1.1 Challenges of tractor aerodynamics

The aerodynamic efficiency of heavy-duty vehicles has gained increasing interest in recent years as fuel prices, competitive freight markets, and overall environmental awareness has focused owners and operators on getting as much useful work out of every gallon of diesel fuel as possible. While designers of heavy-duty vehicles and aftermarket products try to aerodynamically streamline heavy-duty vehicles, there are some challenges. Foremost is balancing the need to maximize the amount of freight that can be transported. For a tractor, this often means pulling a trailer that is as tall and as wide as motor safety laws permit, thereby presenting a large, drag-inducing area perpendicular to the wind (i.e., projected frontal area). As a result, the tractor must also present a relatively large projected frontal area to smoothly manage the flow of air along the cab and transition it to trailer.[14] In instances where the height of the cab is not properly matched with that of trailer, aerodynamic drag can be significantly increased by creating large wakes (when the trailer is much shorter than the cab) or presenting a large non-aerodynamic surface (when the trailer is taller than the cab). Aerodynamic design must also meet practical and safety needs such as providing for physical access and visual inspections of vehicle equipment. Because weight added to the vehicle impacts its overall fuel efficiency and GHG emissions and, in some circumstances the amount of freight the vehicle can carry, aerodynamic design and devices will sacrifice some benefit to overcoming their contribution to the vehicle weight.[15] Aerodynamic designs and devices also must balance being as light and streamlined as possible with being durable enough to withstand the rigors a working, freight vehicle encounters while traveling or loading and unloading. Durability can be a significant concern for cabs designed for specialty applications, such as "severe duty" cabs that may operate on unimproved roads. In addition, absent mandatory requirements, aerodynamic features for heavy-duty vehicles must appeal to the owners and operators. Finally, because the behavior of airflow across the cab (and cab and trailer combination) is dependent upon the entire system, it isn't possible to make inferences about the vehicles aerodynamic performance based upon the performance of individual components. This can make it difficult to assess the benefit of adding (or subtracting) individual aerodynamic features and can discourage owners and operators from adopting aerodynamic technologies.

2.5.1.2 Technology to reduce aerodynamic drag

Addressing aerodynamic drag in Class 7 and tractors requires considering the entire vehicle as a system vehicle as a system to include the tractor and trailer. The overall shape can be optimized to minimize minimize aerodynamic drag and, in fact, the tractor body must have at least a moderately aerodynamic aerodynamic shape (and its relatively smooth flow) to benefit from add-on aerodynamic components. components. Whether integrated into the shape of the tractor body or as an add-on component to a component to a generally aerodynamic tractor, there is a wide range of technologies available for Class 7 for Class 7 and 8 tractors.

Table 2-12 describes several of these potential aerodynamic features and components.

Table 2-12: Technologies to Address Aerodynamic Drag

LOCATION ON CAB	TECHNOLOGY TYPE	DESIGNED EFFECT
Front	Bumper, grill, hood, windshield	Minimize pressure created by front of vehicle moving ambient air to make way for truck
Side	Fuel tank fairings	Reduce surface area perpendicular to wind, minimize opportunity to trap airflow, and smooth surface
Top	Roof fairings (integrated) and wind visors (attached)	Transition air to flow smoothly over trailer and minimize surface area perpendicular to the wind (for tractor and trailer)
Rear	Side extending gap reducers	Transition air to flow smoothly over trailer and reduce entrapment of air in gap between tractor and trailer
Undercarriage	Underbelly treatment	Manage flow of air underneath tractor to reduce eddies and smoothly transition flow to trailer
Accessories	Mirrors, signal horns, exhaust	Reducing surface area perpendicular to travel and minimizing complex shapes that may induce drag
General	Active air management	Manage airflow by actively directing or blowing air into reduce pressure drag
General	Advanced, passive air management	Manage airflow through passive aerodynamic shapes or devices that keep flow attached to the vehicle (tractor and trailer)

2.5.1.3 Aerodynamics in the current fleet

Aerodynamics in the Class 7 and 8 tractors fleet currently on the road ranges from trucks with few modern aerodynamic features to those that address the major areas of aerodynamic drag to tractors applying more advanced techniques. Because they operate at highway speeds less of the time, Class 7 and 8 tractors configured as day cabs (i.e., dedicated to regional routes) tend to have fewer aerodynamic features than cabs designed for line-haul applications. For tractors, it’s useful to consider aerodynamics in the current fleet as in three packages: the “classic” truck body; the “conventional” truck body; and the “SmartWay” truck body.

“Classic” truck body: At the lower end of aerodynamic performance are tractors that have a “classic” truck body. These truck bodies prioritize looks or special duty capabilities (e.g., clearance, durability on unimproved roads, visual access to key vehicle components) and have remained relatively unchanged since the 1970’s. Typical applications are logging, waste hauling, and some agricultural related uses. These trucks incorporate few, if any, aerodynamic features and several that detract from aerodynamics including equipment such as bug deflectors, custom sunshades, air cleaners, b-pillar exhaust stacks, additional horns, lights and mirrors may constitute a conventional vehicle.

"Conventional" truck body: The conventional, modern truck capitalizes on a generally aerodynamic shape and avoids classic features that increase drag. The conventional, modern truck body has removed extra equipment (e.g., bug deflectors, custom sunshades, additional signal horns, decorative lights), moved essential equipment out of the airflow (e.g., b-pillar exhaust stacks and air cleaners), and streamlined fixed-position, essential equipment (e.g., mirrors, steps, and safety lights).

"SmartWay" truck body: The SmartWay aerodynamic package builds off of the aerodynamic package required for a Class 8 sleeper cab high roof tractor to meet the SmartWay design specifications and represents the top aerodynamic package widely, commercially available. The SmartWay package is a fully aerodynamic truck package which has an overall streamlined shape, removes drag inducing features (i.e., those removed or moved in conventional, modern truck body), and adds components to reduce drag in the most significant areas on the tractor. This includes aerodynamic features at the front to the tractor (e.g., streamlined bumper, grill, and hood), sides (i.e., fuel tank fairings and streamlined mirrors), top (i.e., roof fairings), and rear (i.e., side extending gap reducers). Regional and line-haul applications often employ different approaches, such as removable, rooftop wind visors and fully integrated, enclosed roof fairings, respectively, based upon their intended operation.

More advanced aerodynamic features are possible and are the focus of product development, pilot and testing projects, and, in some cases, product lines that have seen limited fleet adoption. Advanced aerodynamic designs can further optimize the overall shape of the tractor and may add other advanced aerodynamic features (e.g., underbody airflow treatment, down exhaust, and lowered ride height). Some advanced aerodynamic features, including those listed above, show promise but will likely need ongoing refinement as these technologies are tailored to specific applications and payback periods are reduced. Fleets with whose line-haul operations permit are currently testing and using some advanced aerodynamic technologies.[16]

2.5.1.4 Aerodynamic Bins

The agencies have characterized the typical aerodynamic performance (expressed as Cd) and cost for select applications. To do so, it was necessary to represent the wide variety of tractor aerodynamic shapes – which are a collection of the shapes of the multitude of component parts – by developing aerodynamic packages. These are the "classic," "conventional," "SmartWay," "Advanced SmartWay," and the "Advanced SmartWay II."

"Classic" aerodynamic package: As described in section 2.4.1.3, these trucks incorporate few, if any, aerodynamic features and several that detract from aerodynamics including equipment such as bug deflectors, custom sunshades, air cleaners, b-pillar exhaust stacks, additional horns, lights and mirrors may constitute a conventional vehicle. No cost for aerodynamics is assumed for the classic package.

"Conventional" package: As described in section 2.4.1.3, the conventional, modern truck capitalizes on a generally aerodynamic shape and avoids classic features that increase drag. No cost for aerodynamics is assumed for the conventional package since there has been no addition of additional body work and these moderate modifications to the tractor shape would not likely require the redesign of other components.

"SmartWay" package: Based upon the design requirements of EPA's SmartWay Certified Tractors, this package has an overall streamlined shape, removes drag inducing features, and adds components (i.e., aerodynamic mirrors, side fairings, aerodynamic bumpers, and side extending gap reducers) to reduce drag in the most significant areas on the tractor. The SmartWay aerodynamics package does add some incremental cost above the classic and conventional packages.

"Advanced SmartWay" and "Advanced SmartWay II" packages: These packages include components similar to that found in the SmartWay package but with additional aerodynamic refinement. This can be a combination of more sophisticated shape and increased coverage of drag inducing elements. Where the Advanced SmartWay package represents a tractor using the most advanced aerodynamics available today, the Advanced SmartWay II package is designed to represent aerodynamics expected to be available in the near future. With more attention paid to aerodynamic performance than the conventional package, the Advanced SmartWay package is estimated to be slightly more expensive. As a representation of the future aerodynamics, the Advanced SmartWay II package is estimated as being 50 percent more expensive than the Advanced SmartWay package.

The agencies developed the typical coefficient of drag (Cd) values for the truck categories based on coast down testing conducted by EPA and from literature surveys. If the Cd values found in literature were described with a frontal area, then they were converted to a Cd value that represents the frontal area being proposed by the agencies for each subcategory. In addition to the absolute values, the agencies used the results of a wind tunnel evaluation of aerodynamic components. SAE 2006-01-3456[17] evaluated aerodynamic components on a Class 8 high roof tractor and found that side extenders provide a Cd reduction of 0.04 and tank and cab skirts provide a Cd reduction of 0.03.

Table 2-13: Tractor Cd Values

Truck	Expected Bin	Source	Frontal Area (m^2)	Cd
Class 8 Sleeper Cab High Roof				
International ProStar	SmartWay – Adv. SmartWay	ATDS[18]	9.8	0.54-0.56
NAS – Improved Tractor	Adv. SmartWay	NAS	unknown	0.55-0.56
SmartWay Tractor	SmartWay	NAS	unknown	0.59-0.60
Best Aero Truck	SmartWay	DDC Spec Manager	9.8	0.61
Full Aero	SmartWay	EPA PERE & MOVES Model	9.8	0.59
Roof Deflector	Conventional	EPA PERE & MOVES Model	9.8	0.65
International 9200i #1	Conventional	TRC	9.8	0.71
International 9200i #2	Conventional	NVFEL	9.8	0.70
CE-CERT	Conventional	EPA PERE & MOVES Model	9.8	0.74
No Aero Feature	Classic	DDC Spec Manager	9.8	0.77
Baseline Truck	Classic	McCallen, 1999	9.8	0.77
Class 8 Day Cab High Roof				
International ProStar	SmartWay	ATDS	9.8	0.58
Aero Features	SmartWay	SAE 2005-01-3512	9.8	0.61
Roof Fairing Only	Conventional	SAE 2005-01-3512	9.8	0.66
Class 8 Day Cab Low Roof				
International ProStar	Conventional - SmartWay	ATDS	6.0	0.78

Based on the testing and literature information, the agencies developed the Cd value for each aerodynamic bin and tractor subcategory, as shown in Table 2-14.

Table 2-14: Coefficient of Drag Performance of the Aerodynamic Bins

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics (Cd)							
Frontal Area (m^2)	6.0	9.8	6.0	9.8	6.0	6.6	9.8
Classic	0.85	0.75	0.85	0.75	0.85	0.80	0.75
Conventional	0.80	0.68	0.80	0.68	0.80	0.75	0.68
SmartWay	0.75	0.60	0.75	0.60	0.75	0.70	0.60
Advanced SmartWay	0.70	0.55	0.70	0.55	0.70	0.65	0.55
Advanced SmartWay II	0.65	0.50	0.65	0.50	0.65	0.60	0.50

The agencies estimated the cost of the aerodynamic packages based on ICF's price estimates.[19] The estimates.[19] The agencies applied a 15 percent reduction to the prices to reflect a large volume discount

volume discount which would be applicable to the tractor manufacturers. Although technologies such as technologies such as roof fairings may already be in widespread use today, the ICF study researched retail researched retail prices that a consumer would pay for the purchase of a single item in addition to addition to researching possible discounts based on a large volume sale, therefore this 15 percent discount percent discount was applied to reflect bulk purchases on these items. In addition, the agencies removed agencies removed an RPE of 1.36 to obtain the direct manufacturer cost and then applied a low low complexity ICM of 1.14 or a medium complexity ICM of 1.26 (for Advanced SmartWayII) to obtain SmartWayII) to obtain the overall technology costs included in Table 2-15 and

Table 2-16. In

Table 2-17 and

Table 2-18 the costs are shown including the expected penetration rates which range between 20 percent and 50 percent for most technologies shown.

Table 2-15 Estimated Aerodynamic Technology Costs for Class 7 & 8 DayCabs for the 2014MY (2008$)

	Class 7 DayCab		Class 8 DayCab	
	Low Roof	High Roof	Low Roof	High Roof
Classic	$0	$0	$0	$0
Conventional	$0	$0	$0	$0
SmartWay	$1,079	$1,107	$1,079	$1,107
Advanced SmartWay	$2,179	$2,207	$2,179	$2,207
Advanced SmartWay II	$3,070	$3,111	$3,070	$3,111

Table 2-16 Estimated Aeordynamic Technology Costs for Class 8 Sleeper Cabs for the 2014My (2008$)

	Low Roof	Mid Roof	High Roof
Classic	$0	$0	$0
Conventional	$0	$0	$0
SmartWay	$1,317	$1,345	$1,495
Advanced SmartWay	$2,492	$2,492	$2,564
Advanced SmartWay II	$3,512	$3,512	$3,613

Table 2-17 Estimated Aerodynamic Technology Costs for Class 7 & 8 DayCabs for the 2014MY Inclusive of Penetration Rates (2008$)

	Class 7 DayCab		Class 8 DayCab	
	Low Roof	High Roof	Low Roof	High Roof
SmartWay	$539	$775	$647	$332
Advanced SmartWay	$436	$441	$0	$883

Table 2-18 Estimated Aeordynamic Technology Costs for Class 8 Sleeper Cabs for the 2014MY Inclusive of Penetration Rates (2008$)

	Low Roof	Mid Roof	High Roof
SmartWay	$527	$404	$1,271

Advanced SmartWay	$498	$748	$256

2.5.2 Tires

Tire rolling resistance is defined as the energy consumed by the tire per unit of distance traveled. Energy is consumed mainly by the deformation of the tires, known as hysteresis, but smaller losses are due to aerodynamic drag and other friction forces between the tire and road surface and tire and wheel rim. About 90 percent of a tire's rolling resistance comes from hysteresis. Collectively the forces that result in energy loss from the tires are referred to as rolling resistance. The share of truck energy required to overcome rolling resistance is estimated at nearly 13 percent for Class 8 trucks[20]. Reducing a tire's rolling resistance will reduce fuel consumption and lower emissions of CO_2 and other greenhouse gases. Low rolling resistance tires are commercially available from most tire manufacturers. The EPA SmartWay program identified test methods and established criteria to designate certain tires as "low rolling resistance" for use in the program's emissions tracking system, verification program, and SmartWay vehicle specifications. Below is a discussion of EPA's approach to quantifying tire rolling resistance and the emission reductions associated with reduced rolling resistance, and a discussion of single wide tires, retread tires, and replacement tires.

To measure a tire's efficiency the vertical load supported by the tire must be factored because rolling resistance is a function of the load on a tire. EPA uses a tire's rolling resistance coefficient (RR_c), which is measured as the rolling resistance force over vertical load (kg/metric ton). The RR_c baseline for today's fleet is 7.8 kg/metric ton for the steer tire and 8.2 kg/metric ton for the drive tire, based on sales weighting of the top three manufacturers based on market share. These values are based on new tires, since rolling resistance decreases as the tread wears.

Beginning in 2007, EPA began designating certain Class 8 sleeper-cab configurations as Certified SmartWay Tractors. In order for a tractor to be designated as Certified SmartWay, the tractor must be equipped with verified low rolling resistance tires (either dual or single wide), among other criteria. In order to be verified as a low rolling resistance tire, a steer tire must have a RR_c less than 6.6 kg/metric ton and a drive tire must have a RR_c less than 7.0 kg/metric ton. SmartWay-verified low rolling resistance tires are the best performing tires available based on fuel efficiency. The SmartWay program expects to decrease the maximum allowable rolling resistance coefficient by 10 percent between 2010 and 2014. As more low rolling resistance tires are sold, the baseline rolling resistance coefficient value will improve.

Research indicates the contribution to overall vehicle fuel efficiency by tires is approximately equal to the proportion of the vehicle weight on them[21]. On a fully loaded typical Class 8 long-haul truck (tractor and trailer), about 12.5 percent of the total tire energy loss attributed to rolling resistance is from the steer tires and about 42.5 percent is from the drive tires. When evaluating just the tractor, the proportionate amount of energy loss would be about 24 percent from the steer tires and 76 percent from the drive tires.

A tire's rolling resistance is a factor considered in the design of the tire. It is a result of the tread compound material, the architect of the casing, tread design and the tire manufacturing process. Differences in rolling resistance of up to 50 percent have been identified for tires designed to equip the same vehicle[22]. It is estimated that 35 percent to 50 percent of a tire's rolling resistance is from the tread and the other 50 to 65 percent is from the casing[21]. Tires with increased RR_c values are likely designed for treadwear and not fuel efficiency.

Research and testing have shown a 5 percent reduction of rolling resistance provides a fuel consumption reduction of 1 percent while maintaining similar traction and handling characteristics. Bridgestone found a 5 percent improvement in rolling resistance will produce a 1.3 to 1.7 percent improvement in fuel economy[21]. Assuming a truck achieves 6 miles per gallon and is driven 100,000 miles annually, a 1.5 percent improvement in fuel economy results in a fuel consumption reduction of 1.48 percent, which is in line with EPA's study. According to Bridgestone[21], use of a fuel-efficient tire will result in approximately a 12 percent improvement in fuel economy compared to a non-fuel efficient tire at 55 mph, and 9 percent improvement in fuel economy at 65 mph.

To further demonstrate the correlation between rolling resistance and fuel economy, Michelin modeled vehicle fuel consumption using two drive cycles and various rolling resistance values. One drive cycle incorporated several instances of stop and start that replicated driving a vehicle on a secondary road; the other drive cycle replicated driving on a highway at nearly uniform speed but with several elevation changes. Simulations were performed using a base case and for rolling resistance reductions of 10 percent and 20 percent for both the secondary roadway and highway drive cycles. The simulation modeling for the secondary road drive cycle predicts a 1.8 percent and a 3.6 percent improvement in fuel economy as a result of the 10 percent and 20 percent reduction in rolling resistance, respectively[23]. The simulation modeling for the highway drive cycle predicts a 2.6 percent and a 4.9 percent improvement in fuel economy as a result of the 10 percent and 20 percent reduction in rolling resistance, respectively[23]. The modeling demonstrates less of a benefit from reduced rolling resistance when a vehicle is operated on secondary roadways. The modeling predicts an improvement in fuel economy from a reduction in rolling resistance comparable to what Bridgestone demonstrated. A 5 percent reduction in rolling resistance results in a 1 percent improvement in fuel economy.

Proper tire inflation is critical to maintaining proper stress distribution in the tire, which reduces heat loss and rolling resistance. Tires with reduced inflation pressure exhibit more sidewall bending and tread shearing, therefore, have greater rolling resistance than a tire operating at its optimal inflation pressure. Bridgestone tested the effect of inflation pressure and found a 2 percent variation in fuel consumption over a 40 psi range.[21] Generally, a 10 psi reduction in overall tire inflation results in about a 1 percent reduction in fuel economy[24]. To achieve the intended fuel economy benefits of low rolling resistance tires, it is critical that tires are properly maintained.

Tire rolling resistance is only one of several performance criteria that affect tire selection. The characteristics of a tire also influence durability, traction control, vehicle handling and comfort. A single performance parameter can easily be enhanced, but an optimal balance of all the criteria must be maintained. Tire design requires balancing performance, since changes in design may change different performance characteristics in opposing direction[25]. Truck tires are most often axle-specific in relation to these different performance criteria[26]. The same tire on different axles or used in different applications can a have different rolling resistance value. Any changes to a tire would generally be accompanied with additional changes to suspension tuning and/or suspension design.

The Center for Transportation Research at Argonne National Laboratory analyzed technology options to support energy use projections. The Center estimated the incremental cost of low rolling resistance tires of $15 - $20 per tire[39]. The ICF report estimated the cost of low rolling resistance tires to be xx. The NAS panel estimated XX. EPA and NHTSA project a cost of $65 (2008$) for low rolling resistance steer tires for both Class 7 and 8 tractors including a low complexity ICM of 1.14. For low rolling resistance drive tires, the agencies estimate costs of $60 (2008$) and $121(2008$) for Class 7 and 8 tractors, respectively, including a low complexity ICM of 1.14. The higher Class 8 reflects the assumption of one drive axle for Class 7 tractors and two drive axles for Class 8 tractors. All costs are considered valid for the 2014MY and time based learning would be considered appropriate for this technology.

2.5.2.1 Single Wide Tires

Low rolling resistance tires are offered for dual assembly and as single wide tires. They are typically only used on the drive axle of a tractor. A single wide tire is a larger tire with a lower profile. The common single wide sizes include: 385/65R22.5, 425/65R22.5, 445/65R22.5, 435/50R22.5 and 445/50R22.5. Generally, a single wide tire has less sidewall flexing compared to a dual assembly and therefore less hysteresis occurs. Compared to a dual tire assembly, single wide tires also produce less aerodynamic resistance or drag. Single wide tires can contribute to improving a vehicle's fuel efficiency through design as a low rolling resistance tire and/or through vehicle weight reduction.

The use of fuel efficient single wide tires can reduce rolling resistance by 3.7 to 4.9 percent compared to the most equivalent dual tire[27]. An EPA study demonstrated an improvement in fuel economy of 6 percent at 55 mph on the highway, 13 percent at 65 mph on the highway and 10 percent on a suburban loop[28] using single wide tires on the drive and trailer axles. EPA attributed the fuel economy improvement to the reduction in rolling resistance and vehicle weight reduction from using single wide tires. In 2008 the Department of Energy (DOE) compared the effect of different combinations of tires on the fuel efficiency of Class-8 trucks. The data collected based on field testing indicates that trucks with tractors equipped with single wide tires on the drive axle experience better fuel economy than trucks with tractors equipped with dual tires, independent of the type of tire on the trailer[29]. This study in particular indicated a 6.2 percent improvement in fuel economy from single wide tires.

There is also a weight savings associated with single wide tires compared to dual tires. Single wide tires can reduce a tractor and trailer's weight by as much as 1,000 lbs. when combined with aluminum wheels. Bulk haulers of gasoline and other liquids recognize the immediate advantage in carrying capacity provided by the reduction in the weight of tires and have led the transportation industry in retrofitting their tractors and trailers[30].

New generation single wide tires, which were first introduced in 2000, are designed to replace a set of dual tires on the drive and/or trailer positions. They are designed to be interchangeable with the dual tires without any change to the vehicle[31]. If the vehicle does not have hub-piloted wheels, there may be a need to retrofit axle components[30]. In addition to consideration of hub / bearing / axle, other axle-end components may be affected by use of single wide tires. To assure successful operation, suitable components should be fitted as recommended by the vehicle manufacturer[32].

Current, single wide tires are wider than earlier models and legal in all 50 states for a 5-axle, 80,000 GVW truck[27]. Single wide tires meet the "inch-width" requirements nationwide, but are restricted in certain states up to 17,500 lbs. on a single axle at 500 lbs/inch width limit, and are not allowed on single axle positions on certain double and triple combination vehicles[31]. An inch-width law regulates the maximum load that a tire can carry as a function of the tire width. Typically single wide tires are optimized for highway operation and not city or on/off highway operation. However, newer single wide tires are being designed for better scrub resistance, which will allow an expansion of their use. The current market share of single wide tires in combination truck applications is 5 percent and the potential market is all combination trucks[27]. New generation single wide tires represent an estimated 0.5 percent of the 17.5 million tires sold each year in the U.S.[31].

The Center for Transportation Research at Argonne National Laboratory estimated incremental capital cost of single wide tires is $30 - $40 per tire[39]. ICF estimates the incremental price of low rolling resistance tires at $20 for drive tires and $43 for steer tires.[33] With 4 single wide tires replacing 8 dual tires on the drive axle of a tractor, the incremental cost would be between $120 and $160.

2.5.2.2 Replacement Tires

Original equipment (OE) tires are designed and marketed for specific applications and vehicles. Their characteristics are optimized for the specific application and vehicle. Because they are not sold as OE, replacement tires are generally designed for a variety of applications and vehicle types that require different handling characteristics. The tires marketed to the replacement tire market tend to place greater emphasis on tread wear, and therefore often have higher rolling resistance than OE tires.

The market for replacement tires is individual vehicle owners and fleet owners and not the vehicle manufacturers. Many fleets report that the cost of fuel as opposed to driver pay is its number one cost. This has resulted in a greater demand for low rolling resistance replacement tires. Both heavy duty and medium duty truck fleets are looking for ways to reduce operational costs.

In 2007, EPA's SmartWay Transport Partnership introduced a means to distinguish tires based on their rolling resistance. Since 2007 the number of low rolling resistance tires available to vehicle owners and vehicle fleets has increased greatly, which is an indicator of an increase in demand. EPA expects this trend to continue. In addition, effective January 1, 2010, California Air Resource Board requires that all tractor-trailers hauling dry van trailers on any California road be equipped with SmartWay verified low rolling resistance tires; other states may adopt this requirement. EPA expects this requirement will drive the demand for low rolling resistance tires even further.

2.5.2.3 Retreaded Tires

The tread life of a tire is a measure of durability and some tires are designed specifically for greater durability. Commercial truck tires are designed to be retreaded, a process in which a new tread compound is adhered to the tire casing. The original tread of a tire will last anywhere from 100,000 miles to over 300,000 miles, depending on vehicle operation, original tread depth, tire axle position, and proper tire maintenance. Retreading can extend the tire's useful life by 100,000 miles or more.[34] In 2005, the Tire Industry Association estimated that approximately 17.6 million retreaded truck tires were sold in North America[35].

To maintain the quality of the casing and increase the likelihood of retreading, a tire should be retreaded before the tread depth is reduced to its legal limit. At any time, a steer tire must have a tread depth of at least 4/32 of an inch and a drive tire must have a tread depth of at least 2/32 of an inch (49 CFR. § 393.75). To protect the casing, a steer tire is generally retreaded once the tread is worn down to 6/32 of an inch and a drive tire is retreaded once the tread is worn down to 8/32 of an inch.[36] Tires used on Class 8 vehicles are retreaded as many as three times.

Both the casing and the tread contribute to a tire's rolling resistance. It is estimated that 35 percent to 50 percent of a tire's rolling resistance is the result of the tread.[21] Differences in drive tire rolling resistance of up to 50 percent for the same casing with various tread compounds have been demonstrated. For example, a fuel efficient tread compound (as defined by the manufacturer) was added to two different casings resulting in an average increase in rolling resistance of 48 percent. When a nonfuel efficient tread compound (also defined by the manufacturer) was added to the same casings, the rolling resistance increased by 125 percent on average. This characterizes the effect of the tread on the rolling resistance of a tire.

Because tires can be retreaded multiple times, changes in the casing due to wear, damage and material aging may impact rolling resistance to a greater degree than would occur in an original tire. Additionally, as evidenced above, if a tread compound different than the original tread is used, a retreaded tire can have higher or lower rolling resistance than the original tire.

There is a cost savings associated with retread tires. A new retread costs between $150 and $200, compared to a new tire which costs typically around $400. Since retreads are not typically used on the steer axle position, this represents a savings of $1,600 to $2,000 per tractor.

2.5.2.4 Tire Rolling Resistance

The agencies are projecting the following tire rolling resistance performance for setting the proposed tractor standards, as shown in Table 2-19.

Table 2-19Tire Rolling Resistance

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Steer Tires (Crr kg/metric ton)							
Baseline	7.8	7.8	7.8	7.8	7.8	7.8	7.8
SmartWay	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Advanced SmartWay	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Drive Tires (Crr kg/metric ton)							
Baseline	8.2	8.2	8.2	8.2	8.2	8.2	8.2
SmartWay	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Advanced SmartWay	6.0	6.0	6.0	6.0	6.0	6.0	6.0

2.5.3 Weight Reduction

Mass reduction encompasses a variety of techniques ranging from improved design and better component integration to application of lighter and higher-strength materials. Mass reduction can be further compounded by reductions in engine power and ancillary systems (transmission, steering, brakes, suspension, etc.). Although common on light duty passenger vehicles for fuel economy and performance increases, mass reduction on heavy duty vehicles is more complex due to the size and duty cycle of the vehicles.

Reducing a vehicle's mass decreases fuel consumption and GHG output by reducing the energy demand needed to overcome forces resisting motion, and rolling resistance. Passenger vehicle manufacturers employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction plus the additional mass reduction taken from indirect ancillary systems and components, effectively compounding or obtaining a secondary mass reduction from a primary mass reduction. For example, use of a smaller, lighter engine with lower torque-output subsequently allows the use of a smaller, lighter-weight transmission and drive line components. Likewise, the compounded weight reductions of the body, engine and drivetrain reduce stresses on the suspension components, steering components, wheels, tires and brakes, allowing further reductions in the mass of these subsystems. The reductions in unsprung masses such as brakes, control arms, wheels and tires further reduce stresses in the suspension mounting points. This produces a compounding effect of ripple effect of possible mass reductions.

A fully loaded tractor-trailer combination can weigh up to 80,000 pounds. Reduction in overall vehicle weight could enable an increase in freight delivered on a ton-mile basis. Practically, this enables more freight to be delivered per truck and improves freight transportation efficiency. In certain applications, heavy trucks are weight-limited (i.e. bulk cargo carriers), and reduced tractor and trailer weight allows direct increases in the quantity of material that can be carried.

Mass reduction can be accomplished by proven methods such as:

- Smart Design: Computer aided engineering (CAE) tools can be used to better optimize load paths within structures by reducing stresses and bending moments applied to structures. This allows better optimization of the sectional thicknesses of structural components to reduce mass while maintaining or improving the function of the component. Smart designs also integrate separate parts in a manner that reduces mass by combining functions or the reduced use of separate fasteners.

- Material Substitution: Substitution of lower density and/or higher strength materials into a design in a manner that preserves or improves the function of the component. This includes substitution of high-strength steels, aluminum, magnesium or composite materials for components currently fabricated from mild steel. Mass reduction through material substitution is currently broadly applied across in both light and heavy duty applications in all vehicle subsystems such as aluminum engine block, aluminum transmission housing, high-strength steel body structure, etc.

- Reduced Powertrain Requirements: Reducing vehicle weight sufficiently can allows for the use of a smaller, lighter and more efficient engine while maintaining or increasing work or cargo requirements. The subsequent reduced rotating mass (*e.g.*, transmission, driveshafts/halfshafts, wheels and tires) via weight and/or size reduction of components are made possible by reduced torque output requirements.

Reduced mass in heavy duty vehicles can benefit fuel efficiency and CO_2 emissions in two ways. If a truck is running at its gross vehicle weight limit with high density freight, more freight can be carried on each trip, increasing the trucks ton-miles per gallon. If the truck is carrying lower density freight and is below the GVW limit, the total vehicle mass is decreased, reducing rolling resistance and the power required to accelerate or climb grades.

Mass reduction can be achieved by making components with lighter materials (high strength steel, aluminum, composites) or by eliminating components from the truck. A common component-elimination example is to use single wide tires and aluminum rims to replace traditional dual tires and rims, eliminating eight steel rims and eight tires. Although many gains have been made to reduce truck mass, many of the features being added to modern trucks to benefit fuel economy, such as additional aerodynamic features or idle reduction systems, have the effect of increasing truck weight causing mass to stay relatively constant. Material and manufacturing technologies can also play a significant role in vehicle safety by reducing vehicle weight, and in the improved performance of vehicle passive and active safety systems. Although new vehicle systems, such as hybrid power trains, fuel cells and auxiliary power will present complex packaging and weight issues, this will further increase the need for reductions in the weight of the body, chassis, and power train components in order to maintain vehicle functionality.

EPA's SmartWay transport web page discusses how the truck fuel consumption increases with the weight of the vehicle. Many truck components are typically made of heavier material, such as steel. Heavier trucks require more fuel to accelerate and to climb hills, and may reduce the amount of cargo that can be carried.[37] Every 10 percent drop in truck weight reduces fuel use about 5 percent. Generally, an empty truck makes up about one-third of the total weight of the truck. Using aluminum, metal alloys, metal matrix composites, and other lightweight components where appropriate can reduce empty truck weight (known as "tare weight"), improve fuel efficiency, and reduce greenhouse gas emissions. As an example, trimming 3,000 pounds from a heavy truck (about 4 percent of its loaded weight) with lighter-weight components could improve fuel economy by up to 3 percent and trucks that employ more weight saving options would save more. In addition, in weight-sensitive applications, lightweight components can allow more cargo and increased productivity. Another report by the National Commission on Energy Policy estimates that a fuel economy gain of 5.0 percent on certain applications could be achieved by vehicle mass reduction further illustrating the fuel economy gains possible on heavy duty applications[38]. A third report, estimated potential reductions in modal GHG emissions are 4.6 percent, however also states current light-weight materials are costly and are application and vehicle specific with further research and development for advanced materials are needed**Error! Bookmark not defined.**[54].

In support of the overall goal to cost-effectively enable trucks and other heavy vehicles to be more energy efficient and to use alternative fuels while reducing emissions, the 21st Century Truck Partnership seeks to reduce parasitic energy losses due to the weight of heavy vehicles without reducing vehicle functionality, durability, reliability, or safety, and to do so cost-effectively. Aggressive weight reduction goals vary according to the weight class of the vehicle with targets between 10 and 33 percent. The weight targets for each vehicle class depend on the performance requirements and duty cycle. It is important to note that materials or technologies developed for a particular vehicle class are not necessarily limited to that class. For example, materials developed for lightweight frames for pickup trucks, vans, or SUVs will eventually be used in Class 3-5 vehicles, and materials developed to meet the demanding performance requirements for Class 7 and 8 trucks will find application in smaller vehicles. Weight reduction must not in any way sacrifice the durability, reliability, and performance of the vehicle. Attaining these goals by reducing inertial loading will yield substantial benefits such as increased fuel efficiency with concomitant reductions in emissions, increased available payload capacity for some vehicles, reduced rolling resistance, and optimized safety structures and aerodynamic drag reduction systems.

A 2009 NESCAFF report evaluated the potential to reduce fuel consumption and CO_2 emissions by reducing weight from the baseline weight of 80,000 pounds**Error! Bookmark not defined.**[55]. For the purpose of this calculation, the weight reduction could come either from carrying lighter freight or from a reduction in the empty weight of the truck. If the vehicle mass is reduced to 65,000 pounds, the fuel economy improves to 5.9 MPG from 5.4 MPG. The fuel savings and CO_2 reduction on the baseline vehicle amount to about 0.5 percent per 1,000 pounds of mass reduction. This result suggests that efforts to reduce the empty vehicle mass will have only a modest benefit on fuel economy, for long haul routes.

Argonne has also attempted to simulate the effect of mass reduction on the fuel economy of heavy trucks through the National Renewable Energy Laboratory's Advanced

Vehicle Simulator Model, ADVISOR. The Argonne simulations relied on a few driving schedules developed by the West Virginia University (WVU) because there are no established driving schedules for heavy trucks,. While simulating a Class 8 truck on the WVU Intercity Driving Schedule, a fuel economy gain of 0.6 percent was observed for each 1 percent mass reduction from 65,000 lb to 58,000 lb[39]. The maximum speed during the simulation was 61 mph, and the average running speed (excluding stops) was 37.5 mph although most intercity Class 8 trucks average a much higher speed than 37.5 mph. Argonne assumed a 0.66 percent increase in fuel economy for each 1 percent weight reduction and total possible estimated fuel economy increases of 5–10 percent. While simulating a Class 6 truck on a WVU Suburban Driving Schedule, a fuel economy gain of 0.48 percent was observed for each 1 percent mass reduction from 22,600 lb to 21,800 lb. The maximum speed during the simulation was 44.8 mph, and the average running speed was 21.5 mph. The potential fuel economy gains for medium trucks, both heavy- and light-, were capped at 5 percent since they are less likely to be weight or volume limited, and so the use of expensive lightweight material would not be cost-effective.

The principal barriers to overcome in reducing the weight of heavy vehicles are associated with the cost of lightweight materials, the difficulties in forming and manufacturing lightweight materials and structures, the cost of tooling for use in the manufacture of relatively low-volume vehicles (when compared to automotive production volumes), and ultimately, the extreme durability requirements of heavy vehicles. While light-duty vehicles may have a life span requirement of several hundred thousand miles, typical heavy-duty commercial vehicles must last over 1 million miles with minimum maintenance, and often are used in secondary applications for many more years. This requires high strength, lightweight materials that provide resistance to fatigue, corrosion, and can be economically repaired. Additionally, because of the limited production volumes and the high levels of customization in the heavy-duty market, tooling and manufacturing technologies that are used by the automotive industry are often uneconomical for heavy vehicle manufacturers. Lightweight materials such as aluminum, titanium and carbon fiber composites provide the opportunity for significant weight reductions, but their material cost and difficult forming and manufacturing requirements make it difficult for them to compete with low-cost steels. In addition, although mass reduction is currently occurring on both vocational and line haul trucks, the addition of other systems for fuel economy, performance or comfort increases the truck mass offsetting the mass reduction that has already occurred, thus is not captured in the overall truck mass measurement.

Most truck manufacturers offer lightweight tractor models that are 1,000 or more pounds lighter than comparable models. Lighter-weight models combine different weight-saving options that may include: [40]

- Cast aluminum alloy wheels can save 40 pounds each for total savings of 400 pounds
- Aluminum axle hubs can save over 120 pounds compared to ductile iron or steel
- Centrifuse brake drums can save nearly 100 pounds compared to standard brake drums
- Aluminum clutch housing can save 50 pounds compared to iron clutch housing
- Composite front axle leaf springs can save 70 pounds compared to steel springs
- Aluminum cab frames can save hundreds of pounds compared to standard steel frames
- Downsizing to a smaller, lighter-weight engine can save over 700 pounds[41]

2.5.3.1 Derivation of Weight Technology Packages

The agencies see many opportunities for weight reduction in tractors. However, the empty curb weight of tractors varies significantly today. Items as common as fuel tanks can vary between 50 and 300 gallons each for a given truck model. Information provided by truck manufacturers indicates that there may be as much as a 5,000 to 17,000 pound difference in curb weight between the lightest and heaviest tractors within a regulatory subcategory (such as Class 8 sleeper cab with a high roof). Because there is such a large variation in the baseline weight among trucks that perform roughly similar functions with roughly similar configurations, there is not an effective way to quantify the exact CO2 and fuel consumption benefit of mass reduction using [TEST] because of the difficulty in establishing a baseline. However, if the weight reduction is limited to tires and wheels, then both the baseline and weight differentials for these are readily quantifiable and well-understood. Therefore, the agencies are proposing that the mass reduction that would be simulated be limited only to reductions in wheel and tire weight. The agencies still encourage each OEM to reduce tractor curb weight in as many other ways as possible, which would reduce emission and fuel consumption independent of the degree to which such improvements are recognized for fuel consumption and CO_2 compliance purposes. In the context of this heavy duty vehicle program with only changes to tires and wheels, the agencies do not foresee any related impact on safety.

EPA and NHTSA are proposing to specify the baseline vehicle weight for each regulatory class (including the tires and wheels), but allow manufacturers to quantify weight reductions based on the wheel material selection and single wide versus dual tires per **Table 2-20**. The agencies assume the baseline wheel and tire configuration contains dual tires with steel wheels. The proposed weight reduction due to the wheels and tires would be reflected in the payload tons by increasing the specified payload by the weight reduction amount discounted by two thirds to recognize that approximately one third of the truck miles are travelled at maximum payload.

Table 2-20: Proposed Weight Reductions

	Weight Reduction (lb)
Single Wide Tire (per tire)	57
High strength steel dual wheel (per wheel)	8
Aluminum dual wheel (per wheel)	21
Light weight aluminum dual wheel (per wheel)	30
Steel single wide wheel (per wheel)	27
Aluminum single wide wheel (per wheel)	82
Light weight aluminum single wide wheel (per wheel)	90

The agencies have estimated costs for these technologies. Those costs are shown in Table 2-21. The costs shown include a low complexity ICM of 1.14 and time based learning would be considered appropriate for these technologies.

Table 2-21 Estimated Weight Reduction Technology Costs for Class 7 & 8 Tractors for the 2014MY (2008$)

	Class 7 Tractors	Class 8 Tractors
Single Wide Tire (per tire)	$322	$644
Aluminum Steer Wheel	$523	$523
Aluminum Wheels - dual	$1,569	$2,615
Aluminum Wheel – Single wide	$627	$1,254

2.5.4 Extended Idle

Class 8 heavy duty diesel truck extended engine idling wastes significant amounts of fuel in the United States. Department of Transportation regulations require a certain amount of rest for a corresponding period of driving hours. Extended idle occurs when Class 8 long haul drivers rest in the sleeper/cab compartment during rest periods as drivers find it more convenient and economical to rest in the truck cab itself. In many cases it is the only option available. During this rest period a driver will idle the truck in order to provide heating or cooling or run on-board appliances. During rest periods the truck's main propulsion engine is running but not engaged in gear and it remains in a stationary position. In some cases the engine can idle in excess of 10 hours. During this period of time, fuel consumption will generally average 0.8 gallons per hour. Average overnight fuel usage would exceed 8 gallons in this example. When multiplied by the number of long haul trucks without idle control technology that operate on national highways on a daily basis the number of gallons consumed by extended idling would exceed 3 million gallons per day. Fortunately, a number of alternatives (idling reduction technologies) are available to alleviate this situation.

2.5.4.1 Idle Control Technologies

Idle reduction technologies in general utilize an alternative energy source in place of operating the main engine. By using these devices the truck driver can obtain needed power for services and appliances without running the engine. A number of these devices attach to the truck providing heat, air conditioning, or electrical power for microwave oven, televisions, etc.

Another alternative involves electrified parking spaces (EPS) with or without modification to the truck. An EPS system operates independently of the truck's engine and allows the truck engine to be turned off as the EPS system supplies heating, cooling, and electrical power. The EPS system provides off-board electrical power to operate either:

1. A single system electrification requires no on-board equipment by providing an independent heating, cooling, and electrical power system, or
2. A dual system which allows driver to plug in on-board equipment

In the first case power is provided to stationary equipment that is temporarily attached to the truck. In the second, the truck is modified to accept power from the electrical grid to operate on board truck equipment. The retail price of idle reduction systems varies depending on the level of sophistication, for example, on-board technologies such as APUs can retail for over $7,000 while options such as EPS require negligible up-front costs for equipment for the truck itself, but will accrue fees with usage.[5]

2.5.4.2 CO_2 g/ton-mile Idle Reduction Benefit

CO_2 emissions during extended idling are a significant contributor to Class 8 sleeper cabs. The federal test procedure does evaluate idle emissions as part of the drive cycle and related emissions measurement. However, long duration extended idle emissions are not fully represented during the prescribed test cycle. Consequently, there is an opportunity to recognize the CO_2 reductions attributed to idle control systems by employing a credit mechanism for manufacturers who provide for idle control devices in the original truck/ tractor build or in the case of EPS provide a pre-purchase plan for EPS facility use and install all necessary equipment on the tractor. The credit would allow truck manufacturers additional flexibility in product design and performance capabilities as the CO_2 requirements are put in place.

Truck owners can obtain verified idle reduction technologies on a new truck at the time of purchase from the manufacturer or retrofit with verified technology after purchase provided a retrofit agreement is in place prior to introduction into commerce. For a manufacturer to qualify for the reduction, the agencies are proposing that a truck have an automatic engine shut-off system that shuts off the engine after five minutes of idling when it is in a parked position. This approach allows for operational strategies such as electrified parking spaces, team drivers, and overnights spent in hotels to achieve and idle reduction while still being tied back to a verifiable technology (i.e., engine shutoff).

Individual credits would be based on the GHG reduction associated with the technology employed. For example, in the case of an APU, both air conditioning and heating are provided resulting in year round CO_2 reduction opportunity. Therefore, an APU's reductions could apply to the full 1800 hours of extended idle. However, the engine used to power the APU consumes an assumed 0.2 gallons of diesel fuel per hour. Consequently, fuel consumption would be reduced by 0.6 gallons per hour for 1800 hours annually resulting in 1080 gallons of fuel saved per year. Using a factor of 10,180 grams of CO_2 per gallon of diesel fuel, this would result in 10,994,400 grams of CO_2 reduced (24,238 lbs. or 10.99 metric tons equivalent). CO_2 emissions at idle is 8,144 g per hour. Based on 1,800 hours of extended idling per year per truck; 125,000 miles per year per truck; and 19 tons of pay load this equates to 6.2 g/ton-mile. After taking into account the fuel burned by the APU device of 1.5 grams per ton-mile, the credit would be 5 g CO_2 per ton-mile. Credits as proposed are based on the requirement that all Class 8 long haul trucks shall be equipped with and automatic engine shut –off. The credits reflect a technologies' fuel consumption in conjunction with a shut-off.

Table 2-22: Idle Credit Calculation

	Idle Fuel Consumption (gal/hour)	Idle CO2 emissions per hour	Idle Hours per Year	Idle CO2 Emission per year (grams)	Miles Per Year	Payload (tons)	GHG Emissions due to Idling (g/ton-mile)	GHG Reduction (g/ton-mile)	Fuel Consumption Reduction (gal/ton-mile)
Baseline	0.8	8,144	1,800	14,659,200	125,000	19	6.2		
Idle Reduction Technology	0.2	2,036	1,800	3,664,800	125,000	19	1.5	5	0.0005

2.5.5 Vehicle Speed Limiters

As discussed above, the power required to move a vehicle increases as the vehicle speed increases. Travelling at lower speeds provides additional efficiency to the vehicle performance. Most vehicles today have the ability to electronically control the maximum vehicle speed through the engine controller. This feature is used today by fleets and owners to provide increased safety and fuel economy. Currently, these features are able to be changed by the owner and/or dealer.

The impact of this feature is dependent on the difference between the governed speed and the speed that would have been travelled, which is dependent on road type, state speed limits, traffic congestion, and other factors. EPA will be assessing the benefit of a vehicle speed limiter by reducing the maximum drive cycle speed on the 65 mph Cruise mode of the cycle. The maximum speed of the drive cycle is 65 mph, therefore any vehicle speed limit with a setting greater than this will show no benefit for regulations, but may still show benefit in the real world in states where the interstate truck speed limit is greater than the national average of 65.5 mph.

The benefits of this simple technology are widely recognized. The American Trucking Association (ATA) developed six recommendations to reduce carbon emissions from trucks in the United States. Their first recommendation is to enact a national truck speed limit of 65 mph and require that trucks manufactured after 1992 have speed governors set at not greater than 65 mph.[42] The SmartWay program includes speed management as one of their key Clean Freight Strategies and provides information to the public regarding the benefit of lower highway speeds.[43]

Some countries have enacted regulations to reduce truck speeds. For example, the United Kingdom introduced regulations in 2005 which require new trucks used for goods movement to have a vehicle speed limiter not to exceed 90 kph (56 mph).[44] The Canadian Provinces of Ontario and Quebec developed regulations which took effect in January 2009 that requires on-highway commercial heavy duty trucks to have speed limiters which limit the truck's speed to 105 km/h.[45]

Many truck fleets consider speed limiter application a good business practice in their operations. A Canadian assessment of heavy duty truck speed limiters estimated that 60 percent of heavy truck fleets in North America use speed limiters.[46] Con Way Freight, Con Way Truckload, and Wal-Mart currently govern the speeds of their fleets between 62 and 65 mph.[47]

A potential disbenefit of this technology is the additional time required for goods movement, or loss of productivity. The elasticity between speed reduction and productivity loss has not been well defined in industry. The Canadian assessment of speed limiters found that the fuel savings due to the lower operating speeds outweigh any productivity losses. A general consensus among the OEMs is that a one percent decrease in speed might lower productivity by approximately 0.2 percent.[48]

There is no additional capital cost associated with a vehicle speed limiter. There are no hardware requirements for this feature, only software control strategies. Nearly all heavy duty engines today are electronically controlled and are capable of being programmed for a maximum vehicle speed. The only new requirement for truck manufacturers is to offer a vehicle speed limiter which is protected from tampering and cannot be changed by the fleet or truck owner. This technology is required to be used for the full useful life of the vehicle to obtain the GHG emissions reduction.

The vehicle speed limiter is applicable to all truck classes which operate at high speeds. However, due to the structure of the first phase of the Heavy Duty truck program, it is only applicable to the Class 7-8 tractors. The benefits of the vehicle speed limiter are assessed through the use of alternate High Speed Cruise cycles. The baseline cycle contains a constant 65 mph cruise.

2.5.6 Automated Manual Transmission

Most heavy-duty trucks use manual transmissions with 8 to 18 ratios available. The most common transmissions for line haul applications have 10 ratios with an overdrive top gear. Torque-converter automatic transmissions, similar to those used in passenger cars, are used in some stop/go truck applications but are more expensive do not have an efficiency advantage in line-haul applications. Automated manual transmissions have been available on the market for over 10 years now and are increasing in market share. Automated manuals have a computer to decide when to shift and use pneumatic or hydraulic mechanisms to actuate the clutch and hidden shift levers. An automated manual can shift as quickly as the best driver, and the shift schedule can be tailored to match the characteristics of the engine and vehicle. This reduces variability of fuel consumption and CO_2 emissions between drivers, with all drivers achieving results closer to those of the best drivers. In application, there would be a fuel economy improvement proportional to the number of non-fuel-conscious drivers in a fleet. [Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions, NESCCAF/ICCT Final Report, October, 2009]

2.5.7 Class 7-8 Tractor Baseline Assessment

The agencies developed the baseline tractor for each subcategory to represent an average 2010 model year tractor. The approach taken by the agencies was to define the individual inputs to [TEST]. For example, the agencies evaluated the industry's tractor offerings and conclude that the average tractor contains a generally aerodynamic shape (such as roof fairings) and avoid classic features such as exhaust stacks at the b-pillar which increase drag. The agencies consider a baseline truck as having "conventional" aerodynamics. The baseline rolling resistance coefficient for today's fleet is 7.8 kg/metric ton for the steer tire and 8.2 kg/metric ton for the drive tire, based on sales weighting of the top three manufacturers based on market share.[49] However, today there is a large spread in aerodynamics in the new tractor fleet. Trucks are sold that reflect classic styling, or are sold with conventional or SmartWay aerodynamic packages.

Table 2-23

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics (Cd)							
Frontal Area (m^2)	6.0	9.8	6.0	9.8	6.0	6.6	9.8
Baseline	0.81	0.69	0.81	0.69	0.81	0.76	0.69
Steer Tires (Crr kg/metric ton)							
Baseline	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Drive Tires (Crr kg/metric ton)							
Baseline	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Weight Reduction (lbs.)							
Baseline	0	0	0	0	0	0	0
Extended Idle Reduction (gram CO_2/ton-mile reduction)							
Baseline	N/A	N/A	N/A	N/A	0	0	0
Vehicle Speed Limiter							
Baseline	--	--	--	--	--	--	--

2.5.8 Class 7-8 Tractor Standards Derivation

EPA and NHTSA project that CO_2 emissions and fuel consumption reductions can be achieved through the increased penetration of aerodynamic technologies, low rolling resistance tires, weight reduction, extended idle reduction technologies, and vehicle speed limiters. The agencies believe that hybrid powertrains in line haul applications will not be cost effective in the time frame of the rule. The agencies also are proposing to not include drivetrain technologies in the standard setting process, as discussed in Section II, instead are choosing to allow the continuation of the current truck specifying process that is working well today.

The agencies started with a goal of essentially forcing SmartWay technologies (aerodynamics, tires, and extended idle) into 100 percent of Class 7 and Class 8 tractors.

However, as discussed below, the agencies realize that there are some restrictions which prevent 100 percent penetration. Therefore, the agencies took the approach of evaluating each technology and proposing what we deem as the maximum feasible penetration into each tractor regulatory class. The next sections describe the effectiveness of the individual technologies, the costs of the technologies, the proposed penetration rates of the technologies into the regulatory classes, and finally the derivation of the proposed standards.

2.5.8.1 Technology Effectiveness

The agencies' assessment of the proposed technology effectiveness was developed through the use of the [TEST] Model in coordination with chassis testing of three SmartWay certified Class 8 sleeper cabs. The agencies are projecting the following tire rolling resistance performance for setting the proposed tractor standards, as shown in Table 2-19.

Table 2-19 describes the proposed model inputs for the range of Class 7 and 8 tractor technologies.

Table 2-24: TEST Inputs

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics (Cd)							
Frontal Area (m^2)	6.0	9.8	6.0	9.8	6.0	6.6	9.8
Classic	0.85	0.75	0.85	0.75	0.85	0.80	0.75
Conventional	0.80	0.68	0.80	0.68	0.80	0.75	0.68
SmartWay	0.75	0.60	0.75	0.60	0.75	0.70	0.60
Advanced SmartWay	0.70	0.55	0.70	0.55	0.70	0.65	0.55
Advanced SmartWay II	0.65	0.50	0.65	0.50	0.65	0.60	0.50
Steer Tires (Crr kg/metric ton)							
Baseline	7.8	7.8	7.8	7.8	7.8	7.8	7.8
SmartWay	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Advanced SmartWay	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Drive Tires (Crr kg/metric ton)							
Baseline	8.2	8.2	8.2	8.2	8.2	8.2	8.2
SmartWay	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Advanced SmartWay	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Weight Reduction (lbs.)							
Baseline	0	0	0	0	0	0	0
Control	400	400	400	400	400	400	400
Extended Idle Reduction (gram CO_2/ton-mile reduction)							
Baseline	N/A	N/A	N/A	N/A	0	0	0
Control	N/A	N/A	N/A	N/A	5	5	5
Vehicle Speed Limiter							
Baseline	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A

2.5.8.2 Class 7-8 Tractor Application Rates

Vehicle manufacturers often introduce major product changes together, as a package. In this manner the manufacturers can optimize their available resources, including engineering, development, manufacturing and marketing activities to create a product with multiple new features. In addition, manufacturers recognize that an engine and truck will need to remain competitive over its intended life and meet future regulatory requirements. In some limited cases, manufacturers may implement an individual technology outside of a vehicle's redesign cycle. In following with these industry practices, the agencies have created a set of vehicle technology packages for each regulatory class.

With respect to the level of technology required to meet the standards, NHTSA and EPA established technology application caps. The first type of cap was established based on the application of common fuel consumption and CO_2 emission reduction technologies into the different types of tractors. For example, idle reduction technologies are limited to Class 8 sleeper cabs using the assumption that day cabs are not used for overnight hoteling. A second type of constraint was applied to most other technologies and limited their penetration based on factors such as market demands.

The impact of aerodynamics on a truck's efficiency increases with vehicle speed. Therefore, the usage pattern of the truck will determine the benefit of various aerodynamic technologies. Sleeper cabs are often used in line haul applications and drive the majority of their miles on the highway travelling at speeds greater than 55 mph. The industry has focused aerodynamic technology development, including SmartWay certified tractors, on these types of trucks. Therefore the agencies are proposing the most aggressive aerodynamic technology penetration in this regulatory class. All of the major manufacturers today offer at least one truck model that is SmartWay certified. The National Academy of Sciences report on heavy duty truck found that manufacturers indicated that aerodynamic improvements which yield 3 to 4 percent fuel consumption reduction or 6 to 8 percent reduction in Cd values, beyond technologies used in today's SmartWay trucks are achievable.[50] EPA and NHTSA are proposing that the aerodynamic penetration rate for Class 8 sleeper cab high roof cabs to consist of 20 percent of advanced SmartWay, 70 percent SmartWay, and 10 percent conventional. The small percentage of conventional truck aerodynamics is for applications such as refuse haulers which spend a portion of their time off-road at the land fill. Features such as chassis skirts are prone to damage in off-road applications; therefore we are not proposing to require that all trucks have chassis skirts.

The aerodynamic penetration for the other tractor regulatory classes is less aggressive than for the Class 8 sleeper cab high roof. The agencies acknowledge that there are truck applications which require on/off-road capability and other truck functions which restrict the type of aerodynamic equipment applicable. We also recognize that these types of trucks spend less time at highway speeds where aerodynamics have the greatest benefit. The 2002 Vehicle Inventory and Use Survey (VIUS) data ranks trucks by major use.[51] The heavy trucks usage indicates that up to 35 percent of the trucks may be used in on/off-road applications or heavier applications. The uses include construction (16 percent), agriculture (12 percent), waste management (5 percent), and mining (2 percent). Therefore the agencies analyzed the technologies to evaluate the potential restrictions that would prevent 100 percent penetration of SmartWay technologies for all of the tractor regulatory classes.

Trucks designed for on/off-road application may be restricted in the ability to improve the aerodynamic design of the bumper, chassis skirts, air cleaners, and other aspects of the truck. First, off-road applications may require the use of steel bumpers which tend to be less aerodynamic than plastic designs. Second, ground clearance may be an issue for some off road applications due to poor road surface quality. This may pose a greater likelihood those items such as chassis skirts incur damage in use and therefore would not be a technology desirable in these applications. Third, the trucks used in off-road applications may also experience dust which requires an additional air cleaner to manage the dirt. Fourth, some trucks are used in applications which require heavier load capacity, such as those with gross combined weights of greater than 80,000 pounds, which is today's federal highway limit. Often these trucks are configured with different axle combinations than those traditionally used on-road. These trucks may contain either a lift axle or spread axle which allows for greater carrying capability. Both of these configurations limit the design and effectiveness of chassis skirts. Lastly, some work trucks require the use of power take off (PTO) operation or access to equipment which may limit the application of side extenders and chassis skirts.

NHTSA and EPA have considered these potential restrictions while developing the proposed maximum penetration rate of each of the aerodynamic bins for the Class 7 and 8 tractors. The high roof applications are designed for more highway driving and pulling box trailers. Therefore, they have the greatest penetration rates. However, truck buyers will typically purchase low roof cabs to handle the on/off-road or heavier applications. Therefore, the penetration rates are lower for these segments. The agencies welcome comment on our assessment of penetration rates and are interested in data which provides estimates on truck sales to the various applications where aerodynamics are less effective or restricted.

EPA and NHSTA in developing the proposal have received comment from manufacturers and owners that trucks sometimes have very limited on-road usage. These trucks by definition of Title 40, Part 85.1703 are motor vehicles, but will spend the majority of the life off-road. Trucks, such as those used in oil fields, will experience little benefit from improved aerodynamics. The agencies are therefore proposing to allow a narrow range of these off-road trucks to be excluded from the vehicle requirements because the trucks do not travel at speeds high enough to realize aerodynamic improvements and require special off-road tires such as lug tires. The trucks must still use a certified engine, which will provide fuel consumption and CO_2 emission reductions to the truck in all applications. The trucks must meet the following requirements to qualify for an exemption:

- Installed tires which are lug tires or contain a speed rating of less than or equal to 60 mph; and

- Contain PTO controls, or have axle configurations other than 4x2, 6x2, or 6x4 and have GVW greater than 57,000 pounds; and

- Include a vehicle speed limiter governed to 55 mph, and

- Has a frame Resisting Bending Moment (RBM) greater than 2,000,000 lb. in.

EPA and NHTSA have determined that the restrictions and the additional cost to develop a truck which meets these specifications will limit the exemption to trucks built for the desired purposes.[52]

Tire rolling resistance is only one of several performance criteria that affect tire selection. The characteristics of a tire also influence durability, traction control, vehicle handling and comfort. A single performance parameter can easily be enhanced, but an optimal balance of all the criteria must be maintained. Tire design requires balancing performance, since changes in design may change different performance characteristics in opposing direction. Similar to the discussion regarding lesser aerodynamic technology penetration in tractor segments other than sleeper cab high roof, the agencies believe that low rolling resistance tires should not be applied to 100 percent of all tractor segments. The agencies are proposing application rates that vary by class to reflect the on/off-road application of some tractors which require a different balancing of traction versus rolling resistance. We are seeking comment on our assessment.

Weight reductions can be achieved through single wide tires replacing dual tires and lighter weight wheel material. Single wide tires can reduce weight by over 160 pounds per axle. Aluminum wheels used in lieu of steel wheels will reduce weight by over 80 pounds for a dual wheel axle. Light weight aluminum steer wheels and aluminum single wide drive wheels and tires package will provide a 670 pound weight reduction over the baseline steel steer and dual drive wheels. The agencies are proposing 100 percent penetration of a technology package which reduces vehicle weight by 400 pounds.

Idle reduction technologies provide significant reductions in fuel consumption and CO_2 emissions. There are several different technologies available to reduce idling. Auxiliary power units, diesel fired heaters, and battery powered units. Each of these technologies has a different level of fuel consumption and CO_2 emissions. Therefore, the emissions reduction value varies by technology. Also, our discussions with manufacturers indicate that idle technologies are sometimes installed in the factory, but it is also a common practice to have the units installed after the sale of the truck. Therefore, we would like to continue to incentivize this practice while providing some certainty that the overnight idle operations will be eliminated. Therefore, we are allowing the installation of only an automatic engine shutoff, without override capability, to qualify for idle emission reductions. We are proposing a 100 percent penetration rate for this technology

Vehicle speed limiters will be used as a technology to meet the standard, but was not used to set the standard. The agencies do not want to create the perception of setting a national speed limit for trucks. While we believe this is a simple, easy to implement, and inexpensive technology, we want to leave the use up to the truck purchaser. Since truck fleets purchase trucks today with this option, we believe the trend will continue. However, we cannot predict the impact of this technology on the resale value of the truck and the decreased productivity, therefore we leave it to the purchasers to optimize the use of speed limiters based on the fuel savings relative to impact on business operations and resale value.

Table 2-25: Proposed Application Rates

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics (Cd)							
Classic	0%	0%	0%	0%	0%	10%	0%
Conventional	40%	30%	40%	30%	30%	20%	10%
SmartWay	50%	60%	50%	60%	60%	60%	70%
Advanced SmartWay	10%	10%	10%	10%	10%	10%	20%
Advanced SmartWay II	0%	0%	0%	0%	0%	0%	0%
Steer Tires (Crr kg/metric ton)							
Baseline	40%	30%	40%	30%	30%	30%	10%
SmartWay	50%	60%	50%	60%	60%	60%	70%
Advanced SmartWay	10%	10%	10%	10%	10%	10%	20%
Drive Tires (Crr kg/metric ton)							
Baseline	40%	30%	40%	30%	30%	30%	10%
SmartWay	50%	60%	50%	60%	60%	60%	70%
Advanced SmartWay	10%	10%	10%	10%	10%	10%	20%
Weight Reduction (lbs.)							
Baseline	0%	0%	0%	0%	0%	0%	0%
Control	100%	100%	100%	100%	100%	100%	100%
Extended Idle Reduction (gram CO_2/ton-mile reduction)							
Baseline	Not Applicable	Not Applicable	Not Applicable	Not Applicable	0p%	0%	0%
Control	Not Applicable	Not Applicable	Not Applicable	Not Applicable	100%	100%	100%
Vehicle Speed Limiter							
Baseline	--	--	--	--	--	--	--
Control	--	--	--	--	--	--	--

2.5.9 Class 7-8 Tractor Technology Costs

Table 2-26

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics							
Classic	$0	$0	$0	$0	$0	$0	$0
Conventional	$0	$0	$0	$0	$0	$0	$0
SmartWay	$539	$775	$647	$332	$527	$404	$1,271
Advanced SmartWay	$436	$441	$0	$883	$498	$748	$256
Advanced SmartWay II	$0	$0	$0	$0	$0	$0	$0
Steer Tires							
Low Rolling Resistance	$65	$65	$65	$65	$65	$65	$65
Drive Tires							
Low Rolling Resistance	$60	$60	$121	$121	$121	$121	$121
Weight Reduction							
Control	$1,472	$1,472	$2,421	$2,421	$2,421	$2,421	$2,421
Extended Idle Reduction							
Auxiliary Power Unit	N/A	N/A	N/A	N/A	$5,228	$5,228	$5,228
Vehicle Speed Limiter							
Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A

2.6 Class 2b-8 Vocational Trucks

2.6.1 Tires

The range of rolling resistance of tires used on vocational trucks (Class 2b – 8) today is large. The competitive pressure to improve rolling resistance of these tires has been less than that found in the Class 8 line haul tire market. Due to the drive cycles typical for these applications, tire traction and durability are weighed more heavily in a purchaser's decision than rolling resistance. Therefore, EPA believes that a regulatory program that incentivizes the optimization of tire rolling resistance, traction and durability can bring about GHG emission reductions from this segment. It is estimated that low rolling resistance tires used on

Class 3 – 6 trucks would improve fuel economy by 2.5 percent[39] relative to tires not designed for fuel efficiency.

Tires used on vocational vehicles (Class 2b – 8) typically carry less load than a class line haul vehicle. They are also designed for instances of high scrubbing. Because they carry less load and high scrubbing, tires used on vocational vehicles are can retreaded as many as five times.

The baseline tire rolling resistance for this segment of vehicles was derived for the proposal based on the current baseline tractor[53] and passenger car tires.[54] The baseline tractor drive tire has a rolling resistance of 8.2 kg/metric ton. The average passenger car has a tire rolling resistance of 9.75 kg/metric ton. EPA and NHTSA derived the vocational truck tire baseline rolling resistance from the average of these two values. EPA is conducting an extensive tire rolling resistance evaluation during 2010 and anticipates that the baseline value will be updated for the final rulemaking based on the results.

The agencies have estimated the costs of low rolling resistance tires as shown in Table 2-27. These costs include a low complexity ICM of 1.14 and time based learning would be considered appropriate for these technologies.

Table 2-27 Estimated Costs for Low Rolling Resistance Tires on Vocational Trucks in the 2014MY (2008$)

	Light-heavy & Medium-heavy	Heavy-heavy
Low rolling resistance steer tires	$65	$65
Low rolling resistance drive tires	$91	$121

2.6.2 Other Evaluated Technologies

2.6.2.1 Aerodynamics

Aerodynamic drag is an important aspect of the power requirements for Class 2b through 8 vocational trucks. Because aerodynamic drag is a function of the cube of vehicle speed, small changes in the aerodynamics of a vocational trucks reduces drag, fuel consumption, and GHG emissions. The great variety of applications for vocational trucks result in a wide range of operational speed profiles (i.e., in-use drive cycles) with many weighted toward lower speeds where aerodynamic improvement benefits are less pronounced. In addition, vocational trucks have a wide variety of configurations (e.g., utility trucks with aerial devices, transit buses, and pick-up and delivery trucks) and functional needs (e.g., ground clearance, towing, and all weather capability). This specialization can make the implementation of aerodynamic features impractical and, where specialty markets are limited, make it unlikely that per-unit costs will lower with sales volume.

This technology is not expected as a result of the proposed standards.

2.6.2.2 Hybrid Powertrains

A hybrid electric vehicle (HEV) is a vehicle that combines two or more sources of propulsion energy, where one uses a consumable fuel (i.e. gasoline or diesel), and one is rechargeable (during operation, or by another energy source). Hybrid technology is established in the U.S. market and more manufacturers are adding hybrid models to their lineups. Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.

- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.

- The engine is turned off when it is not needed, such as when the vehicle is coasting or stopped, such as extending idle conditions.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption and CO_2 emissions. A fourth mechanism to reduce fuel consumption, available only to plug-in hybrids, is by substituting the petroleum fuel energy with energy from another source, such as the electric grid. Although plug-in hybrids are not considered feasible for truck applications for propulsion power, this mechanism is explored further for trucks in a separate section discussing extended idle.

The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies depending on the power from the hybrid system components. In these cases, performance is improved, while fuel efficiency improves significantly less than if the engine was downsized to maintain the same performance as the conventional version. While this approach has been used in passenger cars it is more likely to be used for trucks where towing, hauling and/or cargo capacity is an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because cargo capability is critical truck attribute, manufacturers are hesitant to offer a truck with downsized engine which can lead to a significantly diminished towing performance with a low battery, and therefore engines are traditionally not significantly downsized for these vehicles.

In addition to the purely hybrid technologies, which decreases the proportion of propulsion energy coming from the fuel by increasing the proportion of that energy coming from electricity, there are other steps that can be taken to improve the efficiency of auxiliary functions (e.g., power-assisted steering or air-conditioning) which also reduce CO_2 emissions and fuel consumption. Optimization of the auxiliary functions, together with the hybrid technologies, is collectively referred to as vehicle or accessory load electrification because they generally use electricity instead of engine power. Fuel efficiency gains achieved only electrification is considered in a separate section although may be combined with the hybrid system.

A hybrid drive unit is complex and consists of discrete components such as the electric traction motor, transmission, generator, inverter, controller and cooling devices. Certain types of drive units may work better than others for specific vehicle applications or performance requirements. Several types of motors and generators have been proposed for hybrid-electric drive systems, many of which merit further evaluation and development on specific applications. Series HEVs typically have larger motors with higher power ratings because the motor alone propels the vehicle, which may be applicable to Class 3-5 applications. In parallel hybrids, the power plant and the motor combine to propel the vehicle. Motor and engine torque are usually blended through couplings, planetary gear sets and clutch/brake units. The same mechanical components that make parallel heavy duty hybrid drive units possible can be designed into series hybrid drive units to decrease the size of the electric motor(s) and power electronics.

An electrical energy storage system is needed to capture energy from the generator, to store energy captured during vehicle braking events, and to return energy when the driver demands power. This technology has seen a tremendous amount of improvement over the last decade and recent years. Advanced battery technologies and other types of energy storage are emerging to give the vehicle its needed performance and efficiency gains while still providing a product with long life. The focus on the more promising energy storage technologies such as nickel metal-hydride (NiMH) and lithium technology batteries along with ultra capacitors for the heavy duty fleet should yield interesting results after further research and applications in the light duty fleet.

Heavy duty hybrid vehicles also use regenerative braking for improved fuel economy, emissions, brake heat, and wear. A conventional heavy vehicle relies on friction brakes at the wheels, sometimes combined with an optional engine retarder or driveline retarder to reduce vehicle speed. During normal braking, the vehicle's kinetic energy is wasted when it is converted to heat by the friction brakes. The conventional brake configuration has large components, heavy brake heat sinks, and high temperatures at the wheels during braking, audible brake squeal, and consumable components requiring maintenance and replacement. Hybrid electric systems recover some of the vehicle's kinetic energy through regenerative braking, where kinetic energy is captured and directed to the energy storage system. The remaining kinetic energy is dissipated through conventional wheel brakes or in a driveline or transmission retarder. Regenerative braking in a hybrid electric vehicle can require integration with the vehicle's foundation (friction) braking system to maximize performance and safety. Today's systems function by simultaneously using the regenerative features and the friction braking system, allowing only some of the kinetic energy to be saved for later use. Optimizing the integration of the regenerative braking system with the foundation brakes will increase the benefits and is a focus for continued work. This type of hybrid regenerative braking system improves fuel economy, GHG emissions, brake heat, and wear.

In addition to electric hybrid systems, EPA is experimenting with a Class 6 hydraulic hybrid that achieves a fuel economy increase similar to electric hybrid gains and given high manufacturing volumes at with similar electric hybrid costs. In this type of system, deceleration energy is taken from the drivetrain by an inline hydraulic pump/motor unit by pumping hydraulic fluid into high pressure cylinders. The fluid, while not compressible, pushes against a membrane in the cylinder that compresses an inert gas to 5,000 PSI or more when fully charged. Upon acceleration, the energy stored in the pressurized tank pushes hydraulic fluid back into the drivetrain pump/motor unit, allowing it to motor into the drivetrain and assist the vehicle's engine with the acceleration event. This heavy duty truck hybrid approach has been demonstrated successfully, producing good results on a number of commercial and military trucks.

Considering the diversity of the heavy duty fleet along with the various types of hybridization, the results are diverse as well. The percentage savings that can be expected from hybridization is very sensitive to duty cycle. For this reason, analyses and efforts to promote hybrids often focus on narrow categories of vehicles. For vocational trucks other than tractor-trailers, hybrid technologies are promising, because a large fraction of miles driven by these trucks are local and under stop-and-go conditions. One study claims hybridization could almost double fuel economy for Class 3-5 trucks and raise Class 6-7 fuel economy by 71 percent in city driving, at costs that will decline rapidly in the coming years with the incremental cost of the hybrid vehicles depending on the choice of technology and the year, the later being a surrogate for progress towards economies of scale and experience with the technology[38]. Another Argonne National Lab study considering only truck Classes 2 and 3 indicates possible fuel efficiency gains of 40 percent[39]. The Hybrid Truck Users Forum has published a selection of four types as good candidates for hybridization; Class 4-8 Specialty Trucks, including utility and fire trucks; Class 4-6 urban delivery trucks, including package and beverage delivery; Class 7 and 8 refuse collection; and Class 7 and 8 less-than-load urban delivery trucks. The average fuel economy increase over the five cycles is 93 percent for the Class 3-4 truck and 71 percent for the Class 6-7 vehicle.

Stop-and-go truck driving includes a fraction of idling conditions during which the truck base engine consumes fuel but produces no economically useful output (e.g., movement of goods, or repositioning of the truck to a new location). Hybrid propulsion systems, shut off the engine under idling conditions or situations of low engine power demand. Trucks that have high fractions of stop-and-go freight transport activities within their driving cycles, such as medium-duty package and beverage delivery trucks, are appropriate candidates for hybridization. Long-haul trucks have a lower proportion of short-term idling or low engine power demand in their duty cycles because of traffic conditions or frequency stops compared to medium-duty trucks in local services. Based on the results of hybridization effects modeling, medium-duty trucks in local service (e.g., delivery) can reduce energy use by 41.5 percent[55]. Another 2009 report states that a 10 percent fuel consumption decrease could be achieved if idle reduction benefits were realized and a 5 percent improvement considering for on-road only [56].

In heavy-duty hybrid research, the industry role will be represented by the heavy-hybrid team members (e.g. Allison Transmission, Arvin-Meritor, BAE Systems, and Eaton

Corporation). The Department of Energy is pursuing heavy hybrid research through the Freedom CAR and Vehicle Technologies Program. The Department of Transportation (Federal Transit Administration) is playing a role in demonstration of these vehicles for the transit bus market. The Department of Defense is working with heavy hybrid equipment suppliers to develop and demonstrate hybrid vehicles for military applications, and has already made significant investments in hybrid technology to reduce fuel consumption and improve their ability to travel silently in combat situations. The Environmental Protection Agency has participated in the heavy hybrid arena through its work on mechanical hybrids for certain applications as discussed previously. The U.S. Department of Energy's 21st Century Truck Partnership (21CTP) has established challenging goals for improving fuel economy and pollutant emissions from heavy-duty vehicles including a diverse set of vehicles ranging from approximately 8,500 lb GVW to 100,000+ lb GVW[20].

In summary, many technologies that apply to cars do not apply to heavy duty trucks and there is a common perception that investments in passenger car (light-duty vehicle) technology can easily benefit heavy duty trucks. This group of vehicles is very diverse and includes tractor-trailers, refuse and dump trucks, package delivery vehicles and buses. The life expectancy and duty cycles for heavy duty vehicles are about ten times more demanding than those for light duty vehicles, technologies and solutions for the fleet must be more durable and reliable. Although a new generation of components is being developed for commercial and military HEVs, more research and testing are required.

There are no simple solutions applicable for each heavy duty hybrid application due to the large fleet variation. A choice must be made relative to the requirements and priorities for the application. Challenges in motor subsystems such as gear reductions and cooling systems must be considered when comparing the specific power, power density, and cost of the motor assemblies. High speed motors can significantly reduce weight and size, but they require speed reduction gear sets that can offset some of the weight savings, reduce reliability and add cost and complexity. Air-cooled motors are simpler and generally less expensive than liquid-cooled motors, but they will be larger and heavier, and they require access to ambient air, which can carry dirt, water, and other contaminants. Liquid-cooled motors are generally smaller and lighter for a given power rating, but they may require more complex cooling systems that can be avoided with air-cooled versions. Various coolant options, including water, water-glycol, and oil, are available for liquid-cooled motors but must be further researched for long term durability. Electric motors, power electronics, electrical safety, regenerative braking, and power-plant control optimization have been identified as the most critical technologies requiring further research to enable the development of higher efficiency hybrid electric propulsion systems.

In addition, because manufacturers will incur expenses in bringing hybrids to market, and because buyers do not purchase vehicles on the basis of net lifetime savings, the cost-effectiveness of hybrids may not in itself translate into market success, and measures to promote hybrids are needed until costs come down. Vocational trucks have diverse duty cycles, and they are used to a far greater extent for local trips. Some of the technologies are much less effective for trucks that generally drive at low speeds and therefore have limited applicability. Conversely, these trucks are the best candidates for hybrid technology, because local trips typically involve a large amount of stop-and-go driving, which permits extensive capture of braking and deceleration energy.

Due to the complexity of the heavy duty fleet, the variation of hybrid system reported fuel efficiency gains and the growing research and testing – vehicle hybridization is not mandated nor included in the model for calculation of truck fuel efficiency and GHG output. Vehicle hybridization is feasible on both tractor and vocational applications but must be tested on an individual basis to an applicable baseline to realize the system benefits and net fuel usage and GHG reductions.

2.6.2.3 EPA Testing of a Hybrid Transit Bus

EPA conducted a hybrid transit bus test to gather experience in testing hybrids and evaluate the GHG emissions and fuel consumption benefits. This section provides an overview of the study and its results.

Following coast down testing, in-use emissions testing was conducted on each bus using portable emissions measurement systems meeting subpart J of 40 CFR 1065. Each bus was operated over two routes, which were meant to simulate normal transit bus operation. The first route was comprised entirely of typical urban stop/go driving, with a number of bus stops along the 4.75 mile route. The second route was comprised of roughly half urban driving and half highway operation, reaching a maximum speed of approximately 60 MPH. This route was approximately 5.75 miles in length.

Fuel economy could be calculated using two methods: through integration of the instantaneous fuel rate broadcast by the ECU (ECU method) or through a carbon balance of the exhaust gases (Carbon Balance Method). Both methods provided repeatable results, however the ECU method tended to consistently yield approximately 5 percent lower fuel consumption on both vehicles. This bias appears to be due to small differences in predicted fuel flow versus measured exhaust carbon, particularly during deceleration where the ECU predicts a complete fuel cut-off. Since the carbon balance method yields more conservative results, all fuel consumption data presented has been calculating using this method.

Error! Reference source not found. Figure 2-1 presents a comparison of the fuel economy of both buses over the two test routes. Each vehicle was tested at least 3 times over each route, and in several cases up to 10 repeats of each route were conducted. The error bars represent the standard deviation over the replicates of each route. Over both routes, the hybrid showed a significant fuel economy benefit over the conventional bus. Over route 1 (urban only), this benefit was greatest and approached 37 percent. Over route 2 (mixed urban/highway), fuel economy was still improved by over 25 percent. Much of this benefit is likely attributable to the regenerative braking and launch assist capability of the hybrid system since there is no idle shut-off of the engine. A secondary benefit to the regenerative braking system is a significant increase in brake service intervals, which was highlighted in discussions with a bus fleet operator.

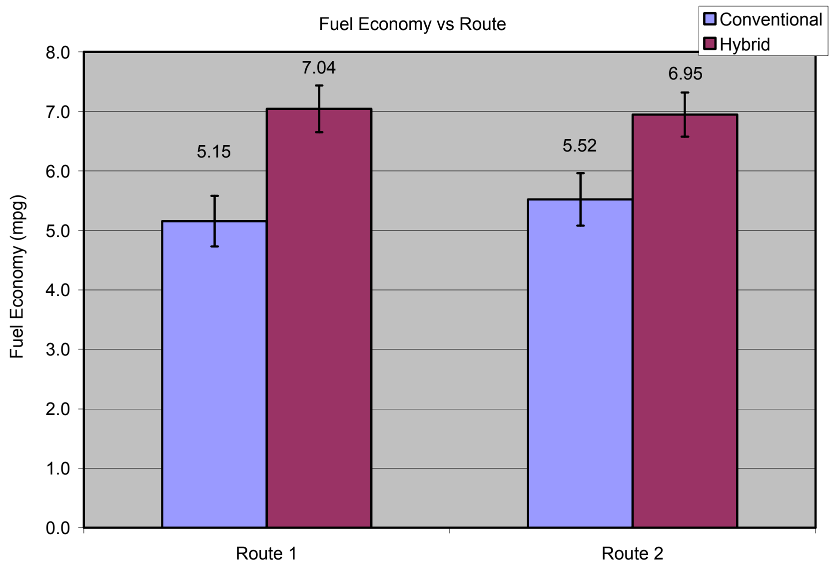

Figure 2-1

Error! Reference source not found. Figure 2-2 presents the CO_2 emissions over each route on a work-specific basis. For comparison, **Error! Reference source not found.**Figure 2-3 presents CO_2 normalized by the mileage travelled. Characterizing the CO_2 reduction due to the hybrid system, both methods show significant decreases in emissions. The work-specific basis may provide a more accurate comparison in this case, since environmental effects are better accounted for (i.e. driver aggressiveness, traffic, etc). This is evident when comparing the variation over the course of testing, represented by the standard deviation. The variability on a work-specific basis is nearly half that of using the distance-based metric.

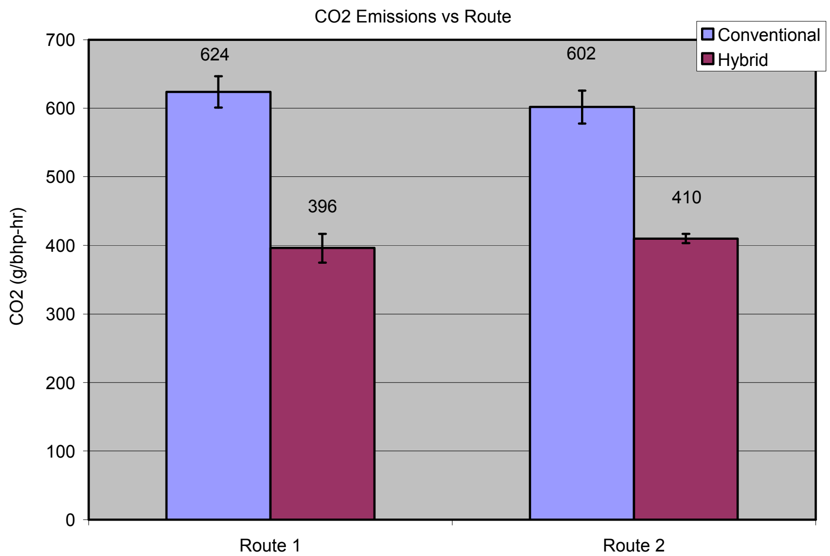

Figure 2-2

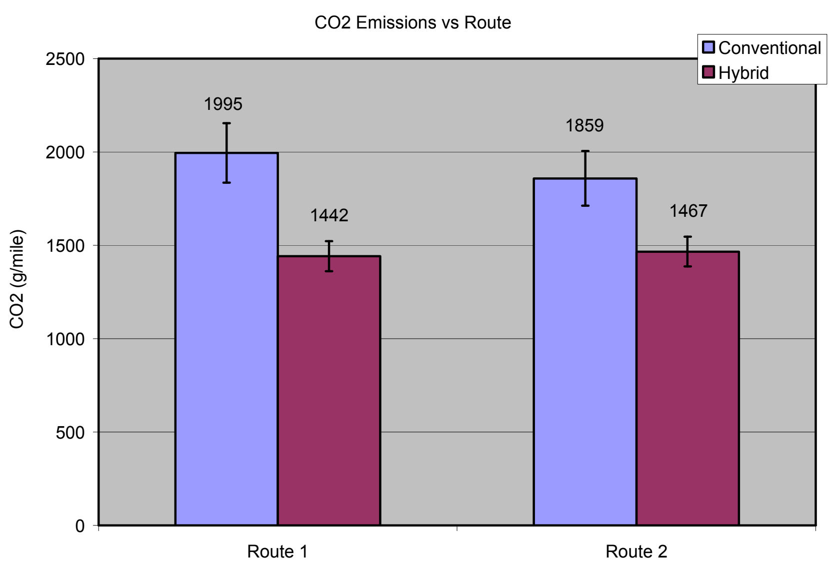

Figure 2-3

Error! Reference source not found. Figure 2-4 (a-d) compares the CO_2 emissions rate (in g/s) during typical launch (starting from a stop) events in both buses. Both vehicles showed a spike in CO_2 emissions when starting from a stop. However, this spike was much more attenuated with the hybrid bus, which demonstrates the ability of the launch assist system to reduce CO_2 emissions. The magnitude of this attenuation varied depending on the exact event, however reductions of over 50 percent were not uncommon. Also worth noting is that near the 0.35 mile mark on **Error! Reference source not found.**Figure 2-4-d (lower-right), the CO_2 emissions are near zero, suggesting that the vehicle is maintaining a speed of approximately 15 MPH solely on electric power.

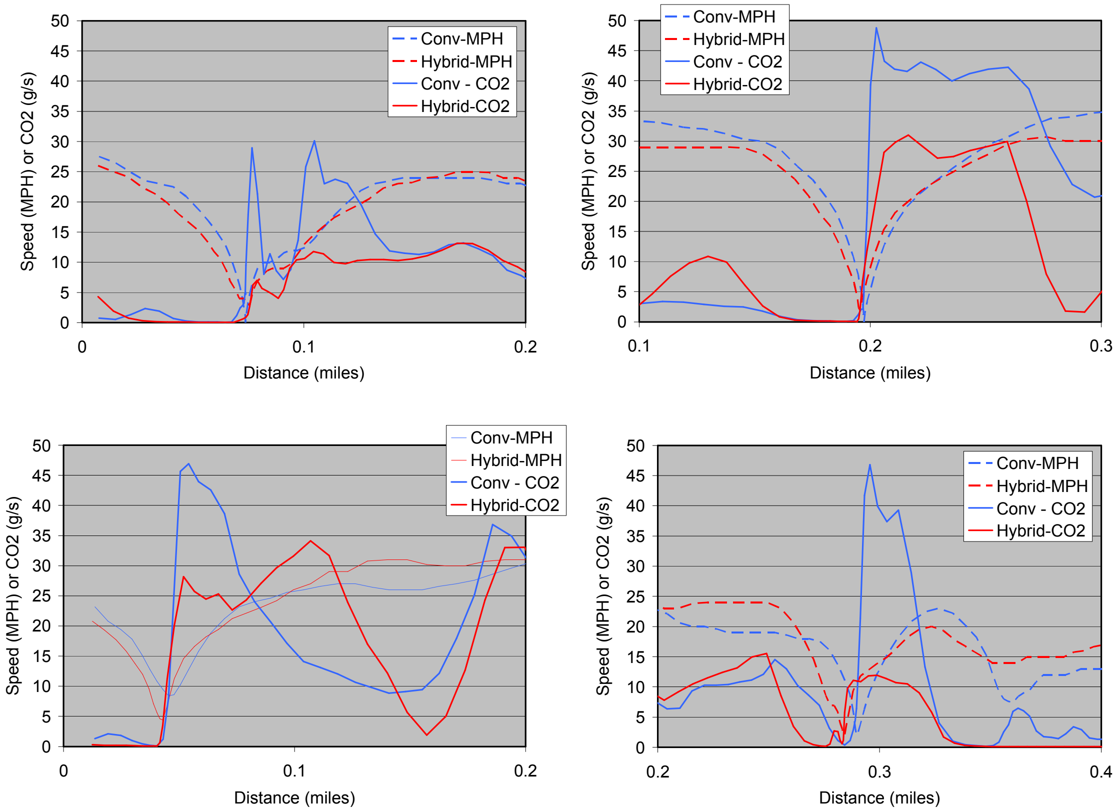

Figure 2-4

Other observations through this testing suggest significant complexity in the calibration of the hybrid powertrain, presumably with the intent of reducing fuel consumption. One example is the set of engine speed-torque points over a give route (**Error! Reference source not found.**Figure 2-5).The calibration of the hybrid powertrain (red) shows distinct patterns for where the engine operates. First, the engine is less frequently loaded at, or near idle speed. Second, the engine frequently operates at 1200 RPM, which is the lowest speed at which peak torque is available. Third, when more power is required (beyond 100 percent torque at 1200 RPM), the engine tends to operate along the maximum torque curve as RPM is increased. Keeping engine speed as low as possible reduces frictional losses, thus increasing efficiency. In contrast, the speed-torque points of the conventional bus show a much more random distribution and propensity for operating at lower engine loads.

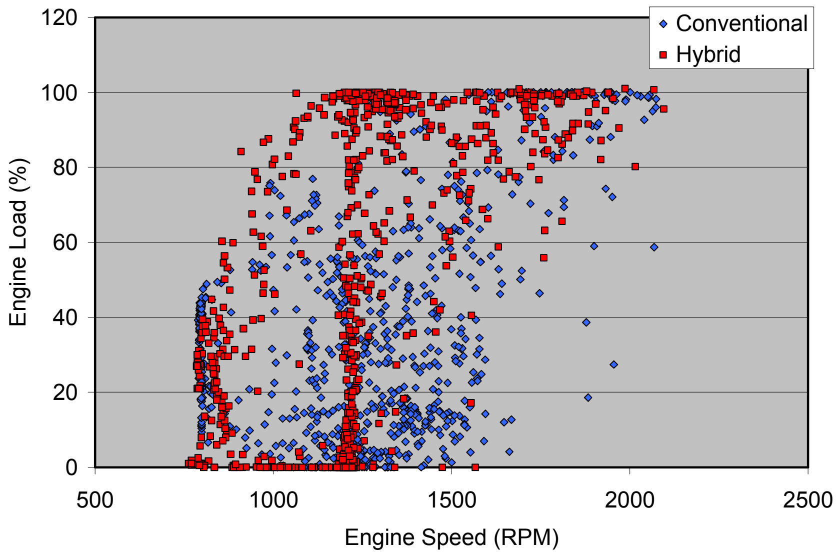

Figure 2-5

In summary, the hybrid powertrain has demonstrated significant opportunity for reduction of fuel consumption and CO_2 emissions in transit bus applications. Testing over typical bus routes showed up to a 37 percent reduction in both fuel consumption and CO_2 emissions. A summary of these finding is presented in **Error! Reference source not found.**Table 2-27. These reductions can be attributed to three features of the hybrid powertrain. First, electric launch assist facilitated through regenerative braking. Second, calibration of the engine to operate in the most efficient regions of the speed-torque map. Third, electric-only drive at lower speeds was witnessed occasionally.

Table 2-28

		Conventional		Hybrid		Benefit	
		Avg	CoV	Avg	CoV	mpg or g/mile	percent
Route 1	MPG	5.15	8.2%	7.04	5.5%	1.89	37%
	CO_2 (g/mile)	1995	8.0%	1442	5.5%	553	28%
	CO_2 (g/bhp-hr)	624	3.7%	396	5.3%	228	37%
Route 2	MPG	5.52	8.0%	6.95	5.3%	1.43	26%
	CO_2 (g/mile)	1859	7.9%	1467	5.5%	392	21%
	CO_2 (g/bhp-hr)	602	4.0%	410	1.7%	192	32%

2.6.2.4 Transmission and Driveline

This technology is not expected to change as a result of the proposed standards.

2.7 Air Conditioning

Air conditioning (A/C) systems contribute to GHG emissions in two ways – direct emissions through refrigerant leakage and indirect exhaust emissions due to the extra load on the vehicle's engine to provide power to the air conditioning system. Hydrofluorocarbon (HFC) refrigerants, which are powerful GHG pollutants, can leak from the A/C system. This includes the direct leakage of refrigerant as well as the subsequent leakage associate with maintenance and servicing, and with disposal at the end of the vehicle's life. No other vehicle system has associated GHG leakage. The current refrigerant – R134a, has a high global warming potential (GWP) of 1430. [6] Due to the high GWP of this HFC, a small leakage of the refrigerant has a much greater global warming impact than a similar amount of emissions of CO2 or other mobile source GHGs.

Heavy duty air conditioning systems today are similar to those used in light duty applications. However, differences may exist in terms of cooling capacity (such that sleeper cabs have larger cabin volumes than day cabs), system layout (such as the number of evaporators), and the durability requirements due to longer truck life. However, the component technologies and costs to reduce direct HFC emissions are similar between the two types of vehicles. .

The quantity of indirect GHG emissions from A/C use in heavy duty trucks relative to the CO2 emissions from driving the vehicle and moving freight is very small. Therefore, a credit approach for improved A/C system efficiency is not appropriate for this segment of vehicles because the value of the credit is too small to provide sufficient incentive to utilize feasible and cost-effective air conditioning leakage improvements. For the same reason, including air conditioning leakage improvements within the main standard would in many instances result in lost control opportunities. Therefore, EPA is proposing that truck manufacturers be required to meet a low leakage requirement for all air conditioning systems installed in 2014 model year and later trucks, with one exception. The agencies are not proposing leakage standards for Class 2b-8 Vocational Vehicles at this time due to the complexity in the build process and the potential for different entities besides the chassis manufacturer to be involved in the air conditioning system production and installation, with consequent difficulties in developing a regulatory system.

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[6] The global warming potentials (GWP) used in the NPRM analysis are consistent with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the IPCC Second Assessment Report (SAR) global warming potential values have been agreed upon as the official U.S. framework for addressing climate change. The IPCC SAR GWP values are used in the official U.S. greenhouse gas inventory submission to the climate change framework. When inventories are recalculated for the final rule, changes in GWP used may lead to adjustments.

2.7.1 Refrigerant Leakage

Based on measurements from 300 European light-duty vehicles (collected in 2002 and 2003), Schwarz and Harnisch estimate that the average HFC direct leakage rate from modern A/C systems was estimated to be 53 g/yr.[57] This corresponds to a leakage rate of 6.9 percent per year. This was estimated by extracting the refrigerant from recruited vehicles and comparing the amount extracted to the amount originally filled (as per the vehicle specifications). The fleet and size of vehicles differs from Europe and the United States, therefore it is conceivable that vehicles in the United States could have a different leakage rate. The authors measured the average charge of refrigerant at initial fill to be about 747 grams (it is somewhat higher in the U.S. at 770g), and that the smaller cars (684 gram charge) emitted less than the higher charge vehicles (883 gram charge). Moreover, due to the climate differences, the A/C usage patterns also vary between the two continents, which may influence leakage rates.

Vincent et al., from the California Air Resources Board estimated the in-use refrigerant leakage rate to be 80 g/yr.[58] This is based on consumption of refrigerant in commercial fleets, surveys of vehicle owners and technicians. The study assumed an average A/C charge size of 950 grams and a recharge rate of 1 in 16 years (lifetime). The recharges occurred when the system was 52 percent empty and the fraction recovered at end-of-life was 8.5 percent.

Since the A/C systems are similar in design and operation between light- and heavy-duty vehicles, and emissions due to direct refrigerant leakage are significant in all vehicle types, EPA is proposing a leakage standard which is a "percent refrigerant leakage per year" to assure that high-quality, low-leakage components are used in each air conditioning system design. The agency believes that a single "gram of refrigerant leakage per year" would not fairly address the variety of air conditioning system designs and layouts found in the heavy duty truck sector. EPA is proposing a standard of 1.50 percent leakage per year for Heavy Duty Pickup Trucks and Vans and Class 7/8 Tractors. The proposed standard was derived from the vehicles with the largest system refrigerant capacity based on the Minnesota GHG Reporting database.[59] As shown in Figure 2-6, the average percent leakage per year of the 2010 model year vehicles in the upper quartile in terms of refrigerant capacity was 1.60 percent (for reference, in the 2010 Light-Duty GHG rule, the average was estimated to be 2.7 percent, based on a leakage rate of 20.7 g/yr and a system capacity of 770 g).

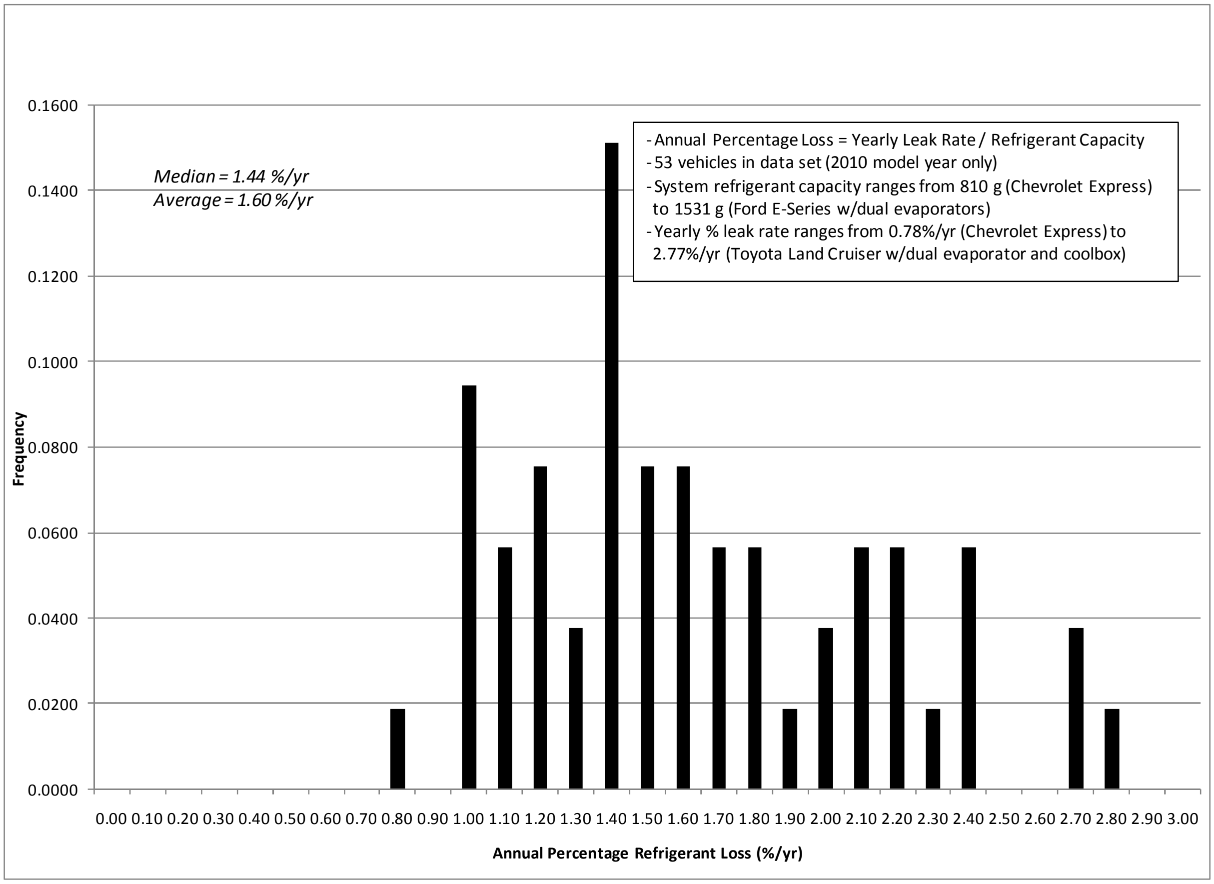

Figure 2-6 Distribution of Percentage Refrigerant Loss Per Year - Vehicles in Upper Quartile of A/C System Refrigerant Capacity (from 2010 Minnesota Reporting Data).

By requiring that all heavy-duty trucks achieve the proposed leakage level of 1.50 percent per year, roughly half of the vehicles in the 2010 data sample would need to reduce their leakage rates, and an emissions reduction roughly comparable to that necessary to generate direct emission credits under the light-duty vehicle program would result. See 75 FR at 25426-247. We believe that a yearly system leakage approach will assure that high-quality, low-leakage, components are used in each A/C system design, and we expect that manufacturers will reduce A/C leakage emissions by utilizing improved, leak-tight components. Some of the improved components available to manufacturers are low-permeation flexible hoses, multiple o-ring or seal washer connections, and multiple-lip compressor shaft seals. The availability of low leakage components is being driven by the air conditioning credit program in the light-duty GHG rule (which applies to 2012 model year and later vehicles). EPA believes that reducing A/C system leakage is both highly cost-effective and technologically feasible. The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program has demonstrated that new-vehicle leakage emissions can be reduced by 50 percent by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system.[60] All of these technologies are already in commercial use and exist on some of today's systems.

While use of alternative refrigerants with a lower GWP is encouraged, we are proposing that the same leakage standard will apply to all A/C systems, regardless of the type of refrigerant used. For A/C systems to maintain their efficiency, the refrigerant charge must be preserved. Systems which lose significant amounts of refrigerant, the cooling capacity is diminished, possibly requiring increased operating duty cycle to achieve a desired cabin comfort level, which will increase indirect CO2 emissions. In addition, as refrigerant levels in the system drop below a critical level, the ability of the refrigerant to move lubrication oil through the system (necessary for compressor durability) is diminished, resulting in deterioration of the compressor, and ultimately, replacement of system components, which will result in service-related direct emissions. Also, even refrigerants with low GWP may not be desirable in the atmosphere, as they are potential VOCs, and the products of their chemical breakdown (e.g. hydrogen fluoride or tri-flouroacetic acid) can affect human health.

EPA proposes that manufacturers demonstrate improvements in their A/C system designs and components through a design-based method. The proposed method for calculating A/C Leakage is based closely on an industry-consensus leakage scoring method, described below. This leakage scoring method is correlated to experimentally-measured leakage rates from a number of vehicles using the different available A/C components. Under the proposed approach, manufacturers would choose from a menu of A/C equipment and components used in their vehicles in order to establish leakage scores, which would characterize their A/C system leakage performance and calculate the percent leakage per year as this score divided by the system refrigerant capacity.

Consistent with the Light Duty Vehicle Greenhouse Gas Emissions rulemaking, EPA is proposing that a manufacturer would compare the components of its A/C system with a set of leakage-reduction technologies and actions that is based closely on that being developed through IMAC and the Society of Automotive Engineers (as SAE Surface Vehicle Standard J2727, August 2008 version).[61] See generally 75 FR at 25426. The SAE J2727 approach was developed from laboratory testing of a variety of A/C related components, and EPA believes that the J2727 leakage scoring system generally represents a reasonable correlation with average real-world leakage in new vehicles. Like the IMAC approach, our proposed approach would associate each component with a specific leakage rate in grams per year identical to the values in J2727 and then sum together the component leakage values to develop the total A/C system leakage. However, in the heavy duty truck program, the total A/C leakage score is then divided the value by the total refrigerant system capacity to develop a percent leakage per year value.

2.7.2 System Efficiency

The agencies can also develop a program that includes efficiency improvements. CO2-equivalent emissions are also associated with air conditioner efficiency, since air conditioners create load on the engine. See 74 FR at 49529. However, EPA is not proposing to set air conditioning efficiency standards for heavy duty trucks, as the CO2 emissions due to air conditioning systems in heavy duty trucks are minimal (compared to their overall emissions of CO2). For example, EPA conducted modeling of a Class 8 sleeper cab using [TEST] to evaluate the impact of air conditioning and found that it leads to approximately 1 gram of CO2/ton- mile. Therefore, a projected 24 percent improvement of the air conditioning system (the level projected in the light duty GHG rulemaking), would only reduce CO_2 emissions by less than 0.3 g CO_2/ton-mile, or approximately 0.3 percent of the baseline Class 8 sleeper cab CO_2 emissions.

2.8 Trailers and GHG Emission Reduction Opportunities

Trailers for use with HD tractors are an important aspect of the GHG emission performance of combination trucks and are estimated to be responsible for 11 to 12 percent of fuel consumed by Class 8 combination trucks. Optimizing the tractor and trailer as a system allows designers to take full advantage of the GHG emission reduction opportunities and, in some cases (e.g., aerodynamic drag reduction), the performance of emission reduction approach is dependent upon the tractor and trailer working in concert. For example, when designing a tractor's roofline it is important to understand the type and physical characteristics of the trailer for which it is intended for use. If the roofline of the tractor and trailer are mismatched, it can result in a large, post-tractor wake (i.e., the tractors roofline is taller than that of the trailer) or present a large, drag inducing surface (i.e., the trailer front is taller than the top of the tractor). Even though trailers are an integral part of a combination truck's ultimate GHG emissions and fuel consumption, trailer design has remained relatively unchanged when compared to the progress made in tractors. The impacts of incorporating improved GHG emission and fuel saving performance into trailers can have long lasting impacts since trailers are often kept in service for longer periods than tractors.

2.8.1 Current trailer fleet

There are approximately 5.6 million HD trailers on the roads today[62]. In general, it is common to have roughly 3 trailers for every tractor to facilitate efficiency in loading and unloading operations. Serving a wide range of needs, this trailer fleet is necessarily comprised of a wide range of trailer types including box van (including refrigerated units), shipping container (e.g., 20 and 40 foot ocean-going container) chassis, flat bed (including drop deck units), dump, tanker, and specialty (e.g., grain, livestock, auto-carriers). Types of trailers can be further subdivided by their length and height. The vast majority of HD trailers on the road are box van trailers that are 53 feet long. Table 2-29 presents the current market share of major types of trailers.[63]

Table 2-29: Composition of Current Heavy-Duty Trailer Fleet

TRAILER TYPE	MARKET SHARE[1] (PERCENT)
Box, van (53')	45
Box, van (40 – 52')	6
Box, van (24 – 39')	9
Box, van (refrigerated)	5
Container chassis	7
Dump	3
Flatbed	8

Flatbed (drop deck)	2
Grain	2
Tagalong	4
Tagalong (enclosed)	2
Other	9

Diversity in the trailer fleet is not limited to the types of trailers on the road but also extends to the owners and operators of trailers. Trailers are owned and operated by individual fleets, logistics companies that move goods for others, and government entities.

While approximately 10 companies manufacture approximately 80 percent of the trailers sold, the entire trailer market includes a large number of trailer producers. [64] Only 14 manufacturers have an annual sales volume of greater than 3,000 trailers with many specializing in a type of trailer (e.g., grain, dump, tanker).

2.8.2 Trailer technologies to reduce GHG emissions

Technologies for use on trailers that reduce GHG emissions and fuel consumption are commercially available. These include aerodynamic devices, low rolling resistance tires, and weight reduction. Trailer systems that allow a tractor to move more goods such as double trailer configurations (e.g., Rocky Mountain Doubles with 28 or 48 foot trailers) can also be considered as trailer strategies to reduce GHG emissions. Of these technologies, trailer aerodynamics and low rolling resistance tires have gained wide acceptance and are discussed in detail below.

2.8.2.1 Trailer Aerodynamics

Trailer aerodynamic technologies have focused on the box, van trailers – the largest segment of the trailer fleet. This focus on box, van trailers may also be partially attributed to the complexity of the shape of the non-box, van trailers which, in many cases, transport cargo that is in the windstream (e.g., flatbeds that carry heavy equipment, car carriers, and loggers). For non-box, van trailers you could have a different aerodynamic shape with every load. While some technologies exist to address aerodynamic drag for non-box, van trailers, it has been either experimental or not widely commercially available.

Current trailer aerodynamic technologies for box, van trailers are estimated to provide approximately 7 percent GHG emission reductions when used as a package. For box, van trailers, trailer aerodynamic technologies have addressed drag at the front of the trailer (i.e., vortex traps, leading edge fairings), underneath the trailer (i.e., side skirts, wheel fairings) and the trailer rear (i.e., afterbodies). These technologies are commercially available and have seen moderate adoption rates. Table 2-30 shows technologies that have generally been accepted for use on box, van trailers. In general, the performance of these technologies is dependent upon the smooth transition of airflow from the tractor to the trailer. True for both tractor and trailer aerodynamic drag reduction, the overall shape can be optimized to minimize aerodynamic drag and, in fact, the trailer body must have at least a moderately aerodynamic shape (and its relatively smooth flow) to benefit from add-on aerodynamic components.

Table 2-30: Trailer Technologies to Address Aerodynamic Drag

LOCATION ON TRAILER	TECHNOLOGY TYPE	DESIGNED EFFECT
Front	Vortex trap	Reduce drag induced by cross-flow through gap between tractor and trailer
Front	Front fairings	Smoothly transition air to flow from tractor to the trailer
Rear	Afterbody (boat tail and rear fairings)	Reduce pressure drag induced by the trailer wake
Undercarriage	Side skirts	Manage flow of air underneath tractor to reduce eddies and wake
Undercarriage	Underbelly treatment	Manage flow of air underneath tractor to reduce eddies and wake
Accessories	General	Reducing surface area perpendicular to travel and minimizing complex shapes that may induce drag
General	Advanced, passive air management	Manage airflow through passive aerodynamic shapes or devices that keep flow attached to the vehicle (tractor and trailer)

Table 2-31

TECHNOLOGY	COST ESTIMATE
Trailer Side Skirts	$1300 – 1600
Gap Fairing	$850
Trailer Aerocone	$1000
Boat Tails	$1960
Air Tabs	$180

2.8.2.2 Tires – single wide and low rolling resistance

Beginning in 2007, EPA began designating certain new dry freight box van trailers for on the road use of 53 feet or greater length Certified SmartWay Trailers. Older or pre-owned trailers could also be certified if properly retrofitted. In order for a trailer to be designated as Certified SmartWay, the trailer must be equipped with verified low rolling resistance trailer tires (either dual or single-wide), among other things.

The RR_c baseline for today's fleet is 6.5 kg/metric ton for the trailer tire, based on sales weighting of the top three manufacturers based on market share. This value is based on new trailer tires, since rolling resistance decreases as the tread wears. To achieve the intended emissions benefit, SmartWay established the maximum allowable RR_c for the trailer tire 15 percent below the baseline or 5.5 kg/metric ton.

Research indicates the contribution to overall vehicle fuel efficiency by tires is approximately equal to the proportion of the vehicle weight on them[21]. On a fully loaded typical Class 8 long-haul tractor and trailer, 42.5 percent of the total tire energy loss attributed to rolling resistance is from the trailer tires.

The Center for Transportation Research at Argonne National Laboratory analyzed technology options to support energy use projections. EPA agrees with their assumed incremental cost of low rolling resistance tires of $15 - $20 per tire[39]. With 8 tires replaced on a trailer, the incremental cost would be between $120 and $160. Often the steer tire is retreaded and placed on the trailer axle. There is a cost savings associated with retread tires. A new retread costs between $150 and $200, compared to a new tire which costs typically around $400. This represents a savings of $1,200 to $1,600 per trailer.

Single wide tires are also used on trailers. The Center for Transportation Research estimated incremental capital cost of single wide tires is $30 - $40 per tire[39]. With 4 single wide tires replacing 8 dual tires on the trailer, the incremental cost would be between $120 and $160.

Based on the ICF report,[65] EPA and NHTSA estimate the incremental retail cost for low rolling resistance tires as $78 per tire. The agencies also estimate that the incremental cost to replace a pair of dual tires with a single wide based tire is $216, however, the cost can be reduced when the wheel replacement cost is considered.

2.8.2.3 Trailer Weight Reduction

Weight reduction opportunities in trailers exist in both the structural components and in the wheels and tires. Material substitution (replacing steel with aluminum) is feasible for components such as roof posts, bows, side posts, cross members, floor joists, and floors. Similar material substitution is feasible for wheels. Weight reduction opportunities also exist through the use of single wide based tires replacing two dual tires.

The agencies' assessment of the ICF report indicates that the expected incremental retail prices of the lightweighted components are as included in Table 2-32.

Table 2-32

COMPONENT	COST
Roof Posts/Bows	$120
Side Posts	$525
Cross Members/Floor Joists	$400
Floor	$1,500
Wheels	$1,500

2.8.2.4 Opportunities in Refrigerated Trailers

Refrigeration units are used in van trailers to transport temperature sensitive products. A traditional trailer refrigeration unit (TRU) is powered by a nonroad diesel engine. There are GHG reduction opportunities in refrigerated trailers through the use of electrical trailer refrigeration units and highly reflective trailer coatings.

Highly reflective materials, such as reflective paints or translucent white fiberglass roofs, can reflect the solar radiation and decrease the cooling demands on the trailer's refrigeration unit. A reflective composite roof can cost approximately $800, the addition of reflective tape to a trailer roof would cost approximately $450.

Hybrid TRUs utilize a diesel engine which drives a generator which in turn powers the compressor and fans. The cost of this unit is approximately $4,000.

All-electric TRUs, needing no diesel engine to power the unit, are being tested in U.S. refrigerated fleets. There is no market price for these units at this time.

2.9 Other Fuel Consumption and GHG Reducing Strategies

There are several other types of strategies available to reduce fuel consumption and GHG emissions from trucks. EPA and NHTSA identify several of these technologies and strategies below, but acknowledge that they are outside the proposed regulatory framework currently identified.

2.9.1 Auxiliaries

The accessories on a truck engine, including the alternator, coolant and oil pumps are traditionally mechanically gear or belt driven by the base engine. In general, the effect of accessory power consumption in trucks is much less than in cars but the mechanical auxiliaries operate whenever base engines are running, which can waste energy when the auxiliaries are not needed. The replacement of mechanical auxiliaries by electrically driven systems can decouple mechanical loads from the base engine and reduce energy use. Since the average engine loads from mechanical auxiliaries are higher than those from a small generator that supplies electricity to electric auxiliaries, base engine fuel can be reduced. A reduction in CO_2 emissions and fuel consumption can be realized by driving them electrically and only when needed ("on-demand"). The heavy and medium trucks have several auxiliary systems:

- Air compressor,
- Hydraulic pumps,
- Coolant pump,
- Engine oil and fuel pumps,
- Fans, and
- Air conditioning compressor.

The systems listed above, although not inclusive, can be optimized by various methods reducing fuel consumption and GHG emissions;

- *Electric power steering (EPS)* – is an electrically-assisted steering system that has advantages over traditional hydraulic power steering because it replaces a continuously operated hydraulic pump, thereby reducing parasitic losses from the accessory drive.

- *Electric water pumps and electric fans* - can provide better control of engine cooling. For example, coolant flow from an electric water pump can be reduced and the radiator fan can be shut off during engine warm-up or cold ambient temperature conditions which will reduce warm-up time, reduce warm-up fuel enrichment, and reduce parasitic losses. Indirect benefit may be obtained by reducing the flow from the water pump electrically during the engine warm-up period, allowing the engine to heat more rapidly and thereby reducing the fuel enrichment needed during cold starting of the engine.

- *High efficiency alternators* - provide greater electrical power and efficiency at road speed or at idle than conventional original equipment replacement alternators that typically operate at 55 percent efficiency.

- *If electric power is not available* - there are still some technologies that can be applied to reduce the parasitic power consumption of accessories. Increased component efficiency is one approach, and clutches can be used to disengage the alternator and air compressor when they are not required. Many MD/HD engines incorporate clutched cooling fans which can be shut off during engine warm-up thereby not requiring electric cooling fans. Air compressors that are rotating but not creating pressure absorb about half the power of a pumping compressor, and compressors normally only pump a small percentage of the time in long-haul trucks.

Several studies have documented the GHG reductions from electrification and/or optimization of truck auxiliaries. One study, based on a full-scaled test of a prototype truck that used a small generator to produce electricity, full electrification of auxiliaries reduces fuel use by 2 percent including extended idle and estimated potential reductions in modal GHG emissions are 1.4 percent**Error! Bookmark not defined.**[54]. Another study recently completed by Ricardo discussed the advantages of electrification of engine accessories along with the potential to increase fuel economy citing examples such as variable flow water pumps and oil pumps[66]. Potential gains may be realized in the range of 1 to 3 percent but are highly dependent on truck type, size and duty cycle. In a NESCAFF study, the accessory power demand of a baseline truck was modeled as a steady state power draw of 5 kW, and 3 kW for more electrical accessories in individual vehicle configurations that included electric turbo compounding. The 2 kW savings versus average engine power of 100 to 200kW over a drive cycle nets roughly 1 to 2 percent savings compared to a baseline vehicle**Error! Bookmark not defined.**[55].

Accurate data providing power consumption values for each discrete accessory over a range of operating conditions was not available due to the variation of the truck fleet. Based on research and industry feedback, a simplified assumption for modeling was made that the average power demand for mechanically driven accessories is 5 kW, and the average power demand for electrically driven accessories is 3 kW. This provides a 2 kW advantage for the electrically driven accessories over the entire drive cycle represent and is estimated to provide a 1.5 percent improvement in efficiency and reduction in CO_2 emissions. As a comparison, the average load on a car engine over a drive cycle may be in the 10 to 20 kW range. At this level, a 2 kW reduction in accessory loads of a passenger vehicle makes a significant difference (approximately 10 percent). Given the higher loads experienced by truck engines, accessory demand is a much smaller share of overall fuel consumption. Accessory power demand determined by discrete components will be not be included in the model at this time and a power draw of 5 kW for standard accessories and 3 kW for electrical accessories will be used. There is opportunity for additional research to improve upon this simple modeling approach by using actual measured data to improve the modeling assumptions.

2.9.2 Driver training

Driver training that targets fuel efficiency can help drivers recognize and change driving habits that waste fuel and increase harmful emissions. Even highly experienced truck drivers can boost their skills and enhance driving performance through driver training programs.[67]

Driving habits that commonly waste fuel are high speed driving, driving at unnecessarily high rpm, excessive idling, improper shifting, too-rapid acceleration, unnecessarily frequent stops and starts, and poor route planning. Well-trained drivers can reduce fuel consumption by applying simple techniques to address vehicle and engine speed, shifting patterns, acceleration and braking habits, idling, and use of accessories.[68] Some techniques include starting out in a gear that does not require using the throttle when releasing the clutch, progressive shifting (upshifting at the lowest possible rpm), anticipating traffic flow to reduce starts and stops, use of block shifting where possible (e.g., shifting from 2nd to 5th gear), using cruise control as appropriate, and coasting down or using the engine brake to slow the vehicle, instead of gearing down or using the brake pedal.

As discussed elsewhere in this chapter, idling can be eliminated by the use of auxiliary power units or other idle reduction solutions that provide power or heating and cooling to the cab at a much lower rate of energy consumption.

Better route planning that reduces unnecessary mileage and the frequency of empty backhauls, and takes into account factors like daily congestion patterns is another facet of a comprehensive driver training program. Such planning can be assisted through the use of logistics companies, which specialize in such efficiencies.

In its report, *Technologies and Approaches to Reducing the Fuel Consumption of Medium and Heavy Duty Vehicles*, the National Research Council cited studies that found, on average, a five percent improvement in vehicle fuel efficiency due to driver training.[69] EPA's SmartWay Transport Partnership has documented the success of dozens of trucking companies' use of driver training programs. One company reported saving an average of 42 gallons per student, or 335,000 gallons of fuel per year; and, saving 837,000 gallons of fuel in the four years it has had its training program in place.[70] Trucking fleets can provide additional motivation to reward drivers for improved performance with incentive programs, which may be monetary or provide other forms of benefits and recognition. Sometimes negative measures are employed to urge compliance with company expectations, up to and including termination of employment. Successful programs are those that perform ongoing reviews of driver techniques, and provide assistance to improve and/or retrain drivers.

While EPA and NHTSA recognize the potential opportunity to reduce fuel consumption and greenhouse gas emissions by encouraging fuel-efficient driver habits, mandating driver training for all of the nation's truck drivers is beyond the scope of this proposed regulation. However, in developing this proposal, the agencies did consider technologies that can provide some of the benefits typically addressed through driver training. Examples include automatic engine shutdown to reduce idling, automated or automated manual transmissions to optimize shifting, and speed limiters to reduce high speed operation. EPA will continue to promote fuel-efficient driving through its SmartWay program. In addition to providing fact sheets on fuel efficient driving,[71] SmartWay is collaborating with Natural Resources Canada's FleetSmart program to develop a web-enabled "fuel efficient driver" training course for commercial truck drivers. Once the course is developed, it will complement the agencies regulatory program by making fuel efficient driver training strategies available to any commercial truck driver.

2.9.3 Automatic Tire inflation and tire pressure monitoring system

Underinflation of tires has the potential to reduce fuel economy by as much as two to three percent[72]. Although most truck fleets understand the importance of keeping tires properly inflated, it is likely that a substantial proportion of trucks on the road have one or more underinflated tires. An industry survey conducted in 2002 at two truck stops found that fewer than half of the tires checked were within five pounds of their recommended inflation pressure. Twenty-two percent of the vehicles checked had at least one tire underinflated by at least twenty pounds per square inch (psi), and four percent of the vehicles were running with at least one flat tire, defined as a tire underinflated by fifty psi or more. The survey also found mismatches in tire pressure exceeding five percent for dual tires on axle ends.[73]

Proper tire inflation pressure can be maintained with a rigorous tire inspection and maintenance program or with the use of tire pressure and inflation systems. These systems monitor tire pressure; some also automatically keep tires inflated to a specific level. However, while the agencies recognize that such devices could have a beneficial effect on fuel economy, their use is not included in the regulatory framework. Notwithstanding the cited survey, the level of underinflation of tires in the American truck fleet is not known,[74] which means that neither a baseline value nor an estimate of the fuel savings from the use of automatic tire inflation systems can be quantified with certainty. Through its SmartWay program, however, EPA does provide information on proper tire inflation pressure and on tire inflation and tire inflation pressure monitoring systems.[75]

2.9.4 Engine Features

Previous sections 2.3.2.2 through 2.3.2.8 describe the technologies that can be tested in an engine test cell for certification purpose and could be potentially implemented in production before the time frame of 2017. Some other technologies that cannot be easily tested in an engine test cell, but can improve engine fuel economy, should be worthwhile mentioning. Examples include these technologies, such as driver rewards, load based speed control, gear down protection, and fan control offered by Cummins's PowerSpec.

The driver reward developed by Cummins monitors and averages the driver trip fuel economy and trip idle percent time at regular intervals, seeking to modify driver behavior by offering incentives to use less fuel. Desirable driving habits, such as low percentage of idle time, and high MPG, are rewarded with higher limits on the road speed governor, cruise control or both. The load based speed control or other similar programs are designed to improve fuel economy, lower vehicle noise, and improve driver satisfaction by managing engine speed (rpm) based on real time operating conditions. During high power requirements, this type of technology enhances engine performance by providing the driver with an extended operating range. In addition to the fuel economy benefits from operating the engine at lower speeds, vehicle noise is lowered.

Gear down protection offered by Cummins is to promote increased fuel economy by encouraging the vehicle driver to operate as much as effectively possible in top gear where fuel consumption is lower. This can be done by limiting vehicle speed in lower gears. Maximizing time in top gear means the engine runs in a lower rpm range, where fuel economy is best with improved durability and without compromising performance. Difference between top gear and one gear down can be as much as 16 percent in fuel economy. More detailed descriptions of many technologies including those mentioned here can be viewed at Cummins's website of http://www.powerspec.cummins.com/site/home/index.html.

Although these technologies mentioned in this section are not able to be tested in an engine test cell environment, thus being unable to be directly used for benefits of certification purpose, the agency encourages manufacturers to continue improving the current and developing new technologies, thereby reducing green house gases in a broader way.

2.9.5 Logistics

Logistics encompasses a number of interrelated, mostly operational factors that affect how efficiently the overall freight transport system works. These factors include choice of mode, carrier and equipment; packaging type and amount; delivery time; points of origin and destination; route choice, including locations of ports and distribution hubs; and transportation tracking systems. These factors are controlled by the organizations that ship and receive goods. Due to the specialized nature of logistics management, organizations increasingly rely upon internal or outsourced business units to handle this function; many transportation providers offer logistics management services to their freight customers.

Because optimizing logistics is specific to each individual freight move, neither EPA nor NHTSA believed it is feasible to manage logistics through this proposed regulation.

However, implementing certain system-wide logistics enhancements on a national level could provide benefits. As described in the National Research Council's recent report,[76] a broader national approach could include enhanced telematics and intelligent transportation systems; changes to existing infrastructure to optimize modal choice; and increased truck capacity through changes to current truck weight and size limits. While such a broad transformation of our freight system is worthwhile to consider, implementing such system-wide changes falls outside the scope of this proposed regulation. As the National Research Council noted,[77] due to its complex nature, logistics management is not readily or effectively addressed through any single approach or regulation; a number of complementary measures and alternatives are needed. Such measures can include initiatives that enable companies to better understand, measure and track the benefits of logistics optimization from an environmental and economic standpoint. The SmartWay program provides uniform tools and methodologies that companies can use to assess and optimize transportation supply chains, and can complement any future regulatory and nonregulatory approaches.

2.9.6 Longer combination vehicles, weight increase

Longer combination vehicles (LCVs) are tractor-trailer combination trucks that tow more than one trailer, where at least one of the trailers exceeds the "pup" size (typically 24-28 feet). Because LCVs are capable of hauling more freight than a typical tractor-trailer combination truck, using LCVs reduces the number of truck trips needed to carry the same amount of freight. On a fleetwide basis, this saves fuel, reduces greenhouse gas emissions, and reduces per-fleet shipping costs. A typical non-LCV may tow a single trailer up to 53 feet in length, or tow two pup trailers, or even be a straight truck with a pup trailer connected via a draw bar. In contrast, the typical LCV may consist of a tractor towing two trailers of 45-48 feet, and occasionally 53 feet in length (a "turnpike double"), or one of that size and one pup (a "Rocky Mountain double"), or may tow three pups (a "triple").

Trucks consisting of a two-axle tractor combined with two one-axle trailers up to 28.5 feet are permitted on all highways in the U.S. National Network, which consists of the interstate highway system and certain other roads. Individual states may permit longer LCVs to operate on roads that are not part of the National Network. They are allowed in 16 western states, but only on turnpikes in the five states east of the Mississippi that allow them; no new states were granted permitting authority for LCVs after 1991.[78] Regulations vary among states; some allow LCVs with more than three trailers, but only by permit. Longer length turnpike doubles are typically restricted to tolled turnpikes. Such restrictions are based on considerations of the difficulty of operation and on expected weather conditions. Other regulations on the types of LCVs allowed are seen in other countries; in Australia, "road trains" of up to four trailers, usually with three axles per trailer, are permitted.

Some proponents of liberalized size and weight regulations project substantial benefits, estimating that highway freight productivity could be doubled and costs reduced. Despite the potential benefits of LCVs, as the National Research Council noted in its recent report, there are considerations that may make LCVs less cost effective and less safe. For example, if infrastructure (e.g., bridges with sufficient capacity; roadways with adequate lane width and curb radii for turning to accommodate an LCV safely) are not available without traveling far from a more efficient route, or if there is insufficient opportunity for the LCV to make the most of the available volume in multiple trailers, then LCVs would not be cost effective.

The increased vehicular weight of LCVs is both a safety issue and a road maintenance issue (see discussion below on increasing vehicle weight and legal load limits). The additional weight of extra trailers increases braking and stopping distance, and adds difficulty in maintaining speed in grade situations.

With additional regard to safety, LCVs might have trouble with offtracking (when the truck's front and rear wheels do not follow the same path, which can result in departing the lane boundaries—a particular problem with longer LCVs), and could increase the challenge of merging with and maneuvering in traffic. Lateral stability is a greater problem in LCVs, and leads to a greater chance of rollover, particularly when the individual trailers are shorter. Also, when a vehicle is passing a LCV on a two-lane road, the period of time spent in the opposing lane (up to 2-3 seconds) poses another safety problem.[79] Such safety considerations impact decisions regarding restrictions on the use of LCVs, even when they may otherwise be a cost effective freight choice.

Moves to increase commercial vehicle weight limits concern not only relaxing limitations on the use of LCVs, but also increasing gross vehicle weight limits for single unit trucks and conventional tractor-trailer combinations, as well as increasing axle load limits and trailer lengths. Some analysts cite scenarios in which such relaxations result in increased highway freight productivity, while yielding significant reductions in shipping costs, congestion, and total vehicle miles traveled. Increasing the weight limits allows commercial freight vehicles to carry heavier loads, reducing the number of trucks required to transport freight, potentially resulting in overall emissions reductions.

Federal law limits gross vehicle weight for commercial vehicles operating in the Interstate Highway System to a maximum of 80,000 lbs. (maximum 20,000 lbs. per single axle, 34,000 lbs. per tandem axle), with permits available for certain oversize or overweight loads and exceptions allowing 400 lbs. more for tractors with idle reduction devices. Additional vehicle weight limitations have been set by state and local regulations. These limitations arise from considerations of infrastructure characteristics, traffic densities, economic activities, freight movement, mode options, and approach to transportation design. In some cases, state limits are higher than federal limits.[80] While these parameters are changeable, federal weight limits on vehicles have not changed since 1982, and limits set by states have been frozen since 1991.

In response to input from the freight transportation sector and other interested parties, the Department of Transportation, the Transportation Research Board, the General Accounting Office, and others have conducted studies examining the impacts of proposals related to liberalized weight limits. However, regardless of the potential benefits of such action, the analyses predict premature degradation of infrastructure (e.g., bridges, pavement, grades) as a consequence. Increased costs required to maintain and upgrade the highway system would impose high burdens on already-strained public resources, raising serious questions on the desirability of relaxing weight limits, and on whether such expenditures provide adequate public good to justify them. Safety issues similar to those cited for LCVs enter into this debate, as do concerns with the effect on the efficiency of automotive travel, impacts on and net productivity of other shipping modes (particularly rail), and potential environmental and social costs.

The National Research Council in its recent report[81] recognized the complexities and potential trade-offs involved in increasing vehicle size and weight limits. While is worthy to discuss the potential emission and energy benefits of heavier and longer trucks, the far-reaching policy ramifications extend far beyond the scope of this proposal.

2.9.7 Traffic congestion mitigation

There are a wide range of strategies to reduce traffic congestion. Many of them are aimed at eliminating light-duty vehicle trips such as mass transit improvements, commute trip reduction programs, ridesharing programs, implementation of high occupancy vehicle lanes, parking pricing, and parking management programs. While focused on reducing light-duty vehicle trips, these types of strategies would allow heavy- and medium-duty vehicles to travel on less congested roads and thereby use less fuel and emit less CO_2.

A second group of strategies would directly impact CO_2 emissions and fuel consumption from all types of vehicles. One example of these strategies is road pricing including increasing the price of driving on certain roads or in certain areas during the most congested periods of the day. A second example is reducing the speed limits on roads and implementing measures to ensure that drivers obey the lower speed limits such as increased enforcement or adding design features that discourage excessive speeds.

Some strategies would be designed to effect trips made by heavy- and medium-duty trucks. These would include programs to shift deliveries in congested areas to off-peak hours. Another example is to modify land use so that common destinations are closer together, which reduces the amount of travel required for goods distribution.

These types of congestion relief strategies have been implemented in a number of areas around the country. They are typically implemented either by state or local governments or in some cases strategies to reduce commuting trips and scheduling off-peak deliveries have been implemented by private companies or groups of companies.

2.10 Summary of Technology Costs Used in this Analysis

Table 2-33 shows the technology costs used throughout this analysis for the years 2014-2020. This table reflects the impact of learning effects on estimated technology costs. Refer to Table 2-1 for details on the ICMs applied to each technology and Table 2-2 for the type of learning applied to each technology. The costs shown in the table include the penetration rates so do not always reflect the true cost of the technology if, for example, the expected penetration rate for that technology is less than 100 percent or, as is the case for turbo compounding, the technology is not expected until the 2017 model year (cost for this technology are shown as $0 in years prior to 2017). One final note of clarification is that the term “HHDD8” in the “Class” column refers specially to engines placed in Class 8 sleeper cabs.

Table 2-33 Technology Costs by Year used in this Analysis (2008$)

Technology	Applied to	Truck type	Class	2014	2015	2016	2017	2018	2019	2020
AI	Engine		LHDD	$111	$108	$104	$101	$98	$96	$94
DSL engine improvements	Engine		LHDD	$217	$210	$204	$198	$192	$188	$184
Cyl_Head	Engine		MHDD	$6	$6	$6	$6	$5	$5	$5
Turbo_Eff	Engine		MHDD	$17	$17	$16	$16	$15	$15	$15
EGR_cooler	Engine		MHDD	$3	$3	$3	$3	$3	$3	$3
Pump_H2O	Engine		MHDD	$87	$84	$82	$79	$77	$75	$74
Pump_Oil	Engine		MHDD	$4	$4	$4	$4	$4	$4	$4
Pump_Fuel	Engine		MHDD	$4	$4	$4	$4	$4	$4	$4
Rail_Fuel	Engine		MHDD	$10	$9	$9	$9	$8	$8	$8
Inj_Fuel	Engine		MHDD	$10	$10	$10	$9	$9	$9	$9
Piston	Engine		MHDD	$3	$3	$2	$2	$2	$2	$2
EFR_VlvTrain	Engine		MHDD	$78	$76	$73	$71	$69	$68	$66
Cyl_Head	Engine		HHDD	$6	$6	$6	$6	$5	$5	$5
Turbo_Eff	Engine		HHDD	$17	$17	$16	$16	$15	$15	$15
EGR_cooler	Engine		HHDD	$3	$3	$3	$3	$3	$3	$3
Pump_H2O	Engine		HHDD	$87	$84	$82	$79	$77	$75	$74
Pump_Oil	Engine		HHDD	$4	$4	$4	$4	$4	$4	$4
Pump_Fuel	Engine		HHDD	$4	$4	$4	$4	$4	$4	$4
Rail_Fuel	Engine		HHDD	$10	$9	$9	$9	$8	$8	$8
Inj_Fuel	Engine		HHDD	$10	$10	$10	$9	$9	$9	$9
Piston	Engine		HHDD	$3	$3	$2	$2	$2	$2	$2
Cyl_Head	Engine		HHDD8	$6	$6	$6	$6	$5	$5	$5
Turbo_Eff	Engine		HHDD8	$17	$17	$16	$16	$15	$15	$15
EGR_cooler	Engine		HHDD8	$3	$3	$3	$3	$3	$3	$3
Pump_H2O	Engine		HHDD8	$87	$84	$82	$79	$77	$75	$74
Pump_Oil	Engine		HHDD8	$4	$4	$4	$4	$4	$4	$4
Pump_Fuel	Engine		HHDD8	$4	$4	$4	$4	$4	$4	$4
Rail_Fuel	Engine		HHDD8	$10	$9	$9	$9	$8	$8	$8
Inj_Fuel	Engine		HHDD8	$10	$10	$10	$9	$9	$9	$9
Piston	Engine		HHDD8	$3	$3	$2	$2	$2	$2	$2
Turbo_MechComp	Engine		HHDD8	$0	$0	$0	$823	$798	$782	$767
EFR	Engine		HDG	$0	$0	$88	$88	$88	$88	$88
VVTC-OHV-V	Engine		HDG	$0	$0	$43	$42	$40	$40	$39
DI-V8	Engine		HDG	$0	$0	$372	$361	$350	$343	$336
LRR_steer5.7	Truck	Vocational	LH	$65	$65	$52	$52	$42	$40	$39
LRR_drive7.0	Truck	Vocational	LH	$91	$91	$72	$72	$58	$56	$55
LRR_steer5.7	Truck	Vocational	MH	$65	$65	$52	$52	$42	$40	$39
LRR_drive7.0	Truck	Vocational	MH	$91	$91	$72	$72	$58	$56	$55
LRR_steer5.7	Truck	Vocational	HH	$65	$65	$52	$52	$42	$40	$39
LRR_drive7.0	Truck	Vocational	HH	$121	$121	$97	$97	$77	$75	$73
Aero_SW	Truck	Class7_DayCab	LowRoof	$539	$523	$507	$492	$477	$468	$459
Aero_SWadvance	Truck	Class7_DayCab	LowRoof	$436	$436	$349	$349	$279	$271	$262
LRR_steer	Truck	Class7_DayCab	LowRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class7_DayCab	LowRoof	$60	$59	$57	$55	$53	$52	$51
WR_SWide	Truck	Class7_DayCab	LowRoof	$322	$312	$303	$294	$285	$279	$274
WR_AlWheel_Steer	Truck	Class7_DayCab	LowRoof	$523	$507	$492	$477	$463	$454	$445
WR_AlWheel_Swide	Truck	Class7_DayCab	LowRoof	$627	$608	$590	$572	$555	$544	$533
Aero_SW	Truck	Class7_DayCab	HighRoof	$775	$752	$729	$707	$686	$672	$659
Aero_SWadvance	Truck	Class7_DayCab	HighRoof	$441	$441	$353	$353	$283	$274	$266
LRR_steer	Truck	Class7_DayCab	HighRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class7_DayCab	HighRoof	$60	$59	$57	$55	$53	$52	$51
WR_SWide	Truck	Class7_DayCab	HighRoof	$322	$312	$303	$294	$285	$279	$274
WR_AlWheel_Steer	Truck	Class7_DayCab	HighRoof	$523	$507	$492	$477	$463	$454	$445

WR_AlWheel_Swide	Truck	Class7_DayCab	HighRoof	$627	$608	$590	$572	$555	$544	$533
Aero_SW	Truck	Class8_DayCab	LowRoof	$647	$628	$609	$591	$573	$562	$550
LRR_steer	Truck	Class8_DayCab	LowRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class8_DayCab	LowRoof	$121	$117	$114	$110	$107	$105	$103
WR_SWide	Truck	Class8_DayCab	LowRoof	$644	$624	$606	$588	$570	$559	$547
WR_AlWheel_Steer	Truck	Class8_DayCab	LowRoof	$523	$507	$492	$477	$463	$454	$445
WR_AlWheel_Swide	Truck	Class8_DayCab	LowRoof	$1,254	$1,216	$1,180	$1,144	$1,110	$1,088	$1,066
Aero_SW	Truck	Class8_DayCab	HighRoof	$332	$322	$313	$303	$294	$288	$282
Aero_SWadvance	Truck	Class8_DayCab	HighRoof	$883	$883	$706	$706	$565	$548	$532
LRR_steer	Truck	Class8_DayCab	HighRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class8_DayCab	HighRoof	$121	$117	$114	$110	$107	$105	$103
WR_SWide	Truck	Class8_DayCab	HighRoof	$644	$624	$606	$588	$570	$559	$547
WR_AlWheel_Steer	Truck	Class8_DayCab	HighRoof	$523	$507	$492	$477	$463	$454	$445
WR_AlWheel_Swide	Truck	Class8_DayCab	HighRoof	$1,254	$1,216	$1,180	$1,144	$1,110	$1,088	$1,066
Aero_SW	Truck	Class8_SleeperCab	LowRoof	$527	$511	$496	$481	$466	$457	$448
Aero_SWadvance	Truck	Class8_SleeperCab	LowRoof	$498	$498	$399	$399	$319	$309	$300
LRR_steer	Truck	Class8_SleeperCab	LowRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class8_SleeperCab	LowRoof	$121	$117	$114	$110	$107	$105	$103
WR_SWide	Truck	Class8_SleeperCab	LowRoof	$644	$624	$606	$588	$570	$559	$547
WR_AlWheel_Steer	Truck	Class8_SleeperCab	LowRoof	$523	$507	$492	$477	$463	$454	$445
WR_AlWheel_Swide	Truck	Class8_SleeperCab	LowRoof	$1,254	$1,216	$1,180	$1,144	$1,110	$1,088	$1,066
APU	Truck	Class8_SleeperCab	LowRoof	$5,228	$5,071	$4,919	$4,772	$4,628	$4,536	$4,445
Aero_SW	Truck	Class8_SleeperCab	MidRoof	$404	$391	$380	$368	$357	$350	$343
Aero_SWadvance	Truck	Class8_SleeperCab	MidRoof	$748	$748	$598	$598	$479	$464	$450
LRR_steer	Truck	Class8_SleeperCab	MidRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class8_SleeperCab	MidRoof	$121	$117	$114	$110	$107	$105	$103
WR_SWide	Truck	Class8_SleeperCab	MidRoof	$644	$624	$606	$588	$570	$559	$547
WR_AlWheel_Steer	Truck	Class8_SleeperCab	MidRoof	$523	$507	$492	$477	$463	$454	$445
WR_AlWheel_Swide	Truck	Class8_SleeperCab	MidRoof	$1,254	$1,216	$1,180	$1,144	$1,110	$1,088	$1,066
APU	Truck	Class8_SleeperCab	MidRoof	$5,228	$5,071	$4,919	$4,772	$4,628	$4,536	$4,445
Aero_SW	Truck	Class8_SleeperCab	HighRoof	$1,271	$1,232	$1,196	$1,160	$1,125	$1,102	$1,080
Aero_SWadvance	Truck	Class8_SleeperCab	HighRoof	$256	$256	$205	$205	$164	$159	$154
LRR_steer	Truck	Class8_SleeperCab	HighRoof	$65	$63	$61	$59	$57	$56	$55
LRR_drive	Truck	Class8_SleeperCab	HighRoof	$121	$117	$114	$110	$107	$105	$103
WR_SWide	Truck	Class8_SleeperCab	HighRoof	$644	$624	$606	$588	$570	$559	$547
WR_AlWheel_Steer	Truck	Class8_SleeperCab	HighRoof	$523	$507	$492	$477	$463	$454	$445
WR_AlWheel_Swide	Truck	Class8_SleeperCab	HighRoof	$1,254	$1,216	$1,180	$1,144	$1,110	$1,088	$1,066
APU	Truck	Class8_SleeperCab	HighRoof	$5,228	$5,071	$4,919	$4,772	$4,628	$4,536	$4,445
AC	Truck	Class7_DayCab	LowRoof	$21	$20	$20	$19	$19	$18	$18
AC	Truck	Class7_DayCab	HighRoof	$21	$20	$20	$19	$19	$18	$18
AC	Truck	Class8_DayCab	LowRoof	$21	$20	$20	$19	$19	$18	$18
AC	Truck	Class8_DayCab	HighRoof	$21	$20	$20	$19	$19	$18	$18
AC	Truck	Class8_SleeperCab	LowRoof	$21	$20	$20	$19	$19	$18	$18
AC	Truck	Class8_SleeperCab	MidRoof	$21	$20	$20	$19	$19	$18	$18
AC	Truck	Class8_SleeperCab	HighRoof	$21	$20	$20	$19	$19	$18	$18

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