Reducing Heavy-Duty Vehicle Fuel Consumption and Greenhouse Gas Emissions

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Medium and heavy-duty trucks account for approximately 6% of total anthropogenic greenhouse gas (GHG) emissions in the United States.[1] From 1990 to 2007, medium- and heavy-truck GHG emissions increased 79%, representing the largest percentage increase of any major transportation mode.[1]

Heavy-duty truck activity is responsible for the majority of total truck emissions, and miles traveled are projected to increase steadily in coming decades.[2] As such, policy-makers committed to reducing emissions that contribute to the risk of future climate change have a keen interest in addressing the emissions contribution of the heavy-duty vehicle fleet. The U.S. federal government is in the process of developing a heavy-duty vehicle fuel efficiency regulation, but there is currently no regulation in place. Nor are there regulations for heavy-duty vehicle GHG emissions.

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Study: Reducing GHGs and Fuel Consumption from Heavy-Duty Vehicles

To assist policy-makers in developing GHG and fuel consumption regulations for heavy-duty vehicles, the Northeast States Center for a Clean Air Future (NESCCAF) and the International Council on Clean Technology (ICCT) conducted a study to assess available and emerging technologies to reduce GHG emissions and fuel consumption from heavy-duty, long-haul motor vehicles in the United States in the 2012–2017 timeframe.[3] This article summarizes some of the key findings of the study relative to introducing advanced technology components into heavy-duty, long-haul trucks.

Study Method

The analysis consisted of a series of modeled simulations to predict the fuel consumption and emissions impacts of incorporating various technology combinations in new trucks. The simulations were performed by Southwest Research Institute (SwRI) for a long-haul, Class 8 truck (i.e., a tractor-trailer combination with a gross vehicle weight rating above 33,000 lb) using publicly available software (RAPTOR and GT-POWER) that provides detailed information on the acceleration, braking, fuel consumption, and emissions performance of different truck designs, engine designs, and component packages.

Additional steps in the analysis involved estimating the cost of each package and creating technology cost curves based on the simulation results. Detailed cost estimates were developed by TIAX LLC using industry information gathered from technical papers, published cost data, and interviews. TIAX also conducted a fleet-wide fuel consumption and GHG emissions reduction analysis, using a proprietary fleet model to estimate the fuel consumption and GHG emissions that would be reduced in the United States between 2008 and 2030, assuming two scenarios for fleet-wide adoption of technologies to reduce GHG emissions and fuel consumption.

Study Results

The results indicate that substantial, cost-effective GHG emission and fuel consumption reductions are achievable for heavy-duty, long-haul trucks in the 2012–2017 timeframe. Specifically, emissions from heavy-duty, long-haul trucks could be reduced up to 51% relative to a 2007 baseline vehicle. One would expect that if market forces alone are allowed to drive the improvement, the result will be a much lower reduction than 51%.

With the introduction of regulations designed to reduce fuel consumption, the results are expected to be in the 25–50% improvement range. The reason for this is that, in recent years, numerous technologies that could substantially reduce heavy-duty vehicle GHG emissions and fuel consumption have been developed and brought to production. Some of these technologies have been used to improve the efficiency of heavy-duty trucks. Many of them, however, have not been used by the heavy-duty trucking industry for a number of reasons, including the short payback times required by the trucking industry; the lack of integration of truck, tractor, and trailer manufacturers; and the fact that different companies often own different parts of the tractor trailer combination.

All of these factors make it difficult to achieve across-the-board improvements in truck fuel consumption and GHG emissions. Any technical approach to reduce truck fuel consumption and GHG emissions must include both the tractor and the trailer in an integrated strategy. A regulation requiring the introduction of new technologies to reduce fuel consumption and emissions is needed to ensure that technologies are introduced into this sector.

Table 1 presents fuel consumption and emission reduction and cost estimates for 14 technology packages modeled for heavy-duty, long-haul trucks. Column 1 lists the technology package reference

Table 1. Heavy-duty, long-haul GHG and fuel consumption reduction results for combinations of technologies.

Package #	Technology Combinations	Fuel consumption and CO_2 Reduction	Marginal Vehicle Cost[a]	3-Year Net Cost[a]	15-Year Net Cost[a]
1	Baseline: Volvo D13 (2010 emissions), Kenworth T600, 10-speed automatic	n/a	n/a	n/a	n/a
7	Variable valve actuation	1.0%	$300	-$1000	-$2500
11	Advanced exhaust gas recirculation	1.2%	$750	-$400	-$1700
5	Mechanical turbocompound	2.4%	$2650	$400	-$2100
10	Slower road speed (60 mph)	3.8%	$0	-$5000	-$10,600
6	Electrical turbocompound	4.0%	$6650	$3000	-$1000
4	Parallel hybrid system	5.8%	$23,000	$21,100	$20,400
8	Bottoming cycle	7.8%	$15,100	$13,000	$1800
2	Integrated sleeper cab roof fairing, aerodynamic mirrors, aerodynamic bumper, cab-side extenders, fuel tank fairings, super single tires with aluminum wheels, auxiliary power unit	17.8%	$22,930	$800	-$23,600
3	Advanced aero package: boat tail, full skirting of cab and trailer, partially sealed gap, plus the devices listed above in package #2	27.9%	$30,580	-$5500	-$20,300
9	Longer/heavier trailer (rocky mountain doubles—48- and 28-foot trailers)	20.6% (for freight density above 13.3 lb/ft3) 16.6% (for freight density below 11.9 lb/ft3)	$17,500	$2600	-$18,500
12	Standard trailer with hybrid, bottoming cycle, slower road speed, advanced aero package	39.3% (grossed out)[b] 40.9% (cubed out)[c]	$65,480	$18,700	-$31,500
13	Longer heavier trailer with electrical turbocompound, hybrid, advanced aero package	48.1% (grossed out) 45.5% (cubed out)	$74,230	$17,600	-$43,700
14	Longer heavier trailer with bottoming cycle, hybrid, 60 mph, advanced aero package	51.1% (grossed out) 48.7% (cubed out)	$82,980	$24,200	-$39,300

Notes: [a]Calculations based on 2022 high-volume technology costs and 2022 fuel price projection of (US$2.50/gal), all amounts in U.S. dollars; [b]"grossed out" means a truck that is loaded to its maximum legal weight, even if the trailer is not completely full. This applies to high-density freight; [c]"cubed out" refers to a truck that has the trailer completely full, but is below the maximum legal weight. This applies to low-density freight.

number (ordered according to increasing fuel consumption and GHG emission changes); column 2 lists the technologies included in each combination package; column 3 provides the percent carbon dioxide (CO_2) and fuel consumption reduction relative to the 2007 baseline vehicle; column 4 lists the estimated incremental vehicle cost of the technology package; column 5 indicates the net cost of the technology package, defined as the incremental technology cost minus three years of cost savings; and column 6 shows the net cost of the technology package, in this case, defined as the incremental technology cost minus 15 years of cost savings. The net cost analysis assumed a price of US$2.50 per gallon of diesel fuel and a 7% discount rate on the initial investment.

Table 1 shows estimated emission and fuel consumption reductions up to 51%, relative to the 2007 baseline vehicle, for the 14 technology packages modeled. Assuming a standard size trailer, combinations of technologies already used in some production heavy-duty, long-haul trucks can reduce CO_2 emissions up to 17.8%. Examples of these technologies include hybrid vehicle systems, turbocompounding (i.e., the use of a second power generating turbine in the exhaust system in addition to the normal turbocharger), as well as aerodynamic and rolling resistance improvements.

Reductions beyond this level will require the introduction of more advanced technologies, such as advanced aerodynamic improvements and a bottoming cycle (i.e., a secondary heat engine that extracts power from the waste heat of the engine). For example, a package including advanced aerodynamic components and improved tires can provide an estimated 27.9% reduction in CO_2 and fuel consumption for an incremental vehicle cost of US$30,580. Even greater CO_2 and fuel consumption reductions can be achieved—up to 40%—using a combination of bottoming cycle, slower road speed, advanced aerodynamics, and hybridization.[4]

Assuming a longer and heavier trailer design alone, CO_2 and fuel consumption reductions ranging from 17% to 21% are feasible for an incremental vehicle cost of US$17,500.[5] Greater reductions can be achieved by combining longer and heavier truck trailers with advanced technologies such as bottoming cycle and hybridization. The technology package that provides the greatest CO_2 and fuel consumption reduction—51% from the baseline vehicle—includes advanced aerodynamics, low rolling resistance tires, a longer and heavier trailer combination, and bottoming cycle. While the costs of using advanced technologies are greater than the cost of conventional long-haul truck technologies, fuel-cost savings in many cases outweigh additional technology costs for the technology packages. Assuming a three-year payback requirement, the net cost of 8 of the 10 technology packages evaluated that produce up to 27% CO_2 and fuel consumption reductions is within US$3000 of the break-even point or negative, meaning that these packages result in little cost or in a net cost savings over a three-year period.

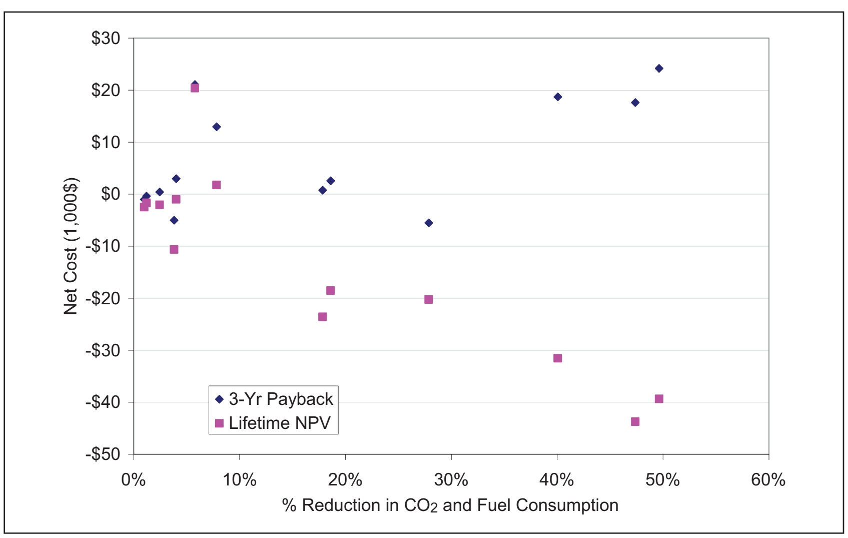

Figure 1. Net vehicle costs for heavy-duty, long-haul trucks, given two payback period scenarios.

Assuming a 15-year payback period, fuel cost savings far outweigh the additional technology costs for most of the technology packages. Table 1 and Figure 1 show negative net costs of technology packages that produce up to 51% CO_2 and fuel consumption reductions. In the 15-year payback scenario, owners of conventional trucks with 53-foot trailers save between US$1000 and US$31,500 over the life of the vehicle due to avoided fuel purchases. The savings for trucks with longer, heavier trailers are larger.

As noted in Table 1, the emission reduction packages evaluated in this study include a range of individual technologies. Some of the most cost-effective packages include advanced aerodynamics, lower rolling resistance tires, longer heavier trailers, turbocompounding, and slower road speeds. This study also assessed the CO_2 and fuel consumption reduction potential of technologies that are relatively expensive in an effort to provide a robust overview of the benefits and costs of candidate CO_2 reduction technologies. Consequently, the complete set of technology packages does not constitute a low-cost solution to any particular CO_2 reduction scenario, but rather presents a host of possible solutions across a range of reductions and costs.

Figure 1 depicts the relative benefits and costs of each of the evaluated technology packages. The plotted shapes indicate the relationship between CO_2 emissions reduction potential and cost. Only technologies that will fit within the existing regulatory environment in all 50 states were included (no longer, heavier trucks are included). The diamond shapes in Figure 1 represent the fuel consumption and CO_2 reductions for packages given a three-year payback period requirement. The square shapes represent the same technology packages with an assumed payback period of 15 years rather than three. The zero line on the graph represents the break-even point for vehicle owners.

In the three-year payback scenario, technology packages providing CO_2 reductions from 2.4% to 27.9% encompass a net cost range from approximately –US$5000 (i.e., net consumer savings) to +US$21,000 for standard size trucks. Clearly, a least-cost solution would favor the technology packages in the lower end of this cost range. The least-cost technologies, however, may not be viable for some segments of the market, so vehicle manufacturers may not introduce specific least-cost CO_2 reduction solutions across the entire vehicle class. For example, because an approach such as turbocompounding may be limited to a subset of heavy-duty vehicles, an analysis constructed solely on the basis of least-cost solutions may understate the actual cost of class-wide CO_2 reduction solution.

The three-year payback scenario shows modest cost penalties for CO_2 and fuel consumption reduction, ranging from near zero for small reductions up to US$18,700 for a 40% reduction. The 15-year supply curve shows cost savings over the vehicle life. At the 51% reduction point, the savings is US$39,300.

By 2030, assuming the U.S. fleet employs the technology combinations modeled in this study, 45% of total U.S. heavy-duty, long-haul fleet CO_2 and projected business-as-usual fuel consumption could be avoided. If this were the case, an estimated 7 billion gallons of diesel fuel would be saved annually by 2030, with lesser reductions being achieved as soon as 2012. Cumulative fuel savings between now and 2030 would equal 93 billion gallons of diesel fuel. Approximately 60 million metric tons of CO_2 emissions would be reduced annually by 2030. Cumulative avoided CO_2 emissions between now and 2030 would equal 1,130 million metric tons. This assumes that technologies are adopted in new heavy-duty, long-haul trucks over a 30-year timeframe and there is a 15-year payback period for all technologies. Our analysis does not assume that any existing vehicles are retrofitted with technologies, and as such, may underestimate the total potential emissions and fuel use avoided from heavy-duty technologies evaluated in this study.

Implications

Our analysis of existing and emerging truck technologies indicates that they can achieve substantial and cost-effective reductions in heavy-duty vehicle GHG emissions and fuel consumption in the 2012–2017 timeframe. Specifically, GHG and fuel consumption emissions from heavy-duty vehicles could be reduced by as much as 51%.

This analysis did not evaluate fuel consumption and GHG reductions that could occur due to technology, design, nor engineering advances that may occur in the future. Rather, it evaluated only the technologies for which a technical design is currently available. To the extent that scientific advances in design occur, the future emissions and fuel consumption benefits may be higher than predicted.

Assuming a three-year payback period and a diesel fuel price of US$2.50 per gallon, half of the analyzed technology packages would result in a net cost savings to vehicle owners, taking into account both incremental technology costs and fuel savings over the three-year period. Some of the technology combinations that provide the greatest reductions, however, would not be adopted into the fleet when assuming a three-year payback requirement. This indicates that given the short payback period demanded by the trucking industry, a number of these technologies will not be adopted into the U.S. fleet absent regulation. With a longer payback period of 15 years, estimated lifetime net savings are US$39,300 for owners of vehicles that achieve GHG and fuel consumption reductions of up to 51%. **em**

An estimated 7 billion gallons of diesel fuel could be saved annually by 2030.

References

1. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*; U.S. Environmental Protection Agency: Washington, DC, April, 2009.
2. *VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050*; Argonne National Laboratory: Argonne, IL, December, 2003.
3. *Reducing Heavy-Duty Vehicle Fuel Consumption and Greenhouse Gas Emissions*; Draft Report; Northeast States Center for a Clean Air Future (NESCCAF) and the International Council on Clean Technology (ICCT), 2009.

4. Slower road speeds would need to be mandated through a regulation such as lower speed limits or mandatory road speed governor settings in order to be effective. With regard to hybridization, it should be noted that this approach was included in this study mainly to facilitate the use of other technologies. The fuel consumption reductions reported for the hybrid package alone are relatively low, and this is due to the fact that the drive cycle consisted mostly of highway driving. An urban or suburban driving cycle would result in greater fuel savings from a hybrid system.
5. The longer/heavier combinations considered in this study comply with federal bridge formula for weight and do not exceed axle loading requirements for current trucks. Thus, the combinations evaluated should not contribute to increased road wear.