Saving Fuel, Saving Money:

An Assessment of Fleet Cost Savings from High Efficiency Trucks

CALSTART

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EXECUTIVE SUMMARY

Technology improvements feasible in the 2020-2030 timeframe can provide significant cost savings for truck owners. In order to quantify these potential future savings, CALSTART assessed per-truck costs and benefits for three types of end users: package delivery fleets, long-haul trucking fleets, and tractor trailer owner-operators. Our analysis shows that truck owners could potentially save tens of thousands of dollars per truck over typical vehicle ownership periods by investing in advanced technologies over the 2020-2030 timeframe.

In order to compare actual benefits with industry practice and assumptions, we used both a life-cycle cost model and a 2 year simple payback model. The life-cycle model incorporates capital costs, operations and maintenance costs, and residual value of the vehicle, presenting a conservative estimate of costs and benefits over the vehicle period of ownership. The simple payback calculation, on the other hand, only takes into account initial capital costs and fuel savings accrued over a 2-year period. This “back of the envelope” payback calculation is included because it has been a general practice for many fleets considering the purchase of fuel efficiency technologies, as well as manufacturers who are considering developing or marketing these technologies. We find it is not, however, the best tool for fully evaluating new technology benefits.

Compared with the 2 year simple payback calculation, the life-cycle model gives a more complete picture of the cost savings and benefits associated with advanced technology investments. The life-cycle approach to valuing costs and fuel savings shows that future advanced fuel efficiency trucks will generate net savings over a typical ownership period, despite the higher upfront cost. Savings are highly sensitive to both fuel prices and period of ownership, but most of the scenarios we examined yield net savings for truck owners. Per-truck savings estimates are presented below for four truck types, assuming fuel prices of $3.50 per gallon in 2009 dollars (which we consider a conservative assumption):

- Package delivery fleets purchasing box trucks with advanced technology packages can save more than over $18,000 over 8 years of ownership.
- Long haul fleets that limit their drivers to 60 mph can save roughly $120,000 over 8 years of ownership from advanced technology investments.
- Owner-operators purchasing 5 year old trucks with advanced technology packages can save more than $80,000 over 10 years of ownership.

We believe that the savings outlined above and detailed in the report are conservative estimates of potential life-cycle savings for advanced technology trucks, for two reasons. First, the fuel prices used in this analysis are quite conservative and there is reason to believe prices will be much higher over the 2020-2030 timeframe. Second, the life-cycle cost analysis presented here

omits several variables that would generally improve the economic case for advanced technologies. These include possible purchase incentives, “green” image benefits, and labor savings due to reduced refueling.

However, it is important to note that there is some uncertainty around the life-cycle savings estimates. The inputs for both technology costs and fuel economy improvements are estimates for the 2020-2030 timeframe. Costs today are much higher for many technologies, and actual future costs could also exceed predictions. This would reduce the projected benefits. Real world fuel economy improvements could also differ somewhat from the modeling inputs.

In addition to the uncertainties mentioned above, truck owners must contend with volatile fuel prices and unpredictable regulatory environments. Furthermore, new technologies are seen as inherently risky. Truck owners are hesitant to adopt technologies without good information regarding real world durability, performance, maintenance costs, and resale value, though it is expected this information will be more widely understood in this timeframe.

As a result of the uncertain environment in which they are operating, truck owners often insist on very quick payback periods for new technologies, with many fleets looking for a payback in the neighborhood of two years. Though almost all of the advanced technology investments we examined resulted in life-cycle savings for fleet owners, very few could meet the two year simple payback requirement. Life-cycle accounting is important and should be the industry norm, but these market barriers call for more than just a change in purchase analysis methods. Strong and consistent policies and incentives are needed to address these issues and uncertainties. With the right policies in place, advanced efficiency technologies feasible in the 2020-2030 timeframe can drastically increase the efficiency of the U.S. trucking fleet while significantly saving money for truck owners.

Overview

Advanced, high-efficiency truck technologies promise to dramatically reduce fuel consumption and operating costs for fleets. However, these technologies have high upfront costs, potentially adding tens of thousands of dollars to the cost of a conventional truck. Fleets and independent owner-operators therefore have to determine whether the benefits provided by advanced truck technologies justify the higher capital costs. This report examines the economic impact that advanced efficiency technologies will have on truck owners in the 2020-2030 timeframe. A life-cycle approach to valuing costs and fuel savings shows that investments in fuel efficiency technologies will yield net economic benefits over a typical truck ownership period. The common industry practice of valuing only short-term fuel savings, however, means many technologies may not be widely adopted without appropriate incentives and policies.

Method of Analysis

Life-Cycle and Simple Payback Models

We analyzed the costs and benefits of advanced truck efficiency technologies using both a simple payback model and a life-cycle cost model, in order to compare typical industry practice and assumptions with actual benefits. The simple quick payback calculation takes into account only the initial capital costs and the fuel savings accrued over a 2-year period. This "back of the envelope" payback calculation has been a general practice for many fleets considering the purchase of fuel efficiency technologies, as well as manufacturers who are considering developing or marketing these technologies.[1]

We also conducted a life-cycle cost analysis to provide a more complete picture of costs and benefits over the period of time that the fleet is using the vehicle. The life-cycle cost calculation takes into account capital costs, operations and maintenance costs over the term of service, and residual value at the end of the ownership period. Future costs and benefits are discounted to adjust for the time value of money, and the result is a conservative estimate of the full cost of ownership. In developing this model, we drew on years of experience with CALSTART's Hybrid Truck Users Forum (HTUF) fleet working groups.[2] We then validated key elements and considerations through conversations with fleet representatives, some of whom shared their own models for evaluating technology investments in fleet purchase decisions. The life-cycle cost analysis method used here therefore closely resembles the approach used by many forward-thinking fleets.

Trucks and Technology Packages

This analysis examines costs and benefits from technologies feasible in the 2020-2030 timeframe for a representative sample of fleet and truck types. In order to capture the diversity of truck

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[1] A short payback period, often two years or less, is a common requirement among trucking companies and manufacturers. This was recently noted in Cooper, et. al 2009 and NRC 2010.

[2] The Hybrid Truck Users Forum (HTUF) is a national, user-driven program started in 2000 and focused on speeding the commercialization of hybrid and high efficiency truck technologies. The HTUF working groups are composed of early-adopter fleets who are interested in demonstrating new technologies that reduce operating costs and decrease emissions. Through working groups, CALSTART works with more than 80 regional and national fleets representing more than 1 million trucks on the road.

types and business models, we looked at (1) a package delivery fleet with three different truck types, (2) a class 8 long haul fleet, and (3) a class 8 tractor owner operator. There are several additional fleet and truck types that were not analyzed here, due to data and funding constraints.

This report also looks at different technology packages, presenting results for both "moderate" and "advanced" technology configurations for each truck. All of the technologies considered here are considered to be feasible in the 2020-2030 timeframe. The "moderate" packages are near term technologies, while the "advanced" packages also include technologies that are still in the early stages of commercialization.

The incremental costs and fuel economy improvements used as inputs in this analysis assume that the technologies are mature. Some of the efficiency technologies, such as low rolling resistance tires, are mature technologies that are widely available today. Others are still in earlier stages of commercialization and may currently have incremental costs that are higher than those used here. However, costs are expected to come down and efficiencies are expected to increase as the technologies reach maturity in the 2020-2030 timeframe. The actual fuel economy and cost inputs used in this study are drawn from published research on advanced truck technologies, presented in greater detail in Appendix B.

Sensitivity to Fuel Price and Length of Ownership

As might be expected, the results are highly sensitive to fuel prices. Results are therefore presented for a variety of fuel costs, ranging from $2.50 per gallon to $4.50 per gallon. Note that even the high fuel price assumption, at $4.50 per gallon, is conservative when compared with the 2010 Annual Energy Outlook's "high oil price scenario," which predicts 2020 prices of around $5.14 per gallon for gasoline and $5.44 for diesel.[3] With growing demand in the developing world, there is good reason to believe that actual prices will be significantly higher, which would lead to fleet savings far larger than those presented in this analysis.

The results of this analysis are also highly sensitive to the length of ownership. Fleets that keep the vehicles for longer will realize greater fuel and cost savings from efficiency improvements, while those that choose to sell after a few years will see smaller savings. Fleets generally have been increasing their length of ownership for several reasons; however, because industry practice varies, we have presented results for a range of ownership periods. Cost savings over the full expected vehicle lifetime would be greater than the savings presented here, though these savings would most likely be shared amongst several owners over the vehicle lifetime.

Limitations of this Analysis

It is important to note that the life-cycle cost analysis presented here omits several variables that would have improved the economic case for advanced technologies. These include possible purchase incentives, "green" image benefits, and labor savings due to reduced refueling. Additionally, this analysis assumes that the advanced technologies would have incremental maintenance costs, while early evidence suggests that some technologies, such as hybridization,

[3] Average fuel prices for 2020 to 2030 in the Energy Information Administration's 2010 Annual Energy Outlook (adjusted to 2009 dollars) are $3.50 under the reference scenario and $5.30 under the high oil price scenario. Prices for diesel average $3.65 under the reference scenario and $5.52 under the high oil price scenario (EIA 2010).

may actually reduce overall maintenance costs.[4] Furthermore, for the sake of simplicity, this analysis holds fuel prices constant over the vehicle lifetime, while real world experience suggests they are likely to trend upward. All of these factors and missing elements will lead to an underestimation of the overall benefits and savings associated with advanced efficiency technologies.

Also, as noted above, there is some uncertainty involved in conducting a life-cycle analysis for technologies that are not yet fully commercialized. The inputs for both technology costs and fuel economy improvements are informed estimates for the 2020-2030 timeframe. These costs are still speculative, and in reality could be higher or lower than estimated. This would change the projected benefits. Real world fuel economy improvements could also differ somewhat from the modeling inputs, affecting the actual savings. As evaluations of future technology costs are improved over time, they can be used to further refine the model.

Finally, while we examined multiple truck types, ownership periods, and fuel prices, this study still does not provide a complete look at benefits across the many different truck and fleet types. Many types of trucks, such as refuse and utility, were left out. We were also unable to look at leasing or other financing arrangements that would have altered the overall life-cycle costs and may be better models for sharing the total value of new technology across multiple users.

Summary of Findings:

Advanced Efficiency Technologies Have the Potential to Reduce Life-Cycle Costs

This analysis shows that advanced, high-efficiency truck technologies have the potential to dramatically reduce fuel consumption and reduce overall life-cycle costs for fleets, despite their higher upfront costs. However, most technologies analyzed do not provide the two year payback that fleets often demand when considering advanced technology investments. This is not a flaw in the market readiness or efficiency benefits of the technology, but rather a weakness in the simple “back of the envelope” method commonly used to calculate payback. Life-cycle analysis provides a more complete picture of true costs and benefits. Broader use of life-cycle analysis would improve efficiency and increase savings throughout the nation’s trucking fleet and is the preferred method to truly evaluate benefits.

In order to allow for a comparison of life-cycle costs with industry practice, we present per truck savings estimates using both the 2 year simple payback and the life-cycle model. Summary results are presented below, assuming moderate ownership periods and conservative fuel prices of just $3.50 per gallon in 2009 dollars. Additional details are presented in the following section, including results under different fuel prices and ownership period assumptions.

Package Delivery Fleet

There are many technologies that promise to drastically increase fuel economy for package delivery trucks. Hybridization, still in the early stages of commercialization, is a prime example. Today’s first-generation hybrid trucks are already delivering results. The National Renewable Energy Laboratory recently found that UPS hybrid-electric delivery vans had seen fuel-economy

[4] NREL 2009.

gains of 29–37 percent.[5] Other technologies that make up the “advanced technology package” that we examined include aerodynamic improvements, engine and transmission upgrades, low rolling resistance tires, and weight reduction.

As shown in Table 1 below, package delivery fleets can expect to save several thousand dollars per truck in present value terms over a typical period of ownership by investing in the advanced technologies mentioned above. Estimated savings range from a modest $1,000 for a delivery van (not shown below) to $26,000 for a class 4 gasoline box truck over the period of ownership. Differences in ownership periods and annual mileage account for the majority of the large difference in per-truck savings between the two truck types.[6]

Table 1. Overview of Per-Truck Cost Savings from Advanced Technologies: Comparing Life-cycle Savings with Simple Payback

Fleet Type	Truck Type	Technology Assumptions	Cost Analysis Method	Savings
Package Delivery	Class 4 Box Truck (gasoline)	· 78% efficiency gain · $13,062 capital cost	2 Year Simple Payback	($3,457)
			Life-cycle (12 year ownership)	**$26,217**
	Class 4 Box Truck (diesel)	· 73% efficiency gain · $18,242 capital cost	2 Year Simple Payback	($10,879)
			Life-cycle (12 year ownership)	**$10,942**
Long Haul Fleet	Class 8 Tractor and 2 Trailers	· 65% efficiency gain · $61,510 capital cost	2 Year Simple Payback	($6,358)
			Life-cycle (8 year ownership)	**$120,096**
Class 8 Owner Operator	Class 8 Tractor (Purchased new)	· 43% efficiency gain · $41,270 capital cost	2 Year Simple Payback	($13,205)
			Life-cycle (15 year ownership)	**$88,404**
	Class 8 Tractor (Used - 5 years)	· 43% efficiency gain · $17,639 capital cost	2 Year Simple Payback	$10,426
			Life-cycle (10 year ownership)	**$83,304**

Assumptions: (1) All scenarios assume $3.50/gallon fuel price in real terms; (2) 2 Year Simple Payback assumes 24 months of fuel savings, with no discounting; (3) Life-Cycle accounts for fuel savings over the vehicle period of ownership, with future fuel savings discounted at a rate of 7 percent; (4) Capital cost estimates assume a mature market with high volume manufacturing; (5) All costs and savings are presented in 2009 dollars.

For a fleet like UPS or FedEx Express which has thousands of delivery trucks, these life-cycle savings add up. For example, a large package delivery fleet consisting of 1,000 class 3 vans, 8,000 class 4 gasoline box trucks, and 8,000 class 4 diesel box trucks could save a total of nearly

[5] NREL 2009.
[6] The class 3 delivery van is assumed to travel 10,000 per year over a relatively short 10 year service life, while the class 4 box truck is assumed to have annual mileage starting at 25,000 per year, and is expected to be in use for 12 years. The shorter service life and annual mileage for the delivery van severely reduce the potential savings demonstrating the fact that not all truck types and applications will benefit equally from technology improvements.

$300 million over the period of ownership, and considerably more if fuel prices were higher than the $3.50 per gallon assumed. However, fleets relying exclusively on the simple two year payback calculation for investment decisions would likely not invest in advanced technologies and would therefore miss out on the substantial savings that these technologies provide.

Long -Haul Fleet

There is even greater potential for increased efficiency and petroleum reduction in the Class 8 long haul category. Recent analyses of efficiency technologies for long-haul tractors pulling van trailers—the most common configuration—show that fuel-economy gains of 65–100 percent are possible by 2017. Advanced efficiency technologies that may be used in this sector include advanced aerodynamics and tires with low rolling resistance for both a tractor and trailer; engine technologies that convert exhaust heat from the diesel engine into mechanical or electrical energy, known as a “bottoming cycle”; and hybrid power systems that improve engine efficiency and reduce idling. Fleets that implement these technologies (all of which are technologically feasible in the 2020 timeframe) and limit speeds to 60 mph will see fuel economy improvements of 65% at an incremental cost of $61,510 for one tractor and two trailers.[7] This is a significant upfront investment, but lease arrangements can spread the cost over the life of the vehicle and fleets will realize significant reductions in operating costs.

Fleets that invest in this advanced technology package would realize present value savings of roughly $120,000 per truck over 8 years of service, assuming fuel prices remain constant at $3.50. Under these same fuel price and period of ownership assumptions, a long-haul fleet with 5,000 tractors and 10,000 trailers could save a fleet-wide total of $600 million in present value terms by adopting advanced technology packages for all of its vehicles. Once again, however, fleets using the simple 2 year payback calculation may not adopt the advanced technology package because they would not have a complete picture of the true benefits of the advanced technologies.

Class 8 Owner-Operator

Large fleets generally purchase new tractors and may own multiple trailers per tractor as in the example above. But there is a large segment of the tractor-trailer population that is owned by independent owner-operators. These small businesses, often a single person, may own only a tractor and are more likely than fleets to purchase used trucks. Owner-operators are also more likely to hold on to their trucks longer than fleets, though they generally drive fewer miles.

Taking these different business models, driving patterns, and economic considerations into account, owner-operators that invest in trucks with advanced technologies can be expected to see tens of thousands of dollars in net savings. An owner operator purchasing a tractor with a hybrid electric drivetrain, a bottoming cycle, and aerodynamic and tire improvements could save nearly $90,000 over a 15 year period when buying a new tractor, while an owner-operator purchasing a 5 year old tractor and using it for ten years would save more than $80,000 over that time.

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[7] Per-tractor and per-trailer technology costs (including up front capital costs as well as operations and maintenance) and fuel economy improvements are drawn from Cooper, et. al 2009.

Detailed Results: Advanced Technology Costs and Benefits for a Package Delivery Fleet

Package delivery fleets are widespread and play a very important part in our economy. High profile examples of such fleets include UPS and FedEx, both of whom have been aggressively pursuing advanced truck technologies to reduce their operating costs. Costs and benefits of both "moderate" and "advanced" technology packages are presented below for three truck types that might make up a typical package delivery fleet.[8] Complete modeling results for all truck types analyzed in this study can be found in Appendix A.

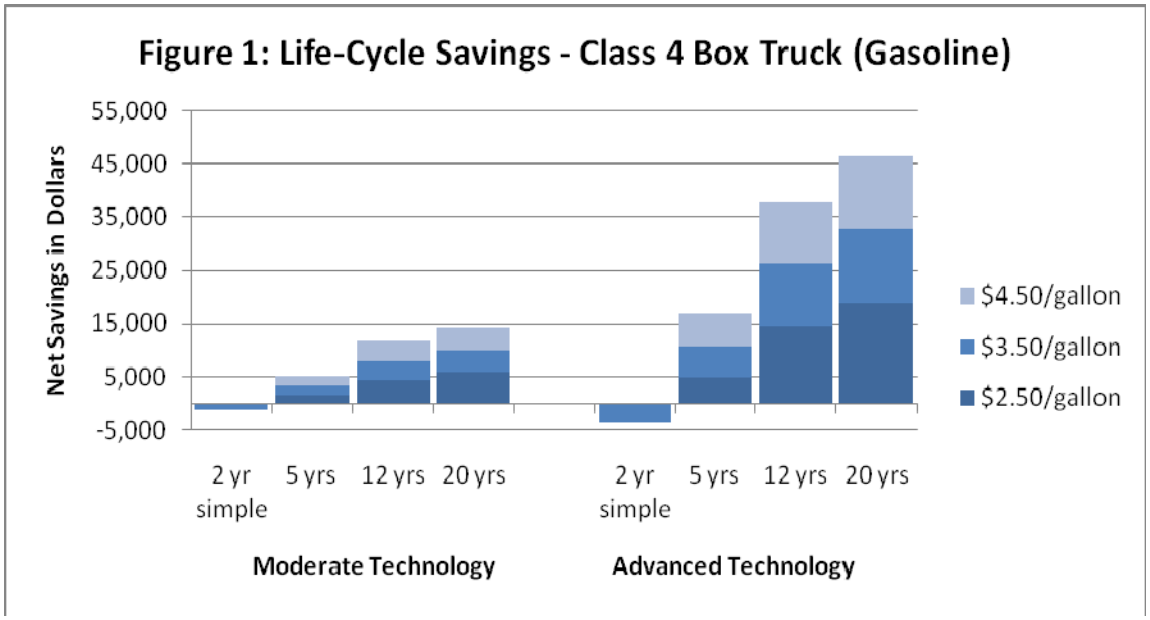
Per Truck Savings: Class 4 Gasoline Box Truck

One commonly used truck in a package delivery fleet is a class 4 gasoline box truck. Fleets tend to hold onto these vehicles for several years; 20 year service lifetimes are not uncommon. Average annual mileage is also greater than with delivery vans. For this analysis, we assumed mileage that starts at 25,000 per year and declines over time. Figure 1 below shows expected life-cycle savings from technology investments for a class 4 gasoline box truck.

> Package delivery giant UPS has spent more than $15 million to develop its advanced vehicle fleet, and recently announced the addition of 200 new hybrid electric delivery trucks in eight U.S. cities.
>
> "By reducing operating costs, advanced efficiency technologies will benefit our industry over the long term. We have thousands of trucks, and the fuel savings really add up over the service life of the vehicles in our fleet. Looking at full life-cycle costs and benefits, we believe we will be able to make a business case for these technologies once the incremental costs come down. However, purchase incentives are vitally important for the next several years, until volumes increase and incremental costs come down."
>
> *- Robert Hall, Director of Maintenance and Engineering for UPS*

The moderate package includes low rolling resistance tires, transmission improvements, integrated starter/alternator with idle off and limited regenerative breaking, and some degree of weight reduction. These technologies would increase fuel economy from by 16%, at an estimated incremental capital cost of cost of $4,093. The life-cycle cost analysis shows that fleets are expected to save thousands of dollars, with roughly $1,500 in savings even in the low fuel price/short lifetime scenario. Longer lifetimes and higher fuel prices lead to much greater savings. With fuel prices at $4.50, fleet savings over a 20 year vehicle lifetime are nearly $15,000 in present value terms. However, the simple payback analysis shows that two years of fuel savings would not be enough to pay back the upfront investment; net costs are estimated at just over $1,000 with fuel prices at $3.50 per gallon. Fleets that rely exclusively on this simple payback analysis for investment decisions would miss out on large life-cycle savings.

[8] Technology costs and fuel economy improvements are drawn from Vyas, et. al 2002.

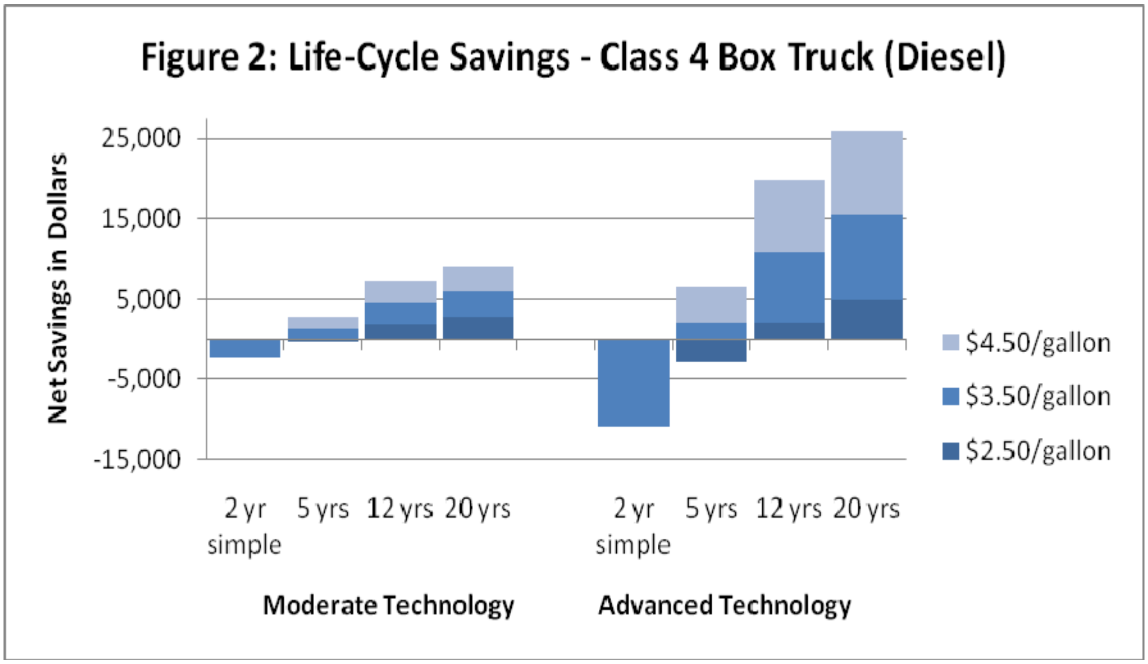


Assumptions: Annual mileage is assumed to start at 25,000 miles and decline over time
Future life-cycle savings are discounted at a rate of 7 percent
2 year simple payback assumes fuel prices at $3.50 per gallon

Potential life-cycle savings from the advanced technology package, which includes the tire and transmission improvements mentioned above, as well as direct injection, a hybrid electric drivetrain, and increased weight reduction, are even greater. This package has an upfront cost of $13,062 and increases baseline fuel efficiency by 78%, from 8 mpg to 14 mpg. Here again, the simple 2 year payback calculation, showing a net cost of over $3,000, suggests that this may not be a sound investment. However, the life-cycle savings are substantial in every price/lifetime scenario we analyzed. Per truck savings with the advanced package exceed $45,000 in a high fuel price / long term of service scenario, and don't fall far below $5,000 under the conservative low fuel price / short term of service scenario.

Per Truck Savings: Class 4 Diesel Box Truck

The final truck type that we examined in the package delivery category is a class 4 diesel box truck with a baseline fuel economy of 10 mpg. Once again, we assumed an ownership period of up to 20 years, with annual mileage starting at 25,000 and declining over time. Figure 2 below shows expected life-cycle savings for these trucks for a variety of price and period of ownership assumptions. The efficiency investments analyzed as part of the moderate technology package include low rolling resistance tires, some aerodynamic improvements, transmission upgrades, integrated starter/alternator with idle off and limited regenerative breaking, and some degree of weight reduction. This moderate package increases fuel efficiency by 15% with an incremental capital cost of cost of $4,600. Costs and savings are very similar to the gasoline box truck, with life-cycle savings of up to $9,000, under the fuel price and period of ownership scenarios we examined. Fuel prices above $4.50 per gallon would result in significantly higher savings.



Assumptions: Annual mileage is assumed to start at 25,000 miles and decline over time
Future life-cycle savings are discounted at a rate of 7 percent
2 year simple payback assumes fuel prices at $3.50 per gallon

Once again, potential cost savings are even greater for a more advanced truck. We assessed costs and benefits for a truck that includes the same tire and transmission upgrades mentioned above, plus engine improvements, a hybrid drivetrain, and increased aerodynamics and weight reduction. This package has an upfront cost of $18,000 and increases baseline fuel efficiency by an impressive 73%. The two year simple payback calculation shows that upfront technology costs exceed 2 year fuel savings by over $10,000. However, a more complete accounting of costs and benefits shows that fleets can expect net savings in most cases over the period of ownership, particularly if fuel prices are at or above $3.50 per gallon. Fleets that keep the truck for 20 years will see benefits of $5,000 or more even with fuel prices at $2.50 per gallon. At $4.50 per gallon, savings over 20 years approach $26,000 in present value terms, which would mean truck owners are saving more than $1,250 per year.

Per Truck Savings: Class 3 Delivery Van (Gasoline)

Many package delivery fleets use class 3 gasoline vans for local deliveries. A typical fleet might hold onto these vehicles for around 10 years, with average annual mileage around 10,000.[9] Figure 3 shows expected savings from moderate and advanced technology investments. Because these vehicles typically have short service lives and modest annual mileage, the economic case for advanced technology investments is less clear.

The moderate technology package includes low rolling resistance tires, transmission improvements, direct injection, and some degree of weight reduction, increasing fuel economy from by 20% at an incremental capital cost of cost of $3,185. A simple 2 year payback

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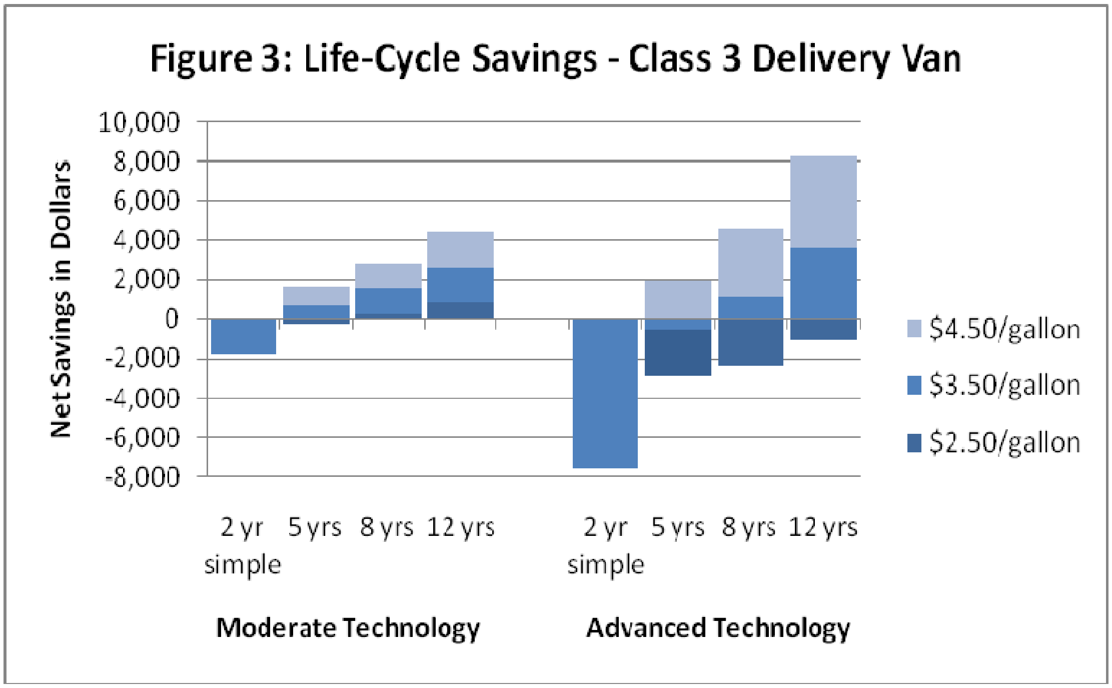
[9] Lifetime and mileage estimates are drawn from CALSTART's Hybrid Truck Users Forum. The lifecycle model assumed annual mileage of 10,000 miles per year.

calculation shows that fuel savings alone is not sufficient to justify the added investment over a short timeframe, with net costs estimated at $1725. However, the life-cycle analysis shows that the efficiency investments will result in per truck savings of hundreds to thousands of dollars in almost all cases. The savings are modest due in large part to low annual mileage.

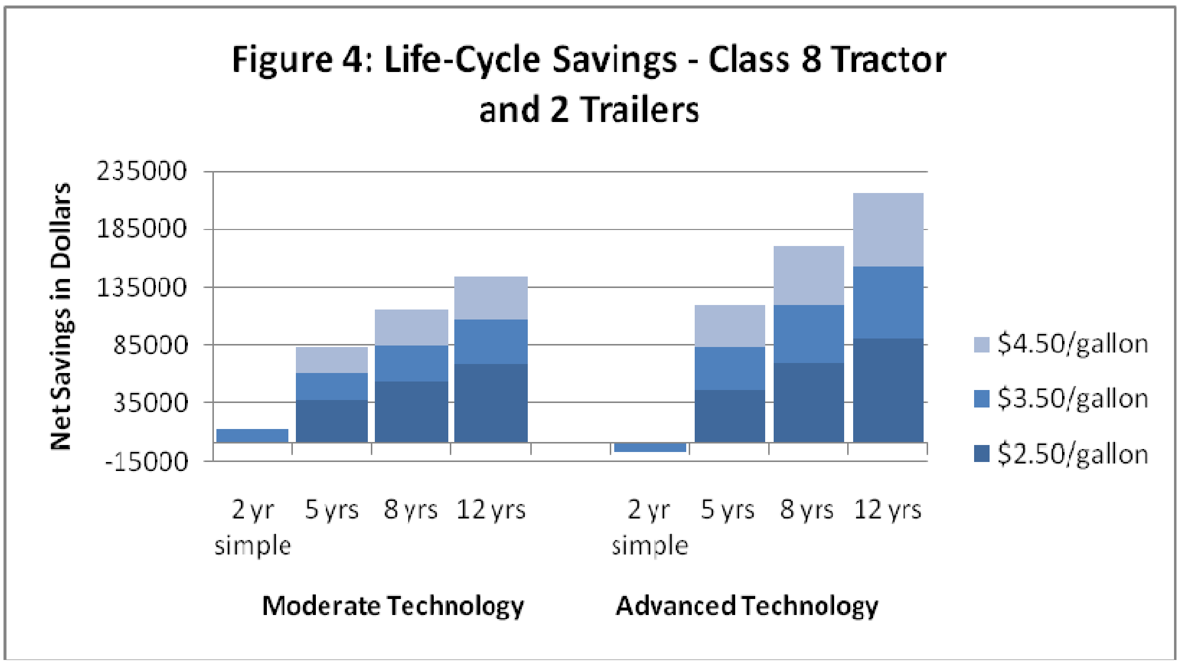


Annual mileage is assumed to start at 10,000 miles
Future Life-cycle savings are discounted at a rate of 7 percent
2 year simple payback assumes fuel prices at $3.50 per gallon

The advanced package includes the technologies outline above, as well as a hybrid electric powertrain and additional weight reduction. This package has an upfront cost of $11,396 and increases baseline fuel efficiency by an impressive 78%. The simple 2 year payback calculation suggests that many fleets would hesitate to install these technologies, as net costs are estimated at roughly $7,500. A look at the life-cycle calculation highlights the importance of fuel prices in making the business case for advanced technology investment. If diesel drops to $2.50 per gallon and remains at that low level, fleets would not recover their costs over a 12 year period of ownership. If, however, fuel prices rise to $4.50 or higher, savings over a 12 year vehicle lifetime would be $8,000 or more.

Detailed Results: Advanced Technology Costs and Benefits for a Class 8 Long Haul Fleet
A typical class 8 truck might travel 120,000 in a year, using roughly 20,000 gallons of diesel fuel. There is enormous potential for increased efficiency and petroleum reduction in the class 8 category, through improved fuel economy and idle reduction improvements. Typical long haul tractor trailers today average around 6 mpg.[10] The technology packages we examined would increase this by 32-65%.

We modeled fuel usage and cost savings for a variety of tractor and trailer technology combinations, assuming that fleets would purchase two trailers for every tractor.[11] Incremental cost estimates for tire and aerodynamic improvements therefore assume that fleets are adding these technologies to two trailers in addition to the tractor.[12] We assumed that new trucks travel 140,000 miles per year and that this number declines over time. As with other trucks in the study, we looked at costs and benefits from both a "moderate" and an "advanced" technology package. Modeling results are presented in Figure 4.



Assumptions: Annual mileage is assumed to start at 140,000 miles
Life-cycle savings are discounted at a rate of 7 percent per year
2 year simple payback assumes 120,000 miles/year at $3.50 per gallon

The moderate package includes advanced SmartWay aerodynamic improvements, as well as mechanical turbocompounding with variable valve actuation, and also assumes a 60 mph top speed. These technologies, all of which can be considered "near term" or currently available, are

[10] Average on-road fuel economy of medium and heavy-duty trucks fluctuated between 5.3 and 6.6 mpg from 1970 to 2007 (DOE 2009, tables 5-1 and 5-2).
[11] There is significant variation between fleets in the number of trailers per tractor. Our assumption of 2 trailers per tractor is based o analysis of tractor and trailer data from Transport Topics 2007 Top 100 For Hire Carriers and Top 100 Private Carriers (Transport Topics 2007), which showed an average of approximately 2 trailers per tractor, and on conversations with analysts at the Union of Concerned Scientists.
[12] Per-tractor and per-trailer technology costs (including upfront capital costs as well as operations and maintenance) are drawn from Cooper et al. 2009.

estimated to increase fuel efficiency by 32% at an incremental cost of $22,060 for improvements to the tractor and two trailers. A fleet manager doing a simple payback calculation would expect to see savings of nearly $12,000 over a 24 month period. While this is significant, a more complete life-cycle analysis shows that fleets can expect much greater savings over the vehicle period of ownership. Even over a relatively short 5 year period of ownership, fleets would see savings of $38,000 with fuel at $2.50 per gallon, and up to $80,000 or more with higher fuel prices. Fleets that hold onto the vehicles for longer would see much greater savings, exceeding $100,000 under many of the scenarios we examined.

The advanced class 8 tractor trailer technology package again includes Advanced SmartWay and a 60 mph top speed, and also includes a hybrid electric drivetrain and bottoming cycle. This package improves fuel efficiency by 65% at an incremental cost of $61,510 for one tractor and two trailers. The simple payback calculation suggests that some fleets would hesitate to adopt the advanced technology package, as net costs over 24 months are estimated at $6,000. However, despite the higher upfront cost, deeper analysis shows life-cycle savings ranging from $46,000 in the low fuel price / short lifetime scenario ($2.50 per gallon, 5 year term of service) to $216,000 in the high fuel price / long lifetime scenario ($4.50 per gallon, 12 year term of service).

Detailed Results: Advanced Technology Costs and Benefits for a Class 8 Owner Operator

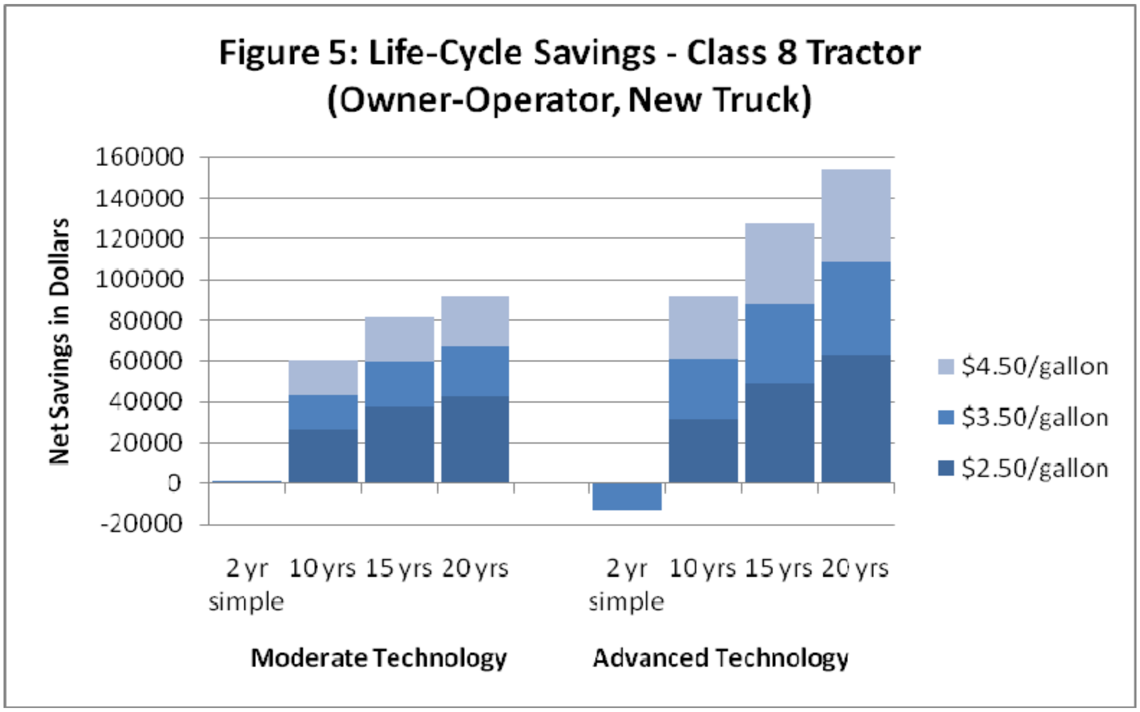
In addition to large fleets, there are many owner-operators in the long haul trucking industry. Owner operators have different business models, driving patterns, and economic considerations than large trucking fleets. Compared with large fleets, owner-operators are less likely to own their own trailers. Owner-operators also tend to drive fewer miles in a given year, but they typically hold on to their trucks for longer than large fleets. Additionally, many owner-operators purchase their trucks used. We therefore assessed costs and benefits for two different hypothetical owner-operators that are representative of the industry: one that purchases a new truck, and another that purchases a 5 year old truck. In each case, we assumed that the truck travels 80,000 miles per year and that this number remains constant over time, as owner-operators do not have the luxury of transitioning older trucks to lower mileage routes.

The moderate and advanced technology packages that we examined here are essentially the same as those examined for the long haul fleet. However, we looked only at technologies that apply to the tractor, and ignored those that apply to the trailer, because we assumed that the owner-operator owns a tractor only and pulls trailers owned by other companies. This reduces the cost to the owner-operator, but it also reduces the efficiency gains.[13] Though we excluded fuel economy gains and technology costs for trailer technologies, the inputs for the SmartWay tractor assume that the trailer also has aerodynamic improvements. To the extent that there is some interaction between tractor and trailer, actual fuel economy gains for a tractor pulling an inefficient trailer may be somewhat smaller. Owner-operators have little control over the trailers that they pull, which complicates the picture for those that want to reduce their fuel consumption.

Modeling results for both moderate and advanced technology packages are presented in Figure 5. The moderate technology package includes the tractor-specific SmartWay aerodynamic improvements, as well as mechanical turbocompounding with variable valve actuation, and a 60

[13] Note that all numbers included here assume that the owner-operators are pulling efficient trailers.

mph top speed, providing a fuel economy improvement of 21% at an incremental cost of $15,000. The simple payback calculation shows that this investment would yield net savings of roughly $1000 over the first 24 months. Life-cycle savings are much more substantial, ranging from just over $26,000 in over 10 years with fuel at $2.50 per gallon to nearly $92,000 over 20 years with fuel at $4.50 per gallon.



Assumptions: Trucks travel 80,000 miles per year
Life-cycle savings are discounted at a rate of 7 percent per year
2 year simple payback assumes 80,000 miles/year at $3.50 per gallon

As we have seen with the other trucks, the advanced technology package has higher upfront costs, estimated at just over $41,000, but also promises greater savings due to expected fuel economy gains of 43%. This package once again includes the technologies outlined in the "moderate" case above, plus a hybrid drivetrain and bottoming cycle. Life-cycle cost savings in the scenarios we examined ranged from $31,000 to over $154,000. While these savings certainly justify the investment over the long term, a simple payback calculation shows that costs exceed savings by more than $13,000 over the first 24 months. This may pose a significant barrier for owner-operators that may lack easy access to capital.

We also analyzed costs and benefits for owner-operators purchasing five year old trucks with these same advanced technology packages. Purchasing a used truck significantly reduces upfront costs, providing increased savings potential for owner-operators, even over a short 24 month period. However, purchasing a five year old truck also shortens the remaining service life of the vehicle, and therefore limits the life-cycle savings.[14]

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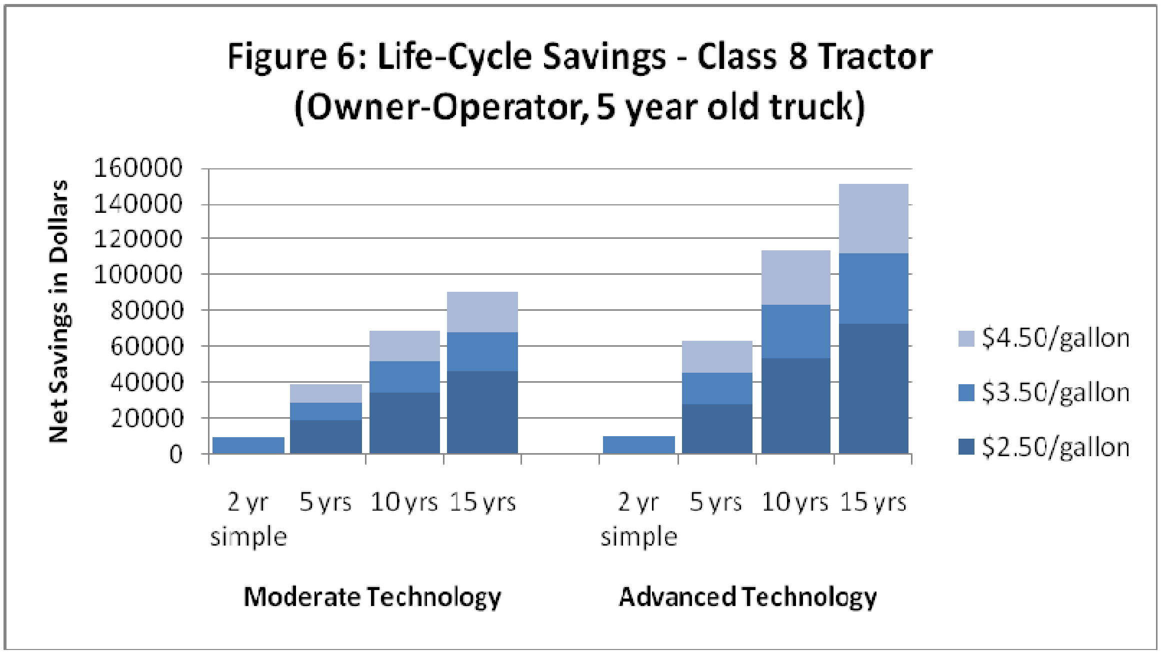
[14] Used truck prices were based on data from California Air Resources Board, 2008. Advanced technology trucks assumed to follow depreciation patterns similar to conventional trucks. We assumed a total truck lifetime of 20

Figure 6 below outlines expected life-cycle cost savings for owner-operators purchasing 5 year old trucks with both moderate and advanced technology packages. Each package is expected to yield savings of roughly $10,000 over the first 24 months, and much greater savings over the next several years. Over 15 years of operation at the fuel prices we examined, owner-operators can expect savings of $45,000 to $90,000 from the moderate technology package and $73,000 to more than $150,000 from the advanced package. Higher fuel prices over the next 15 to 20 years, which we believe are entirely possible, would significantly drive up these savings.



Assumptions: Trucks travel 80,000 miles per year
Life-cycle savings are discounted at a rate of 7 percent per year
2 year simple payback assumes 80,000 miles/year at $3.50 per gallon

Other Fleet Types

The results presented above focused on package delivery and long haul trucks, but other types of fleets are also expected to benefit from advanced technologies and efficiency improvements. Hybrid-electric bucket trucks used by utilities across 14 fleets have also seen fuel use drop by 14–58 percent.[15] The addition of weight reduction, engine improvements, and other advanced technologies would add to these gains. Refuse trucks, with their stop-start duty cycles and payload capacity concerns, are another ideal application for hybridization and weight reduction technologies.

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years, and therefore looked at 15 years as the maximum service life for the owner operator purchasing a truck that has already been in use for five years.

[15] Tomic 2007; Tomic and Van Amburg 2007.

Market Barriers and Uncertainties Remain

Given the size of potential savings outlined above, one might assume that natural market forces would be sufficient to drive the development and deployment of advanced technologies to improve fuel economy. However, there are many serious market barriers and uncertainties impeding the transition toward more efficient trucks. Our analysis of costs and benefits assumes that the technologies are "mature" at the point of purchase, meaning that they are commercialized, understood, and produced at scale. This is not currently the case for many of these early stage technologies, which are not yet fully commercialized and are characterized by uncertainties as to costs and durability. However, they will likely be mature during the analysis period of this report (2020-2030).

Like the typical consumer, truck owners are risk averse and operating in an environment of uncertainty. Getting from early market introduction to full commercialization and maturity is a process that will require the right package of government incentives and supporting policies. Specific market barriers, all of which make it more difficult for truck owners to "make the business case", are briefly outlined below:

- **High Upfront Costs:** Our incremental cost assumptions take into account the cost reductions that come along with high production volumes and economies of scale. However, many early stage technologies are still produced at very low volumes, and consequently have incremental costs far higher than those used in our analysis. Hybrid drivetrains are one obvious example. While hybrid costs are eventually expected to drop to approximately 20% of total vehicle cost, current incremental hybrid costs are 50% or more. Smart policies and targeted incentives are needed to drive demand and production volumes, ultimately allowing incremental prices to fall to a sustainable level.
- **Lack of Real World Experience and Information:** New technologies are characterized by a high level of risk and uncertainty. Truck owners are understandably hesitant to adopt technologies without good information regarding real world durability, performance, maintenance costs, and resale value. Technology demonstrations and incentives are needed to overcome this barrier to widespread technology adoption. We attempted to conservatively address resale value and maintenance costs in the assumptions for this study, but real world results could differ from our assumptions.
- **Volatile Fuel Prices:** Volatile oil prices are both a reason for and a barrier to investment in advanced truck efficiency improvements. Both technology developers and truck owners must make the case that a given technology can compete with traditional technologies, which are powered by gasoline and diesel. Volatile and unpredictable prices for oil (and therefore gasoline and diesel) make this a very difficult task. In order to address this uncertainty, we used relatively low fuel prices for our analysis and looked at a variety of fuel prices. However, uncertain fuel prices remain a serious barrier to truck efficiency improvements. Because of its importance to the business case, better long term fuel price increase certainty could greatly aid fleet and manufacturer planning.
- **Regulatory Uncertainty:** The market needs consistent, predictable regulation that provides certainty and price signals over time. However, political realities and election cycles often lead to technology incentives with very short lifetimes and to policy environments that are constantly in flux. Companies and truck owners cannot base business decisions on short-lived subsidies and tax credits, or on unclear and changing technology standards and mandates.

- **Split Tractor and Trailer Ownership:** For long-haul tractor-trailers, the fact that the tractor and trailer are often owned by different parties prevents investments in aerodynamic and tire improvements in cases where the equipment owner will not ultimately capture the fuel and cost savings.

As a result of the issues outlined above, many fleets take a conservative approach and prefer to invest in new technologies only when they can expect a very quick payback. However, the desire for a 2 year payback on investments in efficiency means that many technologies that are expected to yield net savings over the period of ownership, but not over the first two years, will not be widely adopted. This often prevents wider adoption of even mature technologies, like single-wide tires, and poses an even higher barrier for new technologies, such as hybrid systems, that currently have high incremental costs because of their low production volumes. This common industry practice also has a chilling effect on the development of efficiency technologies that may not meet this 2 year payback requirement.

> The truck market wants reliability as the single most important factor, even above fuel efficiency. They are very reluctant to buy new technologies. Tied to reliability are maintenance costs. Finally, there is resale value. If the second user doesn't value the technology then the money initially paid is not recovered.
>
> --*Supplier of advanced truck technology*

Conclusion:
Potential Fuel and Cost Savings are Great but Barriers and Uncertainties Remain

This report highlights the significant potential that advanced efficiency technologies have to reduce costs for truck owners. Savings are highly sensitive to both fuel prices and ownership periods, but the majority of scenarios we examined resulted in significant net savings for truck owners over the period of ownership. Life-cycle savings analysis is an important tool that can allow truck owners to more accurately assess the true costs and benefits of potential technology investments. A transition toward greater use of life-cycle analysis in the industry would improve the efficiency of our nation's trucking fleet while saving money for truck owners.

However, there are many remaining barriers and uncertainties that must be addressed in order for the potential cost savings to be realized. Unpredictable fuel costs and regulatory environments make planning and forecasting difficult. Uncertainties around the durability, performance, and resale value of new technologies complicate the life-cycle analysis process. High incremental costs for new technologies may be difficult to offset. Life-cycle accounting is important and should be the industry norm, but these market barriers call for more than just a change in purchase analysis methods. Strong and consistent policies and incentives are needed to address these issues and accelerate the development and deployment of advanced truck efficiency technologies.

APPENDIX A – Per-Truck Life-Cycle Cost Savings

Class 4 Gasoline Box Truck

Mileage is assumed to be 25,000 per year for the first ten years, declining thereafter
Future life-cycle savings are discounted at a rate of 7 percent
Baseline fuel economy is 8 mpg

The moderate package includes low rolling resistance tires, transmission improvements, integrated starter/alternator with idle off and limited regenerative breaking, and some degree of weight reduction. These technologies would increase fuel economy from by 16% at an estimated incremental capital cost of cost of $4,093.

Table A1: Life-Cycle Savings for Class 4 Gasoline Box Truck with Moderate Tech Package

(2 year simple payback: $1,119 net cost)*

Fuel Price \ Service Life	5 years	12 years	20 years
$2.50/gallon	$1,456	$4,460	$5,833
$3.50/gallon	$3,320	$8,065	$10,092
$4.50/gallon	$5,184	$11,670	$14,351

*2 year simple payback assumes fuel prices at $3.50 per gallon

The advanced technology package includes the tire and transmission improvements mentioned above, as well as direct injection, a hybrid electric drivetrain, and increased weight reduction. This package has an upfront cost of $13,062 and increases baseline fuel efficiency by 78%, from 8 mpg to just over 14 mpg.

Table A2: Life-Cycle Savings for Class 4 Gasoline Box Truck with Advanced Tech Package

(2 year simple payback: $3,457 net cost)*

Fuel Price \ Service Life	5 years	12 years	20 years
$2.50/gallon	$4,822	$14,575	$19,019
$3.50/gallon	$10,842	$26,217	$32,773
$4.50/gallon	$16,862	$37,858	$46,527

Assumptions: Annual mileage is assumed to start at 25,000 miles
Life-cycle savings are discounted at a rate of 7 percent per year
2 year simple payback assumes fuel prices at $3.50 per gallon

Class 4 Diesel Box Truck

Mileage is assumed to be 25,000 per year for the first ten years, declining thereafter
Future life-cycle savings are discounted at a rate of 7 percent
Baseline fuel economy is 10 mpg

The moderate technology package includes low rolling resistance tires, some aerodynamic improvements, transmission upgrades, integrated starter/alternator with idle off and limited regenerative breaking, and some degree of weight reduction. These technologies fuel efficiency by 15% with an incremental capital cost of cost of $4,600.

Table A3: Life-Cycle Savings for Class 4 Diesel Box Truck with Moderate Tech Package

(2 year simple payback: $2,325 net cost)*

Service Life / Fuel Price	5 years	12 years	20 years
$2.50/gallon	($55)	$1,734	$2,679
$3.50/gallon	$1,357	$4,464	$5,904
$4.50/gallon	$2,768	$7,194	$9,130

*2 year simple payback assumes fuel prices at $3.50 per gallon

The advanced technology package includes the same tire and transmission upgrades mentioned above, plus engine improvements, a hybrid drivetrain, and increased aerodynamics and weight reduction. This package has an upfront cost of $18,000 and increases baseline fuel efficiency by 73%.

Table A4: Life-Cycle Savings for Class 4 Diesel Box Truck with Advanced Tech Package

(2 year simple payback: $10,879 net cost)*

Service Life / Fuel Price	5 years	12 years	20 years
$2.50/gallon	($2,748)	$2,019	$4,898
$3.50/gallon	$1,867	$10,942	$15,441
$4.50/gallon	$6,481	$19,866	$25,983

2 year simple payback assumes fuel prices at $3.50 per gallon

Class 3 Package Delivery Van

Vehicles are assumed to travel 10,000 miles per year
Future Life-cycle savings are discounted at a rate of 7 percent
Baseline fuel economy is 8 mpg

The moderate technology package includes low rolling resistance tires, transmission improvements, direct injection, and some degree of weight reduction, increasing fuel economy by 20% at an incremental capital cost of cost of $3,185.

Table A5: Life-Cycle Savings – Class 3 Van with Moderate Technology Package
(2 year simple payback: $1,725 net cost)*

Fuel Price \ Service Life	5 years	8 years	12 years
$2.50/gallon	($207)	$215	$881
$3.50/gallon	$708	$1,547	$2,650
$4.50/gallon	$1,623	$2,880	$4,419

*2 year simple payback assumes fuel prices at $3.50 per gallon

The advanced package includes the technologies outline above, as well as a hybrid electric powertrain and additional weight reduction. This package has an upfront cost of $11,396 and increases baseline fuel economy by 78%.

Table A6: Life-Cycle Savings – Class 3 Van with Advanced Technology Package
(2 year simple payback: $7,554 net cost)*

Fuel Price \ Service Life	5 years	8 years	12 years
$2.50/gallon	($2,903)	($2,383)	($1,034)
$3.50/gallon	($495)	$1,124	$3,623
$4.50/gallon	$1,913	$4,631	$8,279

*2 year simple payback assumes fuel prices at $3.50 per gallon

Class 8 Long Haul Tractor Trailer (Fleet)

Mileage is assumed to start at 140,000 per year, declining at a rate of 6,000 per year
Future life-cycle savings are discounted at a rate of 7 percent
Baseline fuel economy is 6 mpg

The moderate package includes advanced SmartWay aerodynamic improvements, as well as mechanical turbocompounding with variable valve actuation, and also assumes a 60 mph top speed. This package increases fuel economy by 32%.

Table A7: Life-Cycle Savings for Class 8 Tractor Trailer with Moderate Tech Package
(2 year simple payback: $11,879 net savings)*

Service Life / Fuel Price	5 years	8 years	12 years
$2.50/gallon	$37,789	$53,987	$68,525
$3.50/gallon	$60,662	$85,255	$106,910
$4.50/gallon	$83,455	$116,523	$145,295

*2 year simple payback assumes 120,000 miles/year at $3.50 per gallon

The advanced class 8 tractor trailer technology package again includes Advanced SmartWay and a 60 mph top speed, and also includes a hybrid electric drivetrain and bottoming cycle. This package improves fuel efficiency by 65% at an incremental cost of $73,010 for one tractor and two trailers.

Table A8: Life-Cycle Savings for Class 8 Tractor Trailer with Advanced Tech Package
(2 year simple payback: $6,358 net cost)*

Service Life / Fuel Price	5 years	8 years	12 years
$2.50/gallon	$46,038	$69,286	$91,329
$3.50/gallon	$83,142	$120,096	$153,705
$4.50/gallon	$120,245	$170,906	$216,080

*2 year simple payback assumes 120,000 miles/year at $3.50 per gallon

Class 8 Long Haul Tractor (Owner-Operator, New Truck)

Mileage is assumed to remain constant at 80,000 per year
Future life-cycle savings are discounted at a rate of 7 percent
Baseline fuel economy is 6 mpg

The technologies examined here include the tractor-specific SmartWay aerodynamic improvements, as well as mechanical turbocompounding with variable valve actuation, and also assume 60 mph top speed. This package provides a fuel economy improvement of 21% at an incremental cost of $15,000.

Table A9: Life-Cycle Savings for Class 8 Tractor with Moderate Tech Package (new truck)
(2 year simple payback: $987 net savings)*

Service Life / Fuel Price	10 years	15 years	20 years
$2.50/gallon	$26,331	$37,338	$42,465
$3.50/gallon	$43,516	$59,622	$67,022
$4.50/gallon	$60,700	$81,907	$91,580

*2 year simple payback assumes 80,000 miles/year at $3.50 per gallon

The advanced technology package once again includes the technologies outlined in the "moderate" case above, plus a hybrid drivetrain and bottoming cycle. This package has higher upfront costs, estimated at just over $41,000 but also promises greater savings due to expected fuel economy gains of 43%.

Table A10: Life-Cycle Savings for Class 8 Tractor with Advanced Tech Package (new truck)
(2 year simple payback: $13,205 net cost)*

Service Life / Fuel Price	10 years	15 years	20 years
$2.50/gallon	$31,277	$49,332	$63,441
$3.50/gallon	$61,408	$88,404	$108,889
$4.50/gallon	$91,539	$127,477	$154,338

*2 year simple payback assumes 80,000 miles/year at $3.50 per gallon

Class 8 Long Haul Tractor (Owner-Operator, 5 year old truck)

Mileage is assumed to remain constant at 80,000 per year
Future life-cycle savings are discounted at a rate of 7 percent
Baseline fuel economy is 6 mpg
Used truck prices are based on current conventional truck depreciation rates

The technologies examined here include the tractor-specific SmartWay aerodynamic improvements, as well as mechanical turbocompounding with variable valve actuation, and also assume 60 mph top speed. This package provides a fuel economy improvement of 21%. Incremental technology costs, originally $15,000 for a new truck, are assumed to be $6,420.

Table A11: Life-Cycle Savings for Class 8 Tractor with Moderate Tech Package (5 year old truck)
(2 year simple payback: $9,587 net savings)*

Service Life / Fuel Price	5 years	10 years	15 years
$2.50/gallon	$18,862	$34,299	$45,938
$3.50/gallon	$28,894	$51,484	$68,222
$4.50/gallon	$38,926	$68,669	$90,507

*2 year simple payback assumes 80,000 miles/year at $3.50 per gallon

The advanced technology package once again includes the technologies outlined in the “moderate” case above, plus a hybrid drivetrain and bottoming cycle, providing a 43% efficiency improvement. Incremental technology costs, which are estimated at just over $41,000 for a new truck, are assumed to be $17,639.

Table A12: Life-Cycle Savings for Class 8 Tractor with Advanced Tech Package (5 year old truck)
(2 year simple payback: $10,426 net savings)*

Service Life / Fuel Price	5 years	10 years	15 years
$2.50/gallon	$27,850	$53,173	$72,963
$3.50/gallon	$45,440	$83,304	$112,035
$4.50/gallon	$63,030	$113,435	$151,108

*2 year simple payback assumes 80,000 miles/year at $3.50 per gallon

APPENDIX B – Truck Technology, Cost, and Usage Inputs and Assumptions

Class 3-4 Package Delivery Trucks
The incremental technology costs and fuel economy gains used in this analysis are drawn from published research on advanced truck technologies. Costs and efficiency gains for the class 3-4 package delivery trucks come from drawn from Vyas, Saricks and Stodolsky 2002. Costs for hybrid systems were adjusted from the predictions in the Vyas study to 20% of vehicle cost, based on conversations with industry and Cooper, et. al 2009. Incremental maintenance costs from advanced technologies are assumed to be 2% of upfront technology cost. We expect some technologies to have maintenance costs that are slightly higher, and others to have maintenance costs that are lower or even negative. Hybrid systems, for example, are expected to reduce break wear. For the purpose of this analysis, 2% of capital cost was used to provide a conservative estimate of incremental maintenance costs from advanced technologies.

Residual value at the end of the period of ownership is calculated as a function of initial vehicle cost and years of service. The functions used for residual value closely match used truck price data collected by the California Air Resources Board (California Air Resources Board, 2008) on similar truck types. Advanced technology vehicles are assumed to follow a path of depreciation similar to conventional vehicles, and retain greater residual value as a result of their greater purchase prices.

Class 3 package delivery vans are assumed to travel 10,000 miles per year over a lifetime of 5-12 years. Class 4 box trucks are assumed to have longer periods of ownership, ranging from 5 to 20 years in our analysis. Annual mileage for these vehicles is assumed to be 25,000 per year for the first ten years, declining at a rate of 1% per year thereafter.

Class 8 Long Haul Tractor-Trailers
Baseline data for incremental technology costs, fuel economy gains, and incremental maintenance costs for long haul tractor trailers are drawn from Cooper, et. al 2009. We assumed that large fleets would purchase 2 trailers per tractor. This estimate comes from experiences with CALSTART's HTUF working groups, as well as Transport Topics 2007 Top 100 For Hire and Private Carrier lists. It is important to note that the number of trailers per tractor will vary widely across fleets, with some having a much higher ratio of trailers to tractors. Cooper et. al assumed 3 trailers per tractor, and some fleets may typically have even more. A larger number of trailers will drive up incremental costs for aerodynamics and low rolling resistance tires. We did not take into account the potential higher resale value of trailers with advanced aerodynamic and tire technologies. To the extent that these technologies increase trailer resale value, life-cycle benefits would be greater than those presented in this report.

Owner-operators were assumed to purchase a tractor without a trailer. In order to arrive at an estimate of expected fuel economy improvements, we therefore removed trailer technologies and their associated fuel economy improvements from our calculations. However, it is important to note that the modeling for Cooper et. al included an efficient trailer. To the extent that there is interaction between the tractor and trailer technologies, actual fuel economy improvements could be slightly reduced. In the absence of recent modeling for tractor-only technologies, this approach represents our best estimate of tractor-only improvements.

California Air Resources Board data on used truck prices was again used to create equations expressing used truck value as a function of initial capital cost and vehicle age. This allowed us to determine residual value at the end of the period of ownership, and also allowed us to determine the purchase price for owner-operators purchasing 5 year old trucks. Advanced technology vehicles are assumed to follow a path of depreciation similar to conventional vehicles, and retain greater residual value (and higher purchase price after 5 years) as a result of their higher initial costs.

Long Haul tractor trailers in large fleet applications are assumed to travel 140,000 per year in year 1, declining at 6,000 miles per year. We examined ownership periods ranging from 5 to 12 years for these fleets. Owner-operators are assumed to travel 80,000 miles per year. We examined costs and benefits for 10 to 20 years for new trucks, and 5 to 15 year ownership periods for 5 year old trucks, resulting in a total service life of 20 years for each.

REFERENCES

California Air Resources Board. 2008. *Technical Support Document: Proposed Regulation for In-Use On-Road Diesel Vehicles*, Appendix J. Sacramento, CA.

Cooper, Coralie, Fanta Kamakaté, Thomas Reinhart, and Robert Wilson. 2009. *Reducing heavy-duty long-haul combination truck fuel consumption and* CO_2 *emissions*. Boston, MA: North East States Center for a Clean Air Future.

Energy Information Administration (EIA). 2010. *Annual Energy Outlook 2010*. Washington, DC. Online at http://www.eia.doe.gov/oiaf/aeo/index.html.

National Renewable Energy Laboratory (NREL). 2009. *Twelve-month evaluation of UPS diesel hybrid-electric delivery vans*. Technical report NREL/TP-540-44134. Golden, CO.

National Research Council (NRC), Transportation Research Board, Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles. 2010. *Technologies and approaches to reducing the fuel consumption of medium- and heavy-duty vehicles.* Washington, DC: National Academies Press.

Tomic, J. 2007. "Pilot hybrid utility trucks assessment." Presentation at the national meeting of the Hybrid Truck Users Forum. Seattle, WA.

Tomic J., and B. Van Amburg. 2007. *Heavy-duty hybrid utility trucks: HTUF deployment experiences and results*. EVS-23. Anaheim, CA

Transport Topics Publishing Group. *Top 100 For Hire Carriers 2007* and *Top 100 Private Carriers 2007*. Online at http://www.ttnews.com/tt100/archive/

U.S. Department of Energy (DOE). 2009. *Transportation energy data book, 28th edition.* Washington, DC. Online at http://cta.ornl.gov/data/download28.shtml.

Vyas, A., C. Saricks and F. Stodolsky. 2002. *The potential effect of future energy efficiency and emissions-improving technologies on fuel consumption of heavy trucks.* Argonne, IL: Argonne National Laboratory.