Energy Efficiency Strategies for Freight Trucking: Potential Impact on Fuel Use and Greenhouse Gas Emissions

Jeffrey Ang-Olson*

ICF Consulting

60 Broadway Street

San Francisco, CA 94111

Phone 415-677-7110

Fax 415-677-7177

jangolson@icfconsulting.com

Will Schroeer

ICF Consulting

241 Cleveland Avenue South, Suite 1B

St. Paul, MN 55105

Phone 651-698-0788

Fax 651-698-0782

wschroeer@icfconsulting.com

* Corresponding author

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ABSTRACT

Trucking is the dominant domestic freight mode and offers a substantial opportunity to improve transportation energy efficiency and reduce emissions of both criteria pollutants and greenhouse gases. In response, the United States Environmental Protection Agency (EPA) is proposing a Ground Freight Transportation Initiative, a voluntary initiative that will work with all industry sectors associated with freight movement as well as local governments to improve efficiency and reduce emissions through a wide range of voluntary actions. These may include best management practices, operational improvements, and advanced technologies. This paper explores strategies EPA and partners will be investigating as potential measures that could improve the environmental performance and energy efficiency of a sub-sector of ground freight, the trucking sector. The eight trucking strategies assessed in the paper include both technological innovations and human-factor (operations) strategies. All are commercially available (or, for operations, feasible) today, though most have achieved little market penetration. Each strategy is briefly described, followed by an assessment of the strategy’s impact on the fuel economy of a typical freight truck. The paper then estimates the current and potential maximum market penetration of each strategy, and calculates the potential U.S. greenhouse gas emission reduction resulting from national adoption of the strategy. At a national participation rate of 50%, the total maximum benefit of the initiative in 2010 would be a reduction of 3.4 billion gallons of fuel and 9.5 million metric tons of carbon-equivalent emissions.

INTRODUCTION

Ground freight (freight trucking and freight rail) is a substantial contributor to local and global pollutant emissions. Ground freight annually contributes 30% of mobile source emissions of ozone precursor NO_x, and 26% of mobile source particulate matter (PM) emissions (1). Ground freight accounts for 19.4% of total transportation carbon emissions (a common measure of greenhouse gas emissions) and energy use in the U.S. (2). Energy use by freight trucking is forecast to increase 27% by 2010, and 49% by 2020, faster than any other sector of transportation except air travel (2).

In response to the challenge of growing emissions, and the demonstrated success of other voluntary initiatives, the United States Environmental Protection Agency (EPA) is initiating the Ground Freight Transportation Initiative (GFTI). The GFTI will work with all industry sectors associated with freight movement as well as local governments to improve efficiency and reduce emissions through a wide range of voluntary actions. These may include the use of best management practices, operational improvements, and advanced technologies. EPA proposes to identify performance criteria, develop tracking software, and provide a green transportation label and public recognition to environmentally proactive companies. Industry partners would provide feedback to EPA's performance criteria, participate in focus groups, use the label in print, web, and other promotion, and use software to track environmental benefits. As part of this initiative, EPA has contracted with ICF Consulting to examine the potential benefits of a variety of freight strategies.

The EPA initiative is concerned with improving efficiency and reducing fuel consumption and associated emissions across the entire supply chain, and intends to extend its outreach to the entire freight industry, including shippers, carriers, and equipment manufacturers across all ground freight modes. This paper focuses on the potential efficiencies in trucking, recognizing that trucking is the dominant domestic freight mode and may therefore offer potentially greater opportunities to mitigate emissions. Trucking carries approximately one-third of domestic freight ton-miles, consumes over 80% of freight transport energy, and emits a commensurate portion of greenhouse gases (2,3).

This paper explores strategies that can improve the fuel efficiency of freight trucking and reduce associated carbon emissions. The eight strategies assessed in the paper include both technological innovations and human-factor (operations) strategies. All are commercially available today, and many are cost-effective over a two or three year period, though most have achieved little market penetration. Each strategy is briefly described, followed by an assessment of the strategy impact on the fuel economy of a typical freight truck. The paper then estimates the current and potential maximum market penetration of each strategy and calculates the U.S. CO_2 emission reduction resulting from national adoption of the strategy.

METHODOLOGY

Literature Review

Research began with a review of relevant literature including engineering journals, trade publications, and other reports providing an overview of trucking efficiency issues. Most relevant are recent reports produced in Canada and Europe. The Transportation Table of the Canadian National Climate Change Process (NCCP) recently commissioned more than 20 research reports, including one that assesses the GHG reduction potential of existing trucking technologies in Canada and another that examines the impact of trucking human factor (operations) strategies (4,5). A study for the European Commission briefly examines the GHG reduction potential of freight strategies in Europe as part of an assessment of transport sector emission reductions (6).

Several similar studies were produced in the U.S. in the 1980s and early 1990s (7,8,9). They provide good background material on the characteristics of truck energy loss, but because they are somewhat dated, many of the strategies they evaluate have now achieved wide market penetration.

We also reviewed research conducted under the 21st Century Truck Program and related Department of Energy (DOE) programs (10). Formally announced in April 2000, the 21st Century Truck Program is an aggressive 10-year public-private research effort aimed at increasing the efficiency of trucks and buses. It focuses on how the development of *new* technologies can improve fuel efficiency, whereas EPA's GFTI focuses on how *existing* technologies and operational practices can improve fuel efficiency. Other recent studies of truck fuel efficiency gains also focus primarily on technologies not yet commercially available (11).

Determining Per-Truck Fuel Impact

In order to compare truck fuel economy among current models and options packages, we relied on a variety of sources. Truck manufacturers do not typically release information on fuel economy because the results can vary so widely depending on factors like driving cycle, driver behavior, payload, ambient temperature, wind and road conditions. We obtained this information primarily from:

- Real-world tests performed by fleet owners – These are usually proprietary, but The Maintenance Council of the American Trucking Association (ATA) has attempted to summarize the experience of many fleets in their *Fleet Manager's Guide to Fuel Economy* and other publications (12).
- Simulation software produced by engine manufacturers – We use "Spec Manager" Version 2.1 by Detroit Diesel Corporation.
- On-road and laboratory testing done by researchers and reported in scientific journals.

For each efficiency strategy, fuel savings estimates are based on a "typical" combination truck. For this analysis we assume that a typical combination truck is one engaged in long-haul operation – defined as a truck with the majority of travel more than 200 miles from home base. These vehicles account for 63% of combination truck travel, according to the 1997 Vehicle Inventory and Use Survey (VIUS). The physical characteristics of this truck are (13):

- Configured as a 3-axle tractor pulling a 2-axle trailer
- Annual mileage of 98,000 miles
- Average GVW of 68,200 lbs. (While 5-axle combination trucks are rated for 80,000 lbs. GVW and higher, most operate volume-limited (cube-out) and do not reach their maximum weight.)
- Fuel economy of 6.1 mpg

Determining National Energy and GHG Impact

To calculate the national impact of each trucking strategy, we estimate the current and maximum potential market penetration in terms of VMT. Much of the information on market penetration was obtained from interviews with individuals at truck manufacturers, truck equipment manufacturers and trucking companies. Market penetration is estimated for sub-sectors of the truck population when the strategy impacts vary by these groupings. (For example, aerodynamic improvements affect the fuel economy of van and flatbed trucks differently, so market penetration and national emissions impacts are determined separately for these two groups.)

We apply each strategy's potential market penetration increase and fuel efficiency impact to a baseline inventory of freight truck fuel use and CO_2 emissions. This inventory was developed for current (1999) freight truck VMT, fuel consumption and carbon emissions by truck type (combination vs. single-unit) and fuel type (diesel vs. gasoline). FHWA's *Highway Statistics* is used for VMT and fuel consumption data, and the *Vehicle Inventory and Use Survey* is used to develop the fuel type splits. Baseline forecasts to 2010 are based on the VMT and truck fuel efficiency growth rates used in DOE's NEMS Model and published in the *Annual Energy Outlook*. Note that this baseline assumes a natural increase in freight truck fuel efficiency of 0.7% annually as forecast by DOE. The benefits of the GFTI strategies are generally assumed to be on top of this baseline improvement.

Based on this analysis, we calculate that 1999 combination trucks account for 132,386 million VMT, 26,241 million gallons of fuel use (nearly all diesel), and 72.2 million metric tons of carbon equivalent (MMTCE) emissions. Baseline forecasts call for combination truck fuel use to reach 33,421 million gallons by 2010 and carbon emissions to reach 92.0 MMTCE. These figures do not include single-unit freight trucks, whose fuel use and carbon emissions are roughly one-quarter that of combination trucks.

We estimate the impact of truck efficiency strategies under a 50% "participation rate." The 50% participation rate assumes that 50% of those available to take advantage of a strategy do so. So, for example, a tare weight reduction strategy has a current market penetration of 14% of combination truck VMT, and we assume the maximum potential market penetration to be 64% of VMT. The 50% participation rate assumes that half of the gap between 14% and 64% is closed.

TRUCK ENERGY LOSSES

Internal combustion engines convert fuel energy to heat and mechanical energy. Diesel engines are more efficient than gasoline engines because they produce a higher compression ratio, which yields more work output on the engine expansion stroke, and because diesel engines lack air intake throttle valves that contribute to pressure losses and pumping losses in gasoline engines (11). Diesel and gasoline engine efficiency has been increasing over the last 30 years as a result of technological advances such as turbochargers and intercoolers. In a typical modern diesel truck engine, 53% of the fuel energy is lost as heat through the exhaust system and cooling system, and another 5% is dissipated through engine friction and pumping losses, leaving 42% available as engine output (or "brake work") (14). This energy is used to overcome the following factors:

- Aerodynamic drag
- Rolling resistance
- Drive train friction
- Accessories operation
- Inertial forces (during acceleration or climbing)

The contribution of each of these factors to energy loss and fuel consumption can vary greatly depending on driving speed, truck weight, terrain, driver behavior, wind speed and angle, and pavement conditions. On flat terrain at a constant speed of 50 mph, aerodynamic drag and rolling resistance constitute the biggest power losses, both consuming roughly 40% available horsepower (and fuel). However, unlike rolling resistance, aerodynamic drag force increases exponentially with velocity, so it becomes the largest source of energy loss at typical highway speeds. DOE suggests that at 70 miles per hour, aerodynamic drag accounts for about 65% of the total energy loss for a typical heavy truck (15). Drive train and accessory losses generally account for less than 5% of energy demand at highway speeds (8).

Our paper focuses on strategies that directly address each of these five types of energy loss, as well as strategies that alter the driving cycle in a way that improves efficiency. Each individual strategy is described below. Table 1 presents a summary of each strategy in terms of per-truck fuel economy impact, market penetration and potential national fuel and emission savings.

IMPROVED AERODYNAMICS

Improved aerodynamics can dramatically improve truck fuel efficiency at highway speeds. The coefficient of drag, C_d, is a measure of aerodynamic resistance. It has fallen from about 0.8 in 1970 to roughly 0.6 today for a typical truck, but could be reduced to 0.45 using commercially available aerodynamic options (11).

Fuel Economy Impact

Standard roof deflectors have been used on tractors since the 1970s. Adding a roof deflector to a cab with no aerodynamic devices will improve fuel economy up to 6% (12). In the 1980s, truck manufacturers began offering integrated cab-roof fairings with closed sides. These improve fuel economy by up to 15% compared to a cab with no roof devices (12). Other aerodynamic devices can be added to tractors as well, such as cab extenders (sometime called gap seals), side fairings, and a front bumper air dam. All major truck manufacturers currently offer aerodynamic models that include a sloped hood and streamlined front profile together with a full package of add-on devices, and these vehicles now dominate the long-haul truck population.

One recent trend is the growing popularity of the long-nosed, hard-edged tractor design reminiscent of the 1970s, such as the Peterbilt "379" or Freightliner "Classic" models. These "classic profile" trucks are sold primarily to owner-operators, with a small number also sold to large fleets where they are used as "reward trucks" for drivers with superior performance. They may have the add-on aerodynamic devices, but their hood profile and frontal area make them significantly less streamlined than standard models. Manufacturers do not reveal how the classic profile truck compares with the aerodynamic profile truck (they consider the information proprietary), but they acknowledge that the fuel economy difference is measurable and significant, and could add up to several thousand dollars in annual fuel costs.

There has been relatively little effort by manufacturers to improve trailer aerodynamics. One simple option is to reduce the tractor-trailer gap on trucks that allow this type of adjustment. Reducing the gap from 45 to 25 inches to will improve fuel economy 1-2% (12). Another low-tech option is to arrange cargo on flatbed trailers so as to keep the outline of the total load as low and regular as possible. Securing loose tarpaulins is reported to improve fuel economy by up to 2.5%. Closing the curtains on an empty curtain-sided trailer has been shown to improve fuel economy by 4.5% (16).

Several add-on devices have been developed to improve van trailer aerodynamics. Trailer side skirts are fairings that hang down from the bottom of a trailer, enclosing the open space between the rear wheels of the tractor and the wheels of the trailer. Manufacturers of these devices claim fuel savings of 5% to 18%. Another manufacturer makes triangular plastic pieces that are mounted in rows along the back of the cab and trailer, designed to create a swirl of air (vortex) in the tractor-trailer gap and behind a van trailer. The manufacturer claims at least a 4% improvement in fuel economy.

Many factors affect truck aerodynamics, and the benefits of different technologies are not necessarily additive, so it is not possible to come up with a simple estimate of efficiency gains for each device. For example, installing cab extenders on a tractor without a roof deflector or roof fairing will often increase drag. We estimate benefits for three general packages of aerodynamic technologies, two for the tractor and one for the trailer.

1. One option is to add a full package of aerodynamic devices (roof fairing, cab extenders, side fairings, front air dam) to a tractor. According to the 1997 VIUS, most van-trailer combination trucks already have these features, so the potential market gain is limited primarily to some non-van trailer trucks (flatbeds, tankers, etc.) Simulation suggests that aerodynamic devices reduce fuel consumption by 3.5% for flatbed trailer trucks in long-haul operation and 1.2% in local operation (17).

2. A second option is to use an aerodynamic profile tractor instead of a “classic” profile. We estimate that this option reduces fuel use by 3.6% in long-haul operation, and 1.3% in local operation.

3. The impact of trailer aerodynamic devices is less certain than tractor devices because they have not undergone extensive independent testing. We assume a 3.8% fuel reduction for long-haul operation of van trailers, consistent with the lower end of the range given by makers of trailer side skirts. In local operation, fuel economy gains are smaller, estimated at 1.3%.

Market Penetration and National Emissions Impact

The 1997 VIUS identifies trucks that report having “aerodynamic features,” which presumably means a roof fairing or roof deflector for combination trucks. Among van trailer trucks, nearly 70% of the VMT is associated with vehicles with aerodynamic devices (45,100 out of 65,094 million miles). The market penetration of aerodynamic devices on combination trucks has been increasing steadily over the last decade. Nearly 75% of model year 1997 van trailer trucks report having aerodynamic devices, and if past trends continue, at least 90% of model year 2010 van trailer trucks will have them. Because of the high market penetration of aerodynamic devices among van trailer trucks, the only significant potential fuel efficiency gains for this sub-population are associated with the classic profile tractors. According to truck manufacturers, they currently have about a 20% market share. As described above, even when add-on aerodynamic devices are present, the aerodynamic profile tractor achieves better fuel economy than the classic profile tractor. To calculate the potential national impact, we apply the fuel economy benefits of this strategy to 20% of the VMT associated with van trailer truck travel. Local and long-haul impacts are calculated separately, based on the VMT fractions shown in Table 2 (13). With 50% participation by applicable trucks, strategy would eliminate 0.2 MMTCE in 2010.

Among the fleet of non-van trailer trucks, 34% of the VMT is associated with vehicles with aerodynamic devices according to the VIUS (12,030 out of 35,814 million miles), though market penetration of aerodynamic devices on these vehicles increases with model year. If past trends continue, approximately 50% of the non-van trailer 2010 fleet will have aerodynamic devices. Thus for non-van trailer trucks (flatbeds, tankers, etc.), we assume that the potential market for improvement is 50% of the VMT associated with this truck sub-population. To calculate the national impact, we apply the fuel economy impacts for flatbed trailers (separately for long-haul and local travel) to 50% of the VMT associated with non-van trailer truck travel, using the fractions shown in Table 2 (13). Emissions reduction through this strategy would total 0.2 MMTCE in 2010 at 50% participation.

Trailer aerodynamic devices like side skirts are currently marketed mostly for combination trucks. Their current market share is near zero. All van trailers could benefit from this strategy, accounting for 65% of combination truck VMT. The 2010 emissions reduction would be 0.9 MMTCE at 50% participation.

WIDE-BASE TIRES

Using wide-base tires to replace dual tires on the truck's drive and trailer axles can improve truck fuel economy by reducing rolling resistance and tare weight. Several major tire manufacturers offer versions of this type of tire.

Fuel Economy Impact

Recent tests of the Michelin wide-base tire show fuel economy improvements of 3.7% to 4.9% compared to the most equivalent Michelin dual tire (18). Bridgestone claims fuel economy improvements of 2% to 5% using its new wide-base tire. Computer simulation of truck performance indicates 2.7% mpg improvement compared to dual low profile radial tires (17). Using this conservative figure for benefits calculations, wide-base tires would save 424 gallons per year for a typical long-haul combination truck.

Market Penetration and National Emissions Impact

Although they have been available since the 1980s, wide-base tires have achieved little market penetration among long-haul trucks. One reason for this is the concern about lack of redundancy. Because standard tires are mounted in pairs on the truck drive axles and trailers axles, the failure of one will not prevent a truck from driving to the next service station. Some drivers are concerned that failure of a wide-base tire will leave them immobilized. However, tire manufacturers dispute this claim, noting that because most tractors and trailers have tandem axles, they can continue to operate with the failure of one wide-base tire. In addition, because early versions of wide-base tires violated several state "inch-width" laws, some fleet managers believe that the tires are not legal. Current wide-base tires are wider than earlier models and legal in all 50 states for a 5-axle, 80,000 GVW truck.

We assume the current market share of wide-base tires in combination truck applications to be 5% of VMT, based on discussions with tire manufacturers, and the potential market to be all combination trucks. The 2010 emissions reduction from this strategy would be 1.1 MMTCE, or a fuel savings of 415 million gallons.

PROPER TIRE INFLATION

Maintaining proper tire pressure reduces the rolling resistance and fuel consumption caused by tire underinflation. Proper tire inflation can be achieved using automatic tire inflation (ATI) systems that sense pressure and supply pressurized air to tires on a continuous basis. At least two manufacturers currently produce ATI systems for the U.S. on-road market. One uses a hub-mounted compressor powered by wheel rotation, and the other relies on a central pressurized air supply, powered by the truck's air brake compressor. Tire inflation systems also reduce tire wear, reduce road emergencies caused by tire failure, and decrease time spent on periodic tire pressure inspection.

Fuel Economy Impact

As a rule of thumb, a 10-psi drop in tire pressure will increase rolling resistance by 2% and fuel consumption by 0.5% to 1%. The impact of trailer tire underinflation is estimated to cause a 0.6% reduction in fuel economy on a typical truck (4). Tire inflation systems will eliminate this underinflation entirely. For a typical long-haul freight truck, this would save 97 gallons of fuel per year. The fuel savings could be much larger for trucks that do not frequently check and maintain proper tire pressure.

Market Penetration and National Emissions Impact

According to device manufacturers, ATI systems are relatively new and current market penetration among on-road trucks is near zero. One reason for this is that fleet managers to not perceive that they have a problem with underinflation, and therefore do not see these systems as cost effective. The potential market for ATI systems is essentially all long-haul freight trucks. 2010 carbon emissions would be reduced by 0.3 MMTCE under 50% participation in the strategy, with fuel savings of 95 million gallons.

TARE WEIGHT REDUCTION

Truck tare weight (empty weight) can be reduced by purchasing tractor and trailer components made of lightweight materials, or by eliminating unnecessary components. Weight-saving options include using aluminum for the wheels, axle hubs, the tractor frame and the trailer frame. Since the majority of long-haul trucks are volume-limited (cube-out), tare weight reduction reduces gross-vehicle weight and fuel consumption. For trucks that are weight limited (weigh-out), tare weight reduction can allow for more cargo and a reduction in fuel consumption per ton-mile.

Fuel Economy Impact

The tare weight of a typical combination truck can be reduced by as much as 10,000 pounds by using lightweight materials and eliminating unnecessary components (12). Most trucks will not be able to achieve reductions this large, in part because of the need for certain accessories or more durable components. We assume that trucks could achieve a weight reduction of 3,000 lbs. while still maintaining desired durability and features. A 3,000-pound reduction in vehicle weight improves fuel economy by approximately 0.11 mpg at 65 mph (12). This would reduce fuel use by 296 gallons annually for a typical long-haul freight truck.

Market Penetration and National Emissions Impact

According to trailer manufacturers, aluminum-component trailers currently have high market penetration only in selected niche operations, like heavy-haulers and refrigerated goods. Nearly all refrigerated van trailers use aluminum components because aluminum resists rusting, and because frozen goods are typically heavy. Most dry van trailers do not incorporate many optional weight-saving components, in part because they do not find it cost-effective. Many flatbed trailers have aluminum side rails, but most do not have an aluminum floor or floor joists. Extensive use of aluminum is not possible for many flatbed and tanker trailers because of structural requirements.

We assume the maximum market for 3,000 lbs. in tare weight savings is all van trailer trucks. We assume the current market penetration to be all refrigerated van trailer trucks, which account for 14% of total combination truck VMT (13). Non-refrigerated trucks account for an additional 50% of total VMT, and this represents the potential market share gain. If 50% of eligible trucks participate, emission savings would be 0.4 MMTCE in 2010.

LOW-FRICTION LUBRICANTS

Friction losses in the drive train (transmission and differential) and engine can be reduced by using low viscosity lubricants. Most manufacturers of lubricants produce “fuel economy” brands that have lower viscosity than standard lubricants. Low viscosity lubricants are usually synthetics, since they are better able to meet volatility requirements, but some mineral oils can also improve fuel economy.

Fuel Economy Impact

ATA’s Maintenance Council claims that synthetic transmission and axle lubricants improve fuel economy by 0.5% in the summer and 2% in the winter (when all-mineral lubricants experience higher viscosity). A number of recent studies have examined fuel economy lubricants for trucks and, though they offer varying results, suggest that total possible fuel savings are somewhat higher than ATA’s estimate, and could be as high as 5% using low friction engine lubricants and 4% using low friction transmission lubricants (19,20,21,22,23).

We use an estimate of a 1.5% in fuel economy gains from low-friction engine oils and a 1.5% gain from synthetic drive train lubricants. Together this reduce annual fuel consumption by 479 gallons for a typical long-haul freight truck.

Market Penetration and National Emissions Impact

All combination trucks could potentially benefit from this strategy. Synthetic, low viscosity lubricants are becoming common for transmissions and axles. At least one of the major truck transmission manufacturers now recommends use of synthetic lubricants for nearly all their products. We estimate a current market share of 70% for synthetic drive train lubricants, so 30% of trucks could benefit from this strategy.

Synthetic, low viscosity lubricants are less common in truck engines, in part because of fleet manager concerns over possible increased engine wear. In addition, the lubricant performance requirements specified by engine manufacturers might exclude (or appear to exclude) some synthetics. Because engine warranties may be voided by not following specified maintenance, fleet managers are hesitant to try any products not clearly within the manufacturers' recommendations. We estimate the current truck market share of synthetic engine lubricants to be approximately 10%, based on discussions with lubricant dealers, and a maximum market penetration of 100% of freight trucks is possible by 2010, so 90% of trucks could benefit from this strategy. At 50% participation by eligible trucks, the 2010 emission reduction from both engine and drive train lubricants would be 0.8 MMTCE.

REDUCED ENGINE IDLING

Many long-haul trucks idle for extended periods of time in order to heat or cool the cab, or to run electrical appliances. Estimates of the extent of truck idling range from 1,000 to 5,000 hours per year (24). Using a heavy-duty truck engine to power cab amenities is grossly inefficient. A variety of options are available to provide cab heating, cooling and/or electrical supply without idling the engine.

- *Direct-fire heaters* provide heating only to the cab and/or the engine, and have been available for many years. Common in marine applications, they use a small combustion flame to supply heat through a heat exchanger.
- An *auxiliary power unit* (APU) is mounted externally on the truck cab and consists of a small combustion engine equipped with a generator and heat recovery to provide electricity and heat. Electricity from the APU can be used to power an air-conditioning unit for the cab and sleeper. APUs also have the advantage of continuing to heat in case of an engine breakdown while not draining battery power.
- *Automatic engine idle systems* start and stop the truck engine automatically in order to maintain a specified cab temperature, or to maintain minimum battery voltage. Drivers typically activate the system in the evening and program a desired temperature range, then the engine will start and shut off automatically in order to run heating or air conditioning.

Fuel Economy Impact

There is little information on the hours a truck spends idling per year. EPA currently uses an estimate of 2,400 hours per year (8 hours per day, 300 days per year) on average. Argonne National Laboratory uses an estimate of 1,830 hours per year. Lacking better information, we use an estimate of 2,400 hours for this analysis. We assume a heavy-duty diesel engine consumes 0.6 gallons of fuel per hour of idling without the air conditioner running, and 1.0 gallon per hour with air conditioning (12).

If a direct-fired heater is used to heat the cab in cooler months (consuming 0.14 gallons per hour) and idling the truck engine is used for cooling in warmer months, annual fuel use can be reduced by 552 gallons of diesel annually, or 3.4% of total fuel use. Using an APU to provide both heating and cooling (at an average of 0.2 gallons of diesel per hour) saves 1,440 gallons per year or 8.9% of total fuel consumption.

The fuel savings using automatic engine idle systems can vary greatly depending on local environmental conditions. In very cold or hot weather, the engine will start frequently in order to maintain cab temperature. In mild weather, the engine may rarely start. Both Detroit Diesel and Cummins estimate that users of these systems will reduce idling time by a minimum of 50%, though some users have reduced idling by 80%. Using 50% idling reduction as a conservative estimate, automatic engine idle systems will save 960 gallons per year or 5.9% of total fuel use.

Market Penetration and National Emissions Impact

Potential users of this strategy include all trucks that idle for long periods of time. Trucks typically idle for extended periods at truck stops, rest areas or roadsides while drivers sleep or rest. Long-haul trucks account for 63% of all combination truck VMT, and nearly all of these vehicles could benefit from idling reduction strategies (13).

All anti-idling devices currently have low market share. Truck owners have identified safety concerns, retrofitting costs, and unknown reliability as reasons for their reluctance to install direct-fire heaters (24). While they have been available for many years in the U.S., their market penetration is limited to approximately 5% of combination trucks, according to manufacturers of the devices. (By comparison, over 55% of European long-haul trucks are reportedly equipped with cab heaters.) At 50% participation, this strategy would reduce carbon emissions by 0.9 in 2010. APUs are a newer technology. Device manufacturers report that their current market penetration is near zero. Achieving 50% participation by eligible trucks in 2010 would reduce carbon emissions by 2.6 MMTCE.

Some drivers have been reluctant to use automatic engine idle systems because the starting engine can be disruptive when sleeping in the cab at night. Detroit Diesel first offered the Optimized Idle system in 1997, and approximately 62,000 vehicles currently have it. Cummins began offering their ICON system as an OEM option this year, and reports that approximately 20% of new long-haul trucks are choosing the option (we estimate approximately 19,000 trucks). No other engine manufacturers currently offer an automatic engine idling system. Thus, we estimate that approximately 12% (81,000 out of 671,000) of *long-haul* combination trucks are using this strategy, representing a current market share of 8% of *all* combination truck VMT (calculated as 12% of the long-haul VMT market share of 63%). If the GFTI increases market share by half of the gap between current and maximum penetration (50% participation), the emission reduction in 2010 would be 1.5 MMTCE.

SPEED REDUCTION

Most trucks can improve fuel economy by reducing highway driving speeds. Motor carriers may adopt a maximum speed policy for their drivers as a way to save fuel expenses. Speed reduction can be implemented through engine speed governors, driver training and electronic engine monitoring. Some fleets have incentive programs that reward drivers who stay below target speeds.

Fuel Economy Impact

Truck fuel economy drops significantly as speed rises above 55 mph. Simulation of long-haul combination truck operation shows that fuel economy drops from 7.1 mpg to 6.5 mpg to 6.1 mpg as maximum speed rises from 60 mph to 65 mph and 70 mph (17). No national data is available on the portion of travel that trucks spend at different operating speeds. A Canadian study estimates that approximately 50% of the mileage of *all* combination trucks occurs at speeds over 55 mph (4). This strategy applies primarily to long-haul trucks, which tend to operate at highway speeds much more than local trucks. We assume that 90% of long-haul truck travel is intercity trips for which speed reductions apply. Interstate speed limits are generally 65 mph to 75 mph. Reducing the freeway driving speed from 70 mph to 65 mph would reduce annual fuel use per truck by 972 gallons (6.0% of the annual total). A reduction from 65 mph to 60 mph would reduce fuel use by 1,228 gallons per year (7.6% of the total).

Market Penetration and National Emissions Impact

The potential for fuel savings through speed reduction is available primarily to trucks on long-haul trips, rather than urban trips where most travel occurs at lower speeds. If long-haul trucks (operating the majority of miles greater than 200 miles from home base) represent the potential market for speed reduction, 63% of combination truck VMT could benefit from this strategy (13).

Interviews with trucking companies suggest that many larger combination truck fleets currently set road speed governors to 65 mph or 67 mph as a way to prevent unlawful speeding (in states where the limit is 65 mph) and to prevent unsafe driving practices. Interviews with trucking companies suggests that a small number of fleets limit speeds as low as 60 mph. We assume that all large combination truck fleets (10 or more trucks) limit operating speeds, with 80% setting maximum speeds at 65 mph and 20% setting maximum speeds at 60 mph. We assume that combination trucks belonging to small fleets and owner operators do not limit operating speeds, and typically operate at 70 mph on intercity highways.

Table 3 shows total VMT by truck range and fleet size (13). Among combination trucks, vehicles representing 14% of VMT (all of small fleet, long-haul travel) could potentially reduce maximum speeds from 70 mph to 65 mph. This strategy would cut carbon emissions by 0.4 MMTCE in 2010 at 50% participation. Vehicles representing 52% of VMT (80% of large fleet, long-haul travel and all small fleet, long-haul travel) could potentially reduce maximum speeds from 65 mph to 60 mph. Carbon emissions would be reduced by 1.8 MMTCE in 2010 at 50% participation.

DRIVER TRAINING AND MONITORING PROGRAMS

Driving practices can have a large impact on fuel economy regardless of truck technological issues. In addition to limiting speed and idling time, drivers can improve fuel economy through their acceleration practices, shifting technique, route choice, use of accessories, and number of stops.

Driver training can be provided in-house (at large fleets), through vocational schools, or by outside consultants affiliated with training organizations. An effective program also includes monitoring of driver performance after training and incentives for drivers who reduce fuel consumption. Data from electronic engine monitors can be used by trainers to review detailed operating patterns with drivers and benchmark performance over time. If properly designed and implemented, incentive programs have been found to be very effective at changing driver behavior. Drivers can be rewarded with money or vacation bonuses, or with other types of incentives like being allowed to drive a more powerful or comfortable truck.

Fuel Economy Impact

ATA's Maintenance Council estimates that the best drivers compared to the worst drivers can improve fuel efficiency by 35% (12). This is the extreme case, however, and most fleets would see more modest improvements. A variety of other studies have estimated that driver training programs result in fuel savings ranging from 5% to 20% (5,6,25). Some of the fuel savings that result from training overlap with other strategies included in this report (reduced idling and speed reduction). We use a conservative 4% fuel economy improvement, assuming that this can be achieved through better acceleration, shifting and route choice practices alone. Large gains are likely for vehicles in urban areas where shifting practices have more influence on fuel economy.

Market Penetration and National Emissions Impact

Driver training and monitoring programs can be adopted by most large and medium-sized fleets. Many smaller fleets lack the resources to implement driver training programs that focus on fuel economy, and we assume the strategy is not applicable to owner-operators and very small fleets (less than 10 trucks). Table 4 shows the distribution of truck VMT by fleet size (13). Assuming that the potential market for driver training and monitoring programs is all trucks in fleets with ten trucks or more, a maximum of 74% of combination truck VMT can benefit from this strategy.

According to ATA, many large fleets have adopted driver incentive programs that include training and monitoring as a way to reduce fuel consumption, although the specific percentage is not known. We assume half of the 25+ truck fleets and none of the 10-24 truck fleets have adopted this strategy, so the current market penetration is 32% of combination truck VMT (half of 49% and 16%). With 50% participation by potential adopters, the annual savings of this strategy would be 270 million gallons of fuel and 0.7 MMTCE emissions in 2010.

SUMMARY

Table 1 summarizes the truck efficiency strategies in terms of current market penetration, maximum market penetration, and emissions reduction in 2010 under a 50% participation rate. The strategy benefits are generally additive, although benefits of the three idling reduction strategies should not be added because they overlap. The last line in the table shows the maximum possible emissions reduction achievable if all strategies are adopted. With 50% of the possible market adopting all strategies, a greenhouse gas emissions reduction of 9.5 MMTCE is possible. This is 10% of the 92 MMTCE in baseline freight truck emissions forecast for that year, or nearly half of the expected combination truck MMTCE increase between 1999 and 2010.

The total reduction in carbon emissions resulting from the Ground Freight Transportation Initiative may be slightly lower than indicated in Table 1 because some strategies may not be completely independent of others, thereby reducing the net benefits. For example, speed reduction will slightly reduce the benefits of improved aerodynamics, and APUs and aerodynamic devices slightly offset the gains from tare weight reduction. This effect is probably quite small, however.

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TABLE 1: SUMMARY OF STRATEGY IMPACTS

Strategy (or variant)	Fuel Savings per Participating Truck	Current Market Penetration (% of VMT)	Maximum Market Penetration (% of VMT)	2010 Reduction in: Fuel Use (million gal)	Emissions (MMTCE)
Tractor Aero Profile (Van Trailer)*	3.6%	52%	65%	65	0.2
Tractor Aero Features (Non-Van Trailer)*	3.5%	18%	35%	65	0.2
Improved Trailer Aerodynamics*	3.8%	0%	65%	345	0.9
Wide-Base Tires	2.6%	5%	100%	415	1.1
Automatic Tire Inflation Systems	0.6%	5%	100%	95	0.3
Tare Weight Reduction	1.8%	14%	64%	153	0.4
Low-Friction Engine Lubricants	1.5%	10%	100%	222	0.6
Low-Friction Drive Train Lubricants	1.5%	70%	100%	74	0.2
Idling Reduction (Direct-Fire Heater)	3.4%	5%	63%	330	0.9
Idling Reduction (APU)	8.9%	0%	63%	936	2.6
Idling Reduction (Automatic Engine Idle)	5.9%	8%	63%	545	1.5
Speed Reduction (70 to 65 mph)	6.0%	49%	62%	136	0.4
Speed Reduction (65 to 60 mph)	7.6%	10%	62%	664	1.8
Driver Training and Monitoring	3.8%	32%	74%	270	0.7
Total Maximum Benefit**				3,439	9.5

* Fuel savings vary by operating range; long-haul shown.

** Only one Idling Reduction strategy (APU) is included in this sum.

TABLE 2: VMT BY TRUCK BODY TYPE AND OPERATING RANGE (MILLIONS)

	Local		Long-Haul		Total	
	VMT	Percent	VMT	Percent	VMT	Percent
Combination Trucks						
Van Trailer	16,718	17%	48,376	48%	65,094	65%
Non-Van Trailer	20,933	21%	14,881	15%	35,814	35%
All Trailer Types	37,651	37%	63,256	63%	100,908	100%

TABLE 3: VMT BY DISTANCE FROM HOME BASE (MILLIONS)

		Small Fleets (1-9 trucks)		Large Fleets (10+ trucks)		
Truck Type		Local	Long-haul	Local	Long-haul	Total
Combination	VMT	11,437	12,438	23,306	44,591	91,771
	Percent	12%	14%	25%	49%	100%

TABLE 4: DISTRIBUTION OF COMBINATION TRUCK VMT BY FLEET SIZE

	Fleet Size						
Truck Type	1	2-5	6-9	10-24	25-99	100 +	Total
Combination	11%	10%	5%	9%	16%	49%	100%