Medium- and Heavy-Duty Vehicles

Quick Facts

- Medium-duty vehicles (MDVs) have a vehicle weight of 10,000 to 26,000lbs. Heavy-duty vehicles (HDVs) have a vehicle weight over 26,00lbs.
- Medium- and heavy-duty trucks and buses are responsible for about 16 percent of total transportation energy use and nearly 18 percent of carbon dioxide (CO_2) emissions from transportation.
- Under a business-as-usual (BAU) scenario, energy consumption by trucks is predicted to grow more rapidly than other transportation modes over the next 25 years.
- Studies show that technologies to decrease fuel consumption can have a measurable impact on both short- and long-term fuel use and GHG emissions.
- The U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration (NHTSA) recently proposed a set of complementary CO_2 emission and fuel consumption standards, the first regulation of this type in the U.S. for medium- and heavy-duty vehicles.

Background

Although the exact labels sometimes differ, medium-duty vehicles (MDVs) are those vehicles with a gross vehicle weight of 10,000 to 26,000 pounds. The largest of this group (Class 6 trucks) are also referred to as medium heavy-duty trucks.[1] Heavy-duty vehicles (HDVs) have a gross vehicle weight over 26,000 pounds.

The U.S. Department of Transportation (DOT) uses the following system of vehicle classes to group light-, medium-, and heavy-duty vehicles. This classification system is based on Gross Vehicle Weight Rating (GWVR), which is the weight of the vehicle while empty plus the maximum allowed weight from a cargo load.

Table 1: Description of Vehicle Weight Classes

Size Class	Gross Vehicle Weight Rating (GWVR)	Vehicle Registration (2006)	Characteristics	
Class 1 and 2	Less than 10,000 lb	234,200,000	Light-duty vehicle, most have gasoline engines, most are for personal use	Pickups, small vans, SUVs
Class 3	10,001 – 14,000 lb	690,000	Medium-duty vehicle, gasoline or diesel engine, single rear axle, commercial use	Delivery trucks, ambulances, small buses
Class 4	14,001 – 16,000 lb	290,000		
Class 5	16,001 – 19,500 lb	17,000		

Class 6	19,501 – 26,000 lb	1,710,000		
Class 7	26,001 – 33,000 lb	180,000	Heavy-duty vehicle, gasoline or diesel engine, two or more rear axles, commercial use	Tractor trailers, school and transit buses, refuse trucks
Class 8*	33,001 – 80,000 lb	2,150,000	Heavy-duty vehicle, almost all have diesel engines, two or more rear axles, commercial use	

* Class 8 is divided into two sub-groups: class 8a, which includes dump and refuse trucks, fire engines and city buses, and class 8b, which consists of tractor-trailers. A tractor is defined as a highway vehicle that is designed to tow a vehicle, such as a trailer or semitrailer. The majority of Class 8 vehicles are Class 8b tractor-trailers (1,720,000 registered vehicles in 2006).

Source: National Research Council (NRC), Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, 2010.

Unlike light-duty vehicles, the majority of which are for personal use, there is a range of uses for medium- and heavy-duty vehicles in all sectors of the economy. Some carry passengers, such as urban transit buses, while others move goods across the country. Some vehicles are used primarily on high-speed highways with few stops, while others operate on lower speed urban roads in stop-and-go traffic. The top three uses for medium- and heavy-duty vehicles are construction, agriculture, and “for hire” or transportation of freight.[2] (See also Climate Techbook: Freight Transportation.)

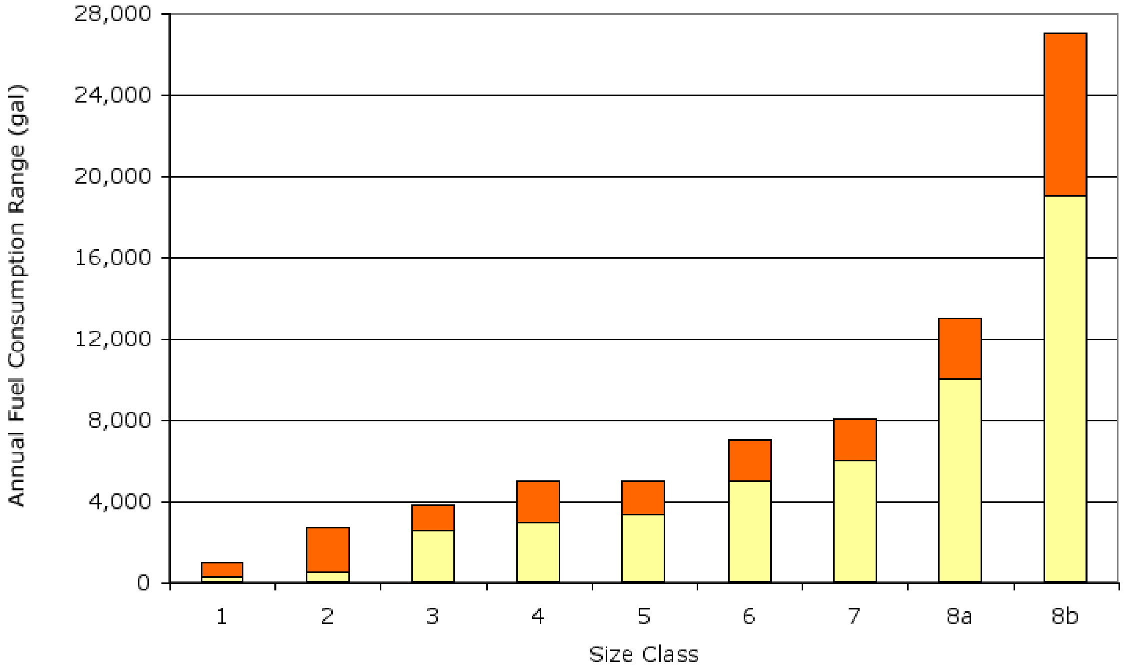
The manufacture and distribution of medium- and heavy-duty vehicles is dependent on a network of suppliers, subcontractors, and other service industries. For example, a major vehicle manufacturer makes the chassis and powertrain,[3] but a separate body or equipment builder determines the final vehicle configuration. The fuel consumption of a medium- or heavy-duty vehicle depends on the decision made by these different actors over the production process. This approach is used for vehicles such as school buses, utility trucks, and delivery trucks and is unlike the manufacture of light-duty vehicles, where automakers are responsible for virtually all aspects of vehicle design (although many parts are manufactured by outside suppliers).

Sales of medium- and heavy-duty vehicles have declined by 30 percent, over a five-year period from 2004 to 2009, although the percent changes differ by size class.[4] This decline can be attributed to the economic downturn and more stringent diesel emission requirements. For example, sales of Class 8 trucks, which have the highest yearly sales among medium- and heavy-duty vehicles, dropped by nearly 50 percent from 2006 to 2007. This change can partly be attributed to an increase in vehicle price due to new emission control devices, which also lowered engine efficiency. The decrease in new engine efficiency may make it difficult for truck owners to upgrade if fuel prices increase, unless future engines can become more energy efficient and comply with emission control requirements at the same time. Sales for Class 8 vehicles continued to decrease in 2008, although to a lesser extent, in part due to the economic recession.[5]

Energy Use and Emissions

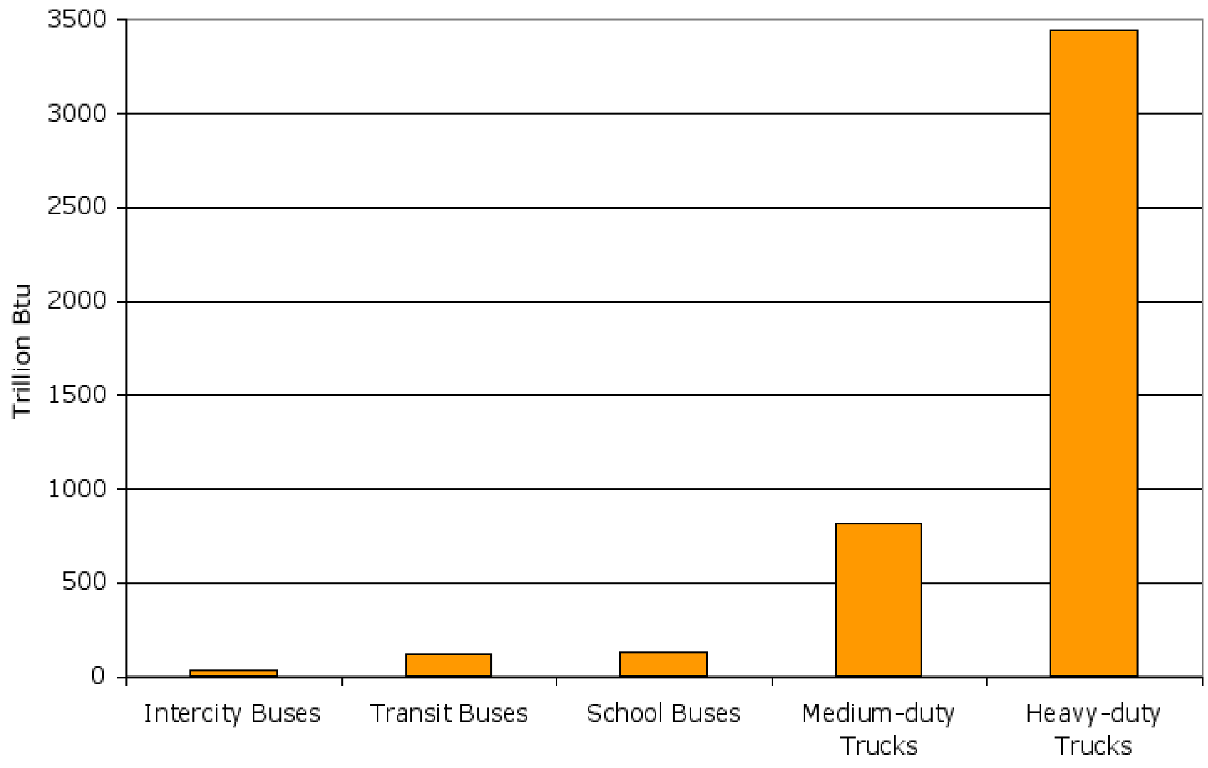
Medium- and heavy-duty trucks and buses are currently responsible for about 16 percent of total transportation energy use (4,525.5 trillion Btu) and nearly 18 percent of the carbon dioxide emissions from transportation in 2009.[6] Although class 8 trucks are only 42 percent of the heavy- and medium-duty truck fleet, they account for most of the fuel consumed (78 percent).[7]

Figure 1: Annual Range in Vehicle Fuel Consumption (gal), by size class



Source: NRC, Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, 2010.

Figure 2: Total Energy Use (trillion Btu) by Mode, 2009

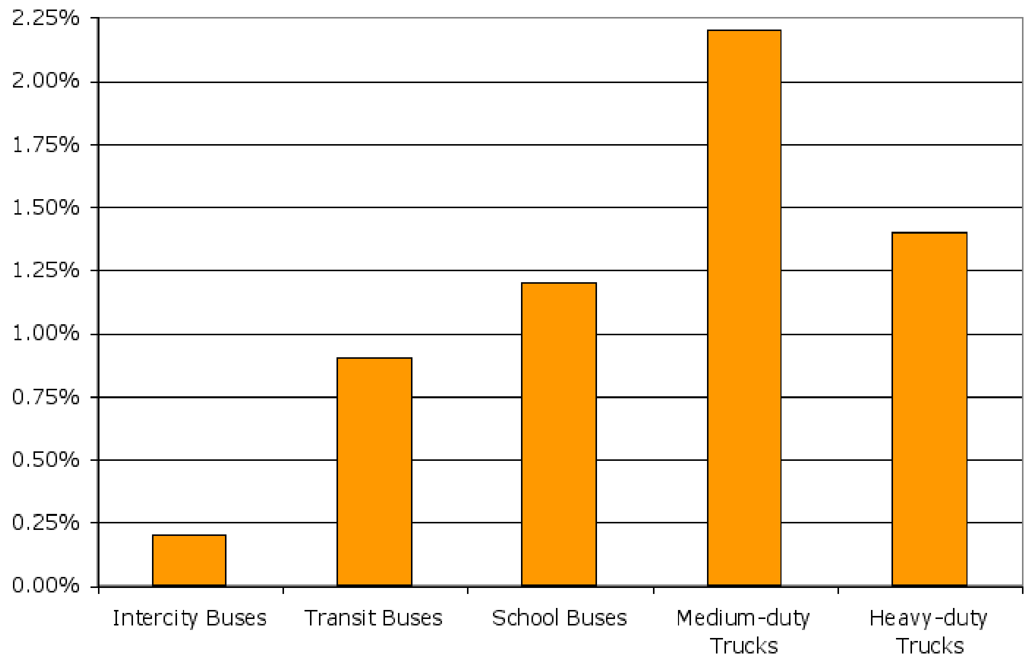


Source: U.S. Department of Energy (DOE) Energy Information Administration. Annual Energy Outlook, 2011.

From 1970 to 2003, energy consumption by heavy trucks grew at a rate of 3.7 percent annually. In comparison, passenger car energy consumption grew 0.3 percent annually over the same period. The divergence in growth rates is a function of a faster increase in miles driven and, to a smaller extent, improvements in car fuel economy. However because medium- and heavy-duty vehicles are designed to move goods, a more accurate measure of truck efficiency is in terms of the energy used to move a ton of goods over a given distance – for example, gallons of diesel or gasoline per ton-mile. From 1975 to 2005, fuel consumption per ton shipped over a given distance (per ton-mile) has decreased by more than half; the rate of improvement has slowed since then, in part due to pollution control requirements that have reduced engine efficiency.[8]

Under a BAU scenario, energy use by medium- and heavy-duty freight trucks is predicted to grow over the next 25 years than other transportation modes.

Figure 3: Average Annual BAU Growth in Energy Use by Mode, 2009-2035



Source: U.S. DOE Energy Information Administration. Annual Energy Outlook 2011.

A study by the National Academy of Sciences found that the best way to calculate fuel consumption for medium- and heavy-duty vehicles is to use load-specific fuel consumption (LSFC), which is measured in gallons of fuel per load-tons per 100 miles. There is an inverse relationship between load-specific fuel consumption and load: generally the higher the load the vehicle carries, the lower the LSFC.[9] As mentioned previously, trucks and buses are load-carrying vehicles with fuel consumption depending on the weight of the load being carried. A loaded HDV can weigh more than double the empty weight of the vehicle. In comparison, a loaded light-duty vehicle weighs only 25 to 35 percent more than its empty weight.[10] Thus, the day-to-day fuel consumption of a HDV can vary significantly, depending on the load being carried.

Technologies to Reduce Fuel Consumption

There is a range of technologies to reduce fuel consumption in medium- and heavy-duty vehicles. The specific technologies used will depend on vehicle size, type, and use.

Powertrain technologies: The powertrain is a group of components that includes the vehicle engine and transmission. The following powertrain technologies can be used to lower fuel consumption:

- Diesel engines: Diesel engines used in MDV and HDVs are highly efficient, turbocharged, direct fuel injected, and electronically controlled. Nevertheless there are a number of technologies that be used to reduce fuel consumption, such as dual turbochargers[11] used in a series configuration and variable-valve actuation.[12]

- Gasoline engines: Gasoline engines are used in Class 2-6 vehicles. These engines can benefit from technologies to reduce fuel consumption: variable-valve actuation and cylinder deactivation,[13] direct injection, turbocharging and downsizing, and electrically driven accessories (rather than mechanically). With some changes, these engines can be configured to use natural gas, propane, hydrogen, ethanol, methanol, and other lower-carbon intensity fuels.[14]
- Transmission improvements: Transmission improvements include designs that increase the efficiency of the transfer of power from the propulsion system to the wheels (e.g., automated manual transmissions, Lepelletier transmissions) and designs that allow the engine to operate at higher efficiencies (e.g., increases in the number of speeds, continuously variable transmissions).
- Hybrid powertrains: There are two main types of hybrid technologies that can be used in medium- and heavy-duty vehicles. The first, a hybrid electric, uses an electric motor and generator, an energy storage device and power electronics, as well as an internal combustion engine. Hybrid electric vehicles are use across almost all weight classes, from light-, medium-, and heavy-duty vehicles. Since they provide little benefit at steady highway cruising, they are not as useful for long-haul trucks. The second, a hydraulic hybrid, has a hydraulic system using pressurized fluid, instead of electric power, as an additional power source alongside the engine. The hydraulic system is suitable for vehicles such as refuse trucks, transit buses, and delivery vehicles, which operate in stop-and-go traffic.[15] The fuel consumption benefits of these technologies will depend on the vehicle use and duty cycle.

Alternative fuels: Lower-carbon fossil fuels, including natural gas and biodiesel blends, can reduce conventional air pollutants as well as GHG emissions in medium- and heavy-duty vehicles.

Box 1: The U.S. Department of Energy's Clean Cities Program recommends the following currently available fuel and powertrain alternatives by vehicle type

Vehicle Type	Alternatives
School Bus	Compressed natural gas (CNG) or propane is the most popular. Hybrid electric and plug-in electric hybrids are also available
Shuttle Bus	CNG, propane, hybrid electric power, and fuel cells
Transit Bus	Hybrid-powered transit buses, CNG and liquefied natural gas (LNG). There are some fuel cell demonstrations currently in progress.
Refuse Truck	CNG, Biomethane from landfill gas. Good application for hybrids, particularly hydraulic hybrid systems, because of stop-and-go operation.
Tractor	Diesel electric hybrids (but not for long-haul trucks), CNG and LNG operation available for some models
Van	Hybrids and plug-in hybrids. Vans that run on a set route (e.g., package delivery service) are well suited for all-electric. CNG and propane are also available.
Vocational Truck	CNG, propane, all-electric, and hybrid vehicles

Source: U.S. DOE. "Clean Cities' Guide to Alternative Fuel and Advanced Medium- and Heavy-Duty Vehicles." http://www.afdc.energy.gov/afdc/pdfs/47984.pdf. Accessed 16 May 2011.

Other technologies and techniques to improve vehicle fuel economy include the following:

- Aerodynamics: Techniques that reduce aerodynamic drag improves fuel efficiency by reducing the amount of work needed to move the vehicle. For example, a heavy-duty truck (tractor-trailer) operating on uncongested highways can save about 15 to 20 percent in fuel consumption from aerodynamic improvements. [16]
- Rolling resistance: About one-third of the power required to propel a Class 8 truck (at highway speeds, on level roads) can be accounted for by tire rolling resistance. Low rolling resistance tires could reduce the fuel consumption in these vehicles by 4 to 11 percent and to a lesser extent for other size classes.[17]
- Operational measures: Operational measures include more fuel-efficient driving techniques and idle

reduction. For tractor-trailers, these can reduce fuel consumption by an estimated 7 percent.[18]

Box 2: Efficiency Improvements for Tractor-trailers

Although tractor trailers (Class 8 trucks) already have highly efficient diesel engines, there remain potential improvements in engine design (highlighted above) that can help reduce fuel consumption. Reduction in aerodynamic drag can be obtained from better cab shaping, replacing mirrors with cameras, closing the gap between cab and trailer, and adding a short boat-tailed rear. Other methods to reduce fuel consumption include: improving freight logistics and driving techniques, using higher capacity trucks, reducing truck idling, and improving product packaging so products need less space and more products can be carried in one trip. One importance means of reducing truck idling is the use of cab heaters and other devices that allow drivers to sleep in the truck while parked without having to run the main engine.

Source: Greene, D. and S. Plotkin. Reducing Greenhouse Gas Emissions from U.S. Transportation. Prepared for the Pew Center on Global Climate Change, 2011.

GHG Reduction Potential

A study by National Academy of Sciences evaluated a wide range of technologies and estimated the potential fuel consumption reduction when applied to six different medium- or heavy-duty vehicles. The study estimated that fuel consumption from tractor-trailers (Class 7 and class 8 trucks) could be cost-effectively reduced by 51 percent in the 2015 to 2020 time frame.[19]

Table 2: Fuel Consumption Reduction and Cost-Effectiveness for New Vehicles in 2015

Vehicle Class	Fuel Consumption Reduction (%)	Capital Cost ($)	Breakeven Fuel Price ($/gal)
Tractor-trailer	51	84,600	1.1
Class 6 box truck*	47	43,120	4.2
Class 6 bucket truck*	50	49,870	5.4
Refuse truck	38	50,800	2.7
Transit bus	48	250,400	6.8
Motor coach	32	36,250	1.7

* A box truck has a “box-shaped” cargo area; a bucket truck has an aerial work platform with a bucket that uses a hydraulic lifting system.

Source: NRC. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, 2010.

A joint study by the Northeast States Center for a Clean Air Future and the International Council on Clean Transportation found similar results. In that case, fuel consumption for new tractor-trailers could be reduced by 20 percent and up to 50 percent from 2012 to 2017. Over the long term, this would reduce fuel consumption and CO_2 emissions from these trucks by 30 percent in 2022 from BAU levels and 39 percent by 2030.[20]

Policy Options

Vehicle Standards: In October 2010, the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) proposed a set of complementary standards as part of the "Heavy-Duty National Program." The EPA expects to issue the final rule in August 2011. The program includes CO_2 emission standards and fuel consumption standards, proposed by EPA and NHTSA respectively. The standards cover model years 2014 to 2018 and would apply to any vehicle with a gross vehicle weight at or above 8,500lbs: tractor-trailers, heavy-duty pickup trucks and vans, and vocational vehicles, which include buses and refuse and utility trucks. The standards use a load-based metric to account for the fact that these vehicles are used primarily for transporting goods and equipment, in addition to passengers, and thereby use more fuel and emit more CO_2 when compared to moving lighter loads.

For tractor-trailers, the CO_2 emission and fuel consumption standards are expected to achieve 7 to 20 percent reduction in GHG emissions in MY 2017, depending on size class and type, from a 2010 baseline.[21] For heavy-duty pickup trucks and vans, MY 2018 standards would result in a reduction in GHG emissions of 17 percent for diesel vehicles and 12 percent for gasoline vehicles. For vocational vehicles, the standards would achieve an emission reductions from seven to 10 percent, also depending on size class, for MY 2017.[22]

Additional emission standards are also included under the EPA proposal – for HFC emissions from vehicle air conditioner, which would apply to pickups, vans and tractors and for N_2O and CH_4 from all heavy-duty engines, pickups and vans.[23] EPA is currently reviewing comments to the proposed rulemaking, which was released in October 2010.

SmartWay Program: In 2004, the EPA launched the SmartWay Program, a collaboration between government, business, and consumers. The program is designed to promote fuel efficient vehicles, help truck owners and freight transport operators choose efficient vehicles, and save energy and lower operating costs through improved logistics, and thereby reduce GHG emissions and air pollution, improve fuel efficiency, and strengthen the freight sector. The program works with shippers, carriers, truck stops and other related groups and currently has more than 2,600 partners. [24] Before the introduction of vehicle standards (above), the SmartWay voluntary certification program was the main approach to deal with GHG emissions from medium- and heavy-duty vehicles.

The program facilitates the adoption of fuel efficient technologies in the freight sector, using the following methods:

- Certified vehicles: Under the SmartWay program the EPA certifies tractors and trailers based on certain design criteria, including aerodynamic improvements, 2007 or newer engines, and idle reduction technology. These certified vehicles are available from eight major truck manufacturers, which offer at least one model meeting SmartWay specifications.
- Verified fuel savings products: EPA evaluates fuel savings and emission reduction or technologies in the following categories: Idle Reduction Technologies, Aerodynamic Technologies, Low Rolling Resistance Tires, and Retrofit Technologies. To help companies upgrade existing vehicles, the EPA

offers "Upgrade Kits," a group of fuel savings technologies and emission-control devices that reduce GHG emission and other air pollutants. According to EPA estimates, installation of these kits may improve fuel economy up to 15 percent.[25]

- Financing: SmartWay offers financing options that provide companies with the capital to invest in fuel-saving technologies. In 2009, the EPA was awarded $30 million from the American Recovery and Reinvestment Act of 2009 to develop financing programs for trucks, school buses, and non-road vehicles and equipment. In addition, SmartWay provides a clearinghouse web site where trucking companies can apply for private loans for SmartWay Certified Tractor or Certified Trailer or SmartWay approved fuel efficiency technologies.
- Federal Excise Tax Exemption: Under the Energy Improvement and Extension Act (EIEA) of 2008, retailers of certain fuel efficiency technologies (idling reduction devices and advanced insulation) are exempt from the federal excise tax.

Other EPA Programs: Other programs coordinated by EPA include the National Clean Diesel Campaign (NCDC) and Clean School Bus USA. Both these programs focus on reducing traditional air pollutants, yet also have the benefit of reducing GHG through strategies that reduce fuel consumption and thereby GHG and tailpipe emissions. National Clean Diesel Campaign works with manufacturers, fleet operators, air quality professionals, environmental and community organizations, and state and local officials to reduce emissions from diesel engines. The program focuses on projects that use diesel technologies, operational strategies and alternative/renewable fuels to reduce emissions and provides grants and funding for technology adoption.[26]

Clean School Bus USA is a public-private environmental partnership that tries to reduce children's exposure to diesel exhaust and air pollution from diesel school buses. The program focuses on reducing emissions through anti-idling strategies, engine retrofits, clean fuels, and bus replacement.[27]

DOE Clean Cities: Clean Cities is a government-industry partnership, sponsored by DOE and designed to reduce petroleum consumption in the transportation sector. The program works with local and state organizations to adopt technologies that reduce fuel consumption, such as:

- Alternative and renewable fuels
- Idle-reduction measures, targeted to buses and heavy-duty trucks
- Fuel economy improvements
- New transportation technologies

Clean Cities facilitates the adoption of these technologies by providing funding and financial incentives to support projects.[28] Its network includes almost 90 coalitions and local partners, which represent about three quarters of the U.S. population. Among the program's accomplishments is increasing the number of alternative fuel transit buses from 6 percent in 1997 to 20 percent in 2007.[29]

Box 3: Case Studies

UPS - UPS has the largest commercial fleet in the United States with over 93,000 trucks in its fleet.[30] Its alternative fuel fleet includes more than 1,900 compressed natural gas, liquefied natural gas, propane, hydrogen fuel cell, electric and hybrid electric vehicles.[31] In 2006, the company was the first to test a full-series hydraulic hybrid truck, built through a partnership between U.S. Environmental Protection Agency (EPA), Eaton, International Truck and Engine, and the U.S. Army National Automotive Center. A hydraulic hybrid uses two power sources to propel the vehicle – a small, fuel-efficient diesel engine and hydraulic components, which removes the need for a mechanical transmission and drive train.[32]

The company has also used a variety of operational measures to reduce vehicle fuel consumption. UPS uses careful routing to avoid unnecessary driving, including the company's famous "right turn policy," which reduces the number of left turns a driver must make. According to company estimates, this policy reduced delivery routes by 30 million miles and saved 3 million gallons of gas.[33] The company also has an anti-idling program that reduced the amount of time delivery vehicles idle by 24 minutes per driver per day.[34]

FedEx - FedEx operates the second largest commercial fleet in the United States, with over 65,000 vehicles.[35] In 2000, FedEx partnered with Environmental Defense Fund (EDF) to begin developing more efficient delivery trucks. The company uses a variety of alternative energy vehicles, and as of 2010, has one of the largest hybrid fleets, with nineteen all-electric vehicles in London, Paris, and Los Angeles.[36] The company has a goal of improving the efficiency of the entire fleet by 20 percent by 2020 from 2008 levels. It plans to use a number of strategies including route optimization, smaller, more efficient vehicles, and couriers who delivery packages by foot or bicycle in New York City and London.[37]

New York City Transit - In 2000, NYC Transit was the first public transportation system to use ultra-low sulfur fuel, which reduces emissions from diesel buses. The agency also has the largest hybrid-electric bus fleet in the world, more than 1,000 vehicles in 2009. In a study by the National Renewable Energy Laboratory, these hybrid-electric buses had an average fuel economy that was 34 percent higher than that for diesel buses.[38]

Maryland Hybrid Truck Initiative - The Maryland Hybrid Truck Initiative is a partnership between the Maryland Energy Administration (MEA), the U.S. Department of Energy, Maryland Clean Cities, ARAMARK, Efficiency Enterprises, Nestlé Waters North America, Sysco Corporation, and United Parcel Service. Launched in early 2011, the Initiative aims to facilitate the deployment of heavy-duty hybrid truck, including 143 Freightliner hybrid electric vehicles (HEVs) and Freightliner Custom Chassis hydraulic hybrid vehicles (HHVs).[39]

State Programs: Thirty-nine states have polices that affect medium- and heavy-duty vehicles. These policies include the following:

- Financial Incentives: tax credits for vehicle retrofit, new vehicle purchase, and refueling infrastructure; grants for fleet modernization, truck stop electrification, and retrofits;
- Idle Reduction: fines for excessive idling; weight exemptions for vehicles containing idle reduction technology;

- State Fleet Procurement: mandates to alternative fuel vehicles and retrofit existing vehicles to be more fuel-efficient; and
- R&D: funding for research and development.

For a map of the states and a description of their policies, see "U.S. States and Regions: Medium- and Heavy-Duty Vehicle Policies"

California Standards: In addition to some of the programs mentioned above, the State of California also regulates heavy-duty truck under its 2006 Global Warming Solutions Act. The program is designed to reduce GHG emissions by improving tractor and trailer aerodynamics and tire rolling resistance, using EPA's SmartWay technologies. The first part of the program began in January 2010; new MY 2011 tractors and trailers purchased after this time must be SmartWay certified. Older vehicles will need to be retrofitted with SmartWay technologies over time, beginning in January 2013.[40]

Related Business Environmental Leadership Council (BELC) Company Activities

Cummins

Daimler

GE

John Deere

Johnson Controls

Toyota

Related Pew Center Resources

Greene, D. L., & Plotkin, A. (2011). *Reducing Greenhouse Gas Emissions From U.S. Transportation*. Arlington: Pew Center on Global Climate Change.

Climate TechBook. Freight Transportation

Further Reading / Additional Resources

U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality. SmartWay.

Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

---

[1] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation

Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[2] See Table 5-7, in U.S. Department of Energy (DOE). Transportation Energy Data Energy Book 29. Oak Ridge, TN: Oak Ridge National Laboratory, 2010.

[3] The powertrain consists of a group of components that includes the vehicle engine and transmission

[4] U.S. DOE. 2008 Vehicle Technologies Market Report. Golden, Colorado: National Renewable Energy Laboratory. July 2009; and Table 5-3, in U.S. Department of Energy (DOE). Transportation Energy Data Energy Book 29. Oak Ridge, TN: Oak Ridge National Laboratory, 2010.

[5] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[6] U.S. DOE. Annual Energy Outlook 2011. http://www.eia.doe.gov/forecasts/aeo/index.cfm. 26 April 2011. Accessed 15 May 2011.

[7] National Renewable Energy Laboratory. "Vehicle Technologies and Program Market Data." http://www.nrel.gov/analysis/market_re_data_vehicle.html. 30 June 2010. Accessed 15 May 2011.

[8] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[9] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[10] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[11] In turbo-charging, the intake air is compressed with some of the exhaust gas energy, which would otherwise be wasted. Thus, more air can be taken in and more engine power can be produced from a given engine size.

[12] Variable valve actuation alters the degree of lift and/or the timing of valve opening and closing within an internal combustion engine.

[13] Cylinder deactivation shuts down some of the cylinders in a multi-cylinder engine when they're not needed, thereby increasing fuel economy during periods of light load.

[14] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[15] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[16] Greene, D. and S. Plotkin. Reducing Greenhouse Gas Emissions from U.S. Transportation. Prepared for the Pew Center on Global Climate Change, 2011.

[17] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[18] Greene, D. and S. Plotkin. Reducing Greenhouse Gas Emissions from U.S. Transportation. Prepared for the Pew Center on Global Climate Change, 2011.

[19] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council,

Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[20] Miller, P., Ed. "Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO2 Emissions." NESCCAF and ICCT, 2009.

[21] The range of possible reductions is due to the different standards depending on cab type and roof type. For example, the gallon per 1,000 ton-mile standard for Class 7, Day Cab, High Roof trucks is 11.4 for MY2017, while Class 8, Sleeper Cab, Low Roof Trucks have a standard of 6.3 gal/1,000 ton-mile.

[22] U.S. EPA. "EPA and NHTSA Propose First-Ever Program to Reduce Greenhouse Gas Emissions and Improve Fuel Efficiency of Medium- and Heavy-Duty Vehicles: Regulatory Announcement." October 2010.

[23] Green Car Congress. "NHTSA, EPA propose first greenhouse gas and fuel efficiency standards for heavy-duty trucks and buses." http://www.greencarcongress.com/2010/10/hd-20101025.html. 25 October 2010. Accessed 12 May 2011.

[24] U.S. EPA. SmartWay. http://www.epa.gov/smartway/. Accessed 13 Apr 2011.

[25] U.S. EPA "Benefits: Upgrade Kits." http://www.epa.gov/smartway/transport/what-smartway/upgrade-kits-benefits.htm Accessed 12 May 2011.

[26] U.S. EPA. "NCDC: Basic Information." http://www.epa.gov/cleandiesel/basicinfo.htm. 15 April 2011. Accessed 12 May 2011.

[27] U.S. EPA. "Clean School Bus USA: Basic Information." http://www.epa.gov/cleanschoolbus/basicinfo.htm. 20 October 2007. Accessed 13 May 2011.

[28] U.S. DOE. "Clean Cities: About the Program." http://www1.eere.energy.gov/cleancities/about.html. 6 May 2011. Accessed 13 May 2011.

[29] U.S. DOE. "Clean Cities: Goals, Strategies, and Top Accomplishments." May 2010.

[30] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[31] UPS. "Alternative Fuels Drive UPS to Innovative Solutions." http://responsibility.ups.com/Environment/Alternative+Fuels. Accessed 13 April 2011.

[32] UPS. "Saving Fuel: Alternative Fuels Drive UPS to Innovative Solutions." http://www.pressroom.ups.com/Fact+Sheets/Saving+Fuel%3A+Alternative+Fuels+Drive+UPS+to+Innovative+Solutions, 25 Feb 2011. Accessed 13 April 2011.

[33] Davis, Scott. Speech: "Right Turn at the Right Time." http://www.pressroom.ups.com/About+UPS/UPS+Leadership/Speeches/D.+Scott+Davis/Right+Turn+at+the+Right+Time. Accessed 16 May 2011.

[34] UPS. "Saving Fuel: The Benefits of No Idling" http://www.pressroom.ups.com/Fact+Sheets/Saving+Fuel%3A+The+Benefits+of+No+Idling. 10 Mar 2011. Accessed 13 April 2011.

[35] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council, Transportation Research Board. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: National Academies Press, 2010.

[36] FedEx. "Alternative Energy: Cleaner Vehicles." http://about.fedex.designcdt.com/corporate_responsibility/the_environment/alternative_energy/cleaner_vehicles, 3 January 2011. Accessed 13 April 2011.

[37] Environmental Defense Fund. "EDF and FedEx: Driving Toward Cleaner Trucks." http://business.edf.org/casestudies/edf-and-fedex-driving-toward-cleaner-trucks. Accessed 13 April 2011.

[38] Barnitt, R. and K. Chandler. "New York City Transit (NYCT) Hybrid (125 Order) and CNG Transit Buses: Final Evaluation Results." Boulder, CO; NREL, 2006.

[39] Maryland Hybrid Truck Initiative. http://www.marylandhti.com. Accessed 13 April 2011.

[40] California Air Resources Board. "Presentation: Heavy-Duty Vehicle Greenhouse Gas (Tractor-Trailer GHG) Emission Reduction Regulation." http://www.arb.ca.gov/cc/hdghg/hdghg_overview_web_pres.pdf. 21 March 2011. Accessed 12 May 2011.