**Invited Testimony for the U.S. House Committee on Science and Technology**
**Energy and Environment Subcommittee**

**Prepared Statement of**
**Terry Penney**
**Technology Manager, Advanced Vehicle Technologies**
**National Renewable Energy Laboratory**
**Golden, Colorado**
**June 10, 2008**

Mr. Chairman, I want to thank you for providing this opportunity to talk about the status and potential of heavy-duty hybrid trucks in the United States, and the research and development and policy support that is needed to give them a more prominent role in the marketplace. As groups like the Hybrid Truck Users Forum have recently noted, hybrid trucks are right "on the cusp" of production in medium- and heavy-duty commercial markets, and there is much we can do to tip the balance in their favor, and in ours, in terms of achieving greater energy security and lessening our reliance on imported fuels.

I am the Technology Manager for Advanced Vehicle Technologies in the Renewable Fuels Science and Technology directorate at the National Renewable Energy Laboratory in Golden, Colorado. NREL is the U.S. Department of Energy's primary laboratory for R&D in renewable energy and energy efficiency technologies, and we are dedicated to helping the nation develop a full portfolio of technologies that can meet our energy needs.

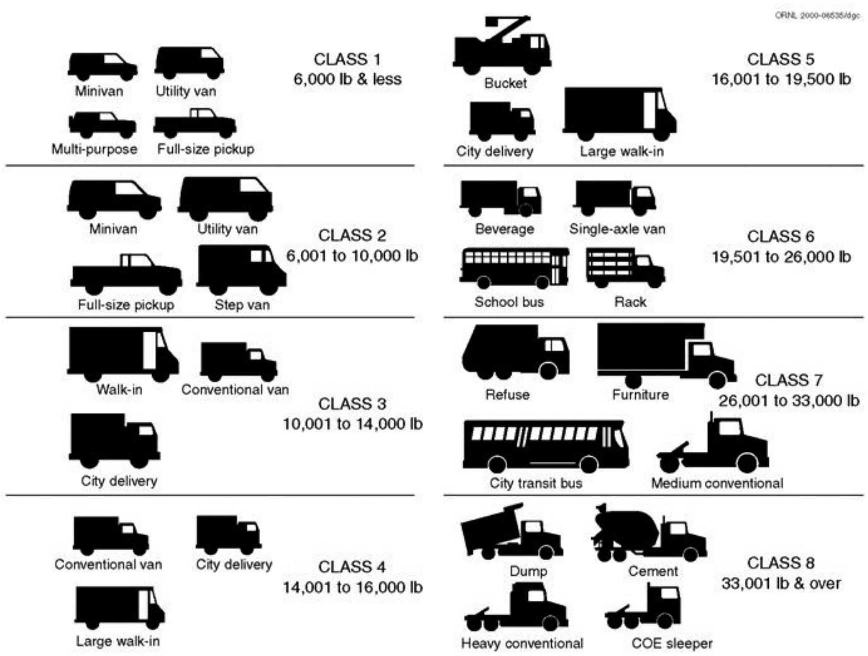
It is an honor to be here and to speak with you today. I want to commend the committee for its interest in exploring ways to reduce the use of imported petroleum in the commercial sector, curb emissions associated with burning fossil fuels for transportation, and increase the competitiveness of U.S. manufacturers and truck fleets through greater use of hybrid trucks.

Despite the progress we have achieved in fuel efficiency and emissions reductions over recent years, the costs associated with producing and operating our heavy-duty fleets have risen at alarming rates. There exists today great potential from several heavy-duty hybrid truck technologies to significantly reduce fuel consumption and emissions. This should in turn improve the economic picture for U.S. truck manufacturers, suppliers, fleets, and customers alike.

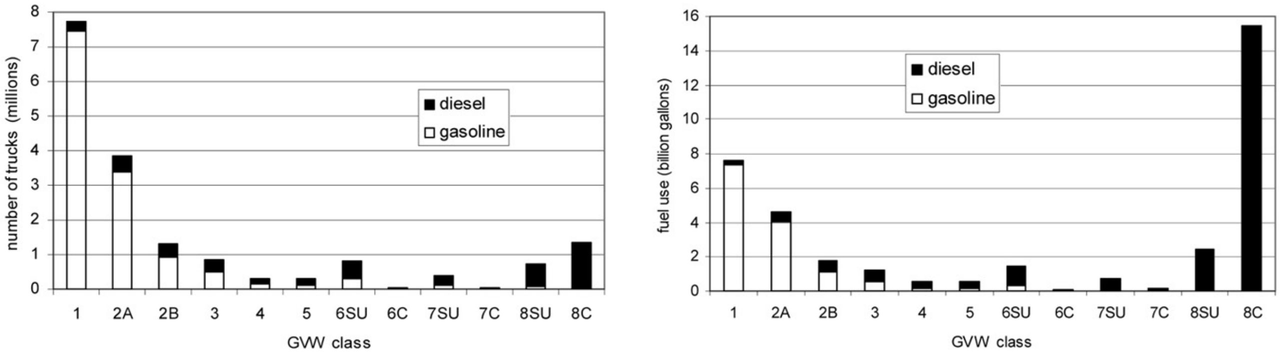
First, a little background. Approximately 80 percent of all the goods transported in the United States today are moved by truck. In all, the United States consumed about 140 billion gallons of gasoline and about 40 billion gallons of diesel fuel for on-road transportation in 2004, according to the Department of Energy. The U.S. now imports more than 60 percent of the crude oil it uses. Retail gasoline and diesel fuel prices have reached record highs in recent months, and the retail price of diesel is well over $4 per gallon in most parts of the nation.

Given the current situation, we see considerable potential for hybrid trucks to reduce fuel use, and thus costs, from 5 percent at minimum, to as much as 50 percent to 60 percent at the high end. Although exact reductions depend on the actual use of the truck – and specifically, the way it's driven and the distance traveled between stops – there is virtually no truck application that cannot benefit from a hybrid drive train and related system improvements. Potential applications include shuttle and school buses, military vehicles, utility trucks, bucket trucks, beverage delivery and parcel delivery trucks, refuse haulers, and some large Class 8 vehicles. Because trucks generally use much more fuel per year than passenger vehicles, the overall savings potential is very significant (see illustrations that follow).

Plug-in hybrid trucks are on the horizon, as well. Plug-in hybrid systems could benefit not only industry and the environment, they perhaps could alter the nature of our utility grids, by providing stored energy and a form of mobile distributed energy generation. Before we can begin to realize these benefits widely, however, we must address some remaining issues surrounding hybrid and plug-in hybrid technologies.




**Truck classes** (courtesy of Oak Ridge National Laboratory, modified from an illustration in the Commercial Carrier Journal, "Industry Trends and Statistics," July 1984)




**The graph on the left shows the number of commercial trucks (Classes 1-8) in use; the graph on the right shows their fuel use** (courtesy of Oak Ridge National Laboratory, 2006)

## Heavy-Duty Hybrid Trucks: Some Major Issues

An article in the April 27, 2008, edition of the New York Times noted that commercial vehicles, particularly those making frequent stops, should be the "killer" application for hybrid technologies, because hybrids often work best in the kind of stop-and-go conditions that delivery trucks and refuse haulers experience. Despite this potential, there remain relatively few hybrid trucks on the road. The primary reasons for this are the costs of the hybrid systems, the limited commercial production to date, and the need to further improve the economics and performance of energy storage, power electronics, auxiliary loads and engine idling systems.

Light-duty hybrid-electric vehicles (HEVs), such as the Toyota Prius and Ford Escape Hybrid, have gained public attention and some market momentum in recent years. The added price of hybrid systems have been somewhat offset by tax policies at the federal and the state levels. It should be noted that light duty and heavy duty applications can be much different in overall design and individual components. The price premium for hybrid systems will be proportionally greater for large commercial vehicles, because of their size and complexities. These higher costs have slowed widespread acceptance of these technologies, potential fuel savings notwithstanding.

Hybrid technologies improve fuel economy, primarily by turning off the engine when idling, such as when coasting or at a stop. They use batteries and electric motors for short accelerations, recharge the batteries by recovering the energy used in braking, and use batteries for auxiliary loads such as cabin cooling. The combustion engines in HEVs can thus be smaller than those in conventional heavy vehicles. Our fleet testing has shown how overall maintenance and operating costs per mile can also be lower for hybrids, in part because of a decrease in brake replacement costs.

The energy storage system is the most critical component for hybridization and electric vehicles generally. The energy storage system must be affordable, safe, and durable enough to last through the major portion of the vehicle's life. Since vehicles operate at many different climates and temperatures, energy storage systems must be able to perform well at low temperatures and not quickly degrade at high temperatures. Current commercial light duty and heavy duty vehicles use Nickel Metal Hydride (NiMH) batteries, mostly from Japanese manufacturers. Research and development on advanced energy storage systems, such as lithium ion batteries and ultrcapacitors, is expanding, with hybrid electric vehicle systems being seen as a primary use.

One major concern is the domestic production of batteries. Relying on a few foreign sources of battery production (Japan, Korea, China, and France) could increase costs and create new energy security concerns. Domestic production of energy storage materials and U.S.-based manufacturing of energy storage systems should be encouraged.

To increase market acceptance, energy storage systems must be improved to reduce their weight and size. Enhanced power and storage capacity are two other key goals of current R&D.

Improving a hybrid's power electronics system likewise is essential. In some vehicle systems, the power electronics module costs as much as the energy storage system. Boosting the performance and cutting the cost of this system will lead to more favorable economics for hybrid trucks.

Other issues include improving the efficiency and cost-effectiveness of idling reduction technologies. For long-haul trucks especially, there exists considerable opportunity to decrease the effects of aerodynamic drag on the vehicle, primarily through use of lightweight yet strong materials for the truck body, and development of heavy-duty tires with low rolling resistance. Government and industry groups working together through the 21st Century Truck Partnership (21 CT) have found that aerodynamic drag resistance, rolling resistance, drive-train losses, and auxiliary load losses represent fully 40 percent of the total fuel energy used to move a heavy-duty vehicle.

**Potential for Fuel Savings and Emission Reductions**

Commercial vehicles running on diesel fuel can easily tally 75,000 miles in a year and, at $4-plus per gallon, pay $1,000 for just one fill-up. Thus, a relatively modest increase in fuel efficiency – even 5 percent – can have a major financial impact over time. Urban hybrid trucks that make frequent stops and starts could see and up to 60 percent savings in fuels costs, depending on the way the truck is driven and which hybrid system is used. The Environmental Protection Agency (EPA) estimates that a typical delivery truck using a hybrid drive train system could save more than 1,000 gallons of fuel per year in comparison to the fuel used by a similar conventional truck.

Energy recovery is a major benefit of hybridization. By converting the vehicle's dynamic energy into electrical energy during braking, less fuel is spent overall. The benefits of energy recovery will be greatest for urban vehicles with repeated start-and-stop cycles. The hybrid's control system effectively allows for separation of the engine speed from the speed of auxiliary or ancillary devices, which offers many advantages.

Electrification of a truck's auxiliary systems, like heating, air conditioning and entertainment systems, allows the engine to be shut down instead of idling. Again, potential fuel savings is significant, as U.S. trucks idle an average of 1830 hours per year.

In addition, modern long haul trucks are increasingly equipped with automated gearboxes to control the engine speed and save fuel. This has opened up the possibility of introducing "Eco-roll". When no engine power is needed, the gearbox goes into neutral and the engine runs on idle, saving 1 percent to 2 percent of fuel. With electrification, we can shut the engine off during coasting for an additional 1 percent savings. Blending the use of gasoline engine and electric systems allows for added fuel savings.

Another feature is the ability for low-speed moving of the vehicle in electric-only mode. This is useful when going in and out of docks, in harbors, in traffic jams, and so on. Considering projected increases for traffic congestion, this feature could be even more valuable in the future.

Future trucks need to be much more efficient than they are today. Electrification of a truck enables waste heat recovery systems, in which heat can be converted back to energy. Waste heat recovery systems are estimated to reduce fuel consumption about 6 percent to 8 percent. Also, using an electric motor for torque assist can help downspeed the engine, or downsize it, with both alternatives saving fuel.

Fuel savings provide emission reductions as well. A recent study by the CALSTART partnership evaluated the increases in fuel economy and reductions in emissions obtained for a hybrid truck during four driving cycles, compared to a conventional vehicle. The study found that in one driving cycle of 70 miles, lasting 1.5 hours, the hybrid truck showed a 68 percent increase in fuel economy and a 58 percent reduction in hydrocarbons, on a gallons-per-mile basis. A 50 percent decrease in carbon monoxide, a 34 percent reduction in oxides of nitrogen and a 25 percent decrease in particulate matter were also reported. This is significant, because to meet current and upcoming EPA regulations, conventional trucks can lose as much as 5-10% in fuel economy. This is a result of the use of fuel by advanced emission control systems and also from aggressive exhaust gas recovery strategies for lower oxide of nitrogen emissions. Hybrid trucks offer the potential to reduce the overall emission reduction requirements and therefore reduce the accompanying emission control fuel economy penalty.

**Applications for Hybrid Technologies**

Hybrid electric powertrains can be used in many, if not most, of the nation's approximately 18 million commercial vehicles. Stop-and-go short-haul commercial vehicles are well-suited for systems that capture braking energy, assist the engine during frequent accelerations, and turn off the engine during coasting and stops. However, each kind of commercial vehicle presents a different set of demands, which in turn determine the vehicle size, configuration, and duty cycles. As a result, each type is likely to have a different hybrid power-train solution. For example, the duty cycle of a refuse hauler usually consists of a long drive to a neighborhood, followed by repeated short starts and stops and ending with a long drive to a waste site. Rather than using batteries, this application might be ideal for ultracapacitors—devices with enough power to move heavy loads over short distances—while the engine is used to and from the waste site.

Hybrid transit buses are in use today and have demonstrated an average 27% reduction in fuel use. Depending on the climate, about 25% of the fuel used for transit buses is for heating and cooling passengers. School buses can double the fuel economy with hybridization, but today cost twice the $70,000 price tag of a conventional bus. Postal delivery vehicles could benefit significantly from plug-in operation if they could use the engine to reach a neighborhood, then go to all-electric mode while making mailbox-to-mailbox stops.

Many commercial vehicles idle for extended periods during package deliveries, refuse collection, or to operate necessary equipment like fans, extension buckets, backhoes, and related equipment. Altogether, idling of commercial vehicles is estimated to consume more than 2 billion gallons of fuel annually, while producing unwanted emissions.

Long-haul trucks, which operate at fairly constant speeds, have challenges all their own. Long-haul trucks consume nearly 16 billion gallons of diesel fuel annually, with opportunities for increasing fuel economy in this truck class centering around development of more efficient engines, reduction of aerodynamic drag, and use of low-rolling-resistance tires. Biofuels may offer advantages as well. Another promising method of cutting fuel consumption and emissions is to use batteries, or plug in directly to electricity sources, at truck stops. Off-board service to the truck can provide heating and cooling, and electricity for lighting, entertainment and ancillary equipment during mandatory driver rest periods. Such needs today are largely met through idling of the truck's main engine.

In addition, long-haul trucks are being studied in order to determine the benefits of some form of hybridization as well, especially when their routes involve climbing and descending hills. Such applications could ultimately deliver huge fuel savings, despite their relatively small gains in efficiency.

**Today's Market Issues**

Promising developments are on the horizon for hybrid trucks, as early prototypes and demonstration vehicles shed new light on both opportunities and challenges.

For example, one delivery service is creating a fleet of 100 hybrid vans that will offer an estimated 57 percent improvement in fuel economy and significantly lower emissions. Other planned new delivery vans can travel up to 20 miles on electricity alone. At a recent Hybrid Truck Users Forum meeting, at least 15 truck manufacturers announced plans to build or demonstrate new vehicles. They will be used in refuse hauling, delivery, shuttle bus, school bus, bucket truck, heavy truck applications and more.

Industry and deployment groups are finding that the applications are quickly expanding for trucks built on a core hybrid chassis and then customized for particular uses. However, because the overall production volume of these trucks is still not high, they are available only at premium prices. This means that system costs, for drive-trains through energy storage systems to power electronics, must continue to be reduced. Consequently, support for continued R&D and for policy incentives remains vital.

**Current Federal Programs and Policies**

The Department of Energy's Vehicle Technologies Program supports the development of advanced combustion and engines design, durable and affordable advanced batteries covering the full range of vehicle applications, from start/stop to full-power hybrid electric, electric, and fuel cell vehicles. NREL's extensive testing and analysis capabilities are being used to understand and solve energy storage thermal issues in both light- and heavy-duty hybrid applications.

The Department of Energy is also the lead federal agency in the 21st Century Truck Partnership, established to develop the heavy-duty vehicles of the future. The partnership also includes the Departments of Defense and Transportation, the EPA, as well as numerous industry members. Groups such as CALSTART and the Hybrid Truck Users Forum are also doing much to support and promote the greater use and availability of hybrid commercial trucks.

Recently the National Academy of Sciences conducted a thorough review of the 21st Century Truck Partnership program. Their final report will be delivered to the Partnership in a few weeks. Their conclusions and recommendation should be valuable to the committee as it evaluates the opportunities in heavy hybrids.

Along with automotive companies and their suppliers, NREL has been developing and evaluating new technologies that reduce climate control loads as well as analyzing and evaluating the thermal performance of advanced lithium-ion batteries and ultracapacitors for energy storage. NREL is conducting research to develop thermal control technologies that enable high power density solutions for reducing the overall cost of the power electronics system. Our research includes experimental and numerical modeling focused on developing advanced thermal interface materials, single-phase liquid, and two-phase jet and spray cooling technology, surface enhancements for advanced heat exchangers, air cooling, and thermal system integration.

NREL's Renewable Fuels and Lubricants (ReFUEL) Research Laboratory, a test facility for advanced fuels in heavy-duty engines and advanced heavy hybrid vehicles, houses unique testing and measurement equipment. These include a heavy-duty vehicle chassis dynamometer for testing hybrid trucks and buses, with a road load simulation capability from 8,000 pounds to 80,000 pounds; a heavy-duty engine transient test cell (up to 400 hp) for fuels research and development; and an emissions measurement capability sensitive enough to be compliant with Federal certification procedures required in 2007. NREL has performed both electric and hydraulic hybrid vehicle test projects with manufacturers including Eaton/International, Oshkosh, and Allison GM, for hybrid buses, refuse haulers, and step vans.

In addition, DOE's Advanced Vehicle Testing activities benchmark and validate the performance of light-, medium-, and heavy-duty vehicles that feature one or more advanced technologies, including internal combustion engines burning advanced fuels, such as 100% hydrogen and hydrogen/compressed natural gas-blended fuels; hybrid electric, pure electric, and hydraulic drive systems; advanced batteries and engines; and advanced climate control, power electronic, and other ancillary systems. The NREL team has conducted medium- and heavy-duty vehicle evaluations, including evaluations of transit buses, trucks, and idle reduction technologies. Tasks include identifying fleets to evaluate, designing test plans, gathering on-site data, preparing technical reports, and communicating the results. This work is funded by the Department's Vehicle Technologies Program.

Numerous other partnership opportunities and incentives help manufacturers to develop and fleets to purchase hybrid trucks in the United States, at both the federal and the state level. The Environmental Defense Fund has compiled an online resource of tax credits and other incentives: www.edf.org/page.cfm?tagID+1124.

**Summary**

This testimony shows that there is no single hybrid truck design or system that will meet all our commercial transportation needs. Different solutions are needed both to improve the fuel economy of heavy-duty vehicles and to reduce associated emissions. Specific technologies and systems for achieving those objectives in heavy-duty hybrid vehicles will differ, depending on the vehicle's application and duty cycle.

As we move toward a future in which advanced vehicle technologies play a larger role, we understand the corresponding need to create a U.S. manufacturing base for heavy-duty hybrids, and their components. Otherwise, we might be trading our dependence on imported petroleum for a dependence on imported batteries and other components, a potentially serious issue for U.S. competitiveness.

Thus, a portfolio of energy-saving and environmental solutions will serve to meet our nation's economic, energy, and transportation challenges as well as enhance our energy security. A strong federal R&D and policy role is essential to development of these solutions.

Thank you.