Vehicle Technologies Program

Advanced Combustion Engine R&D: Goals, Strategies, and Top Accomplishments

Although internal combustion engines have been used for more than a century, significant improvements in energy efficiency and emissions reduction are still possible. In fact, boosting the efficiency of internal combustion engines is one of the most promising and cost-effective approaches to increasing vehicle fuel economy over the next 30 years. The United States can cut its transportation fuel use 20%–40% through commercialization of advanced engines—resulting in greater economic, environmental, and energy security. Using these engines in hybrid and plug-in hybrid electric vehicles will enable even greater fuel savings benefits.

The Advanced Combustion Engine R&D subprogram of the U.S. Department of Energy's Vehicle Technologies Program (VTP) is improving the fuel economy of passenger vehicles (cars and light trucks) and commercial vehicles (medium-duty and commercial trucks) by increasing the efficiency of the engines that power them. The subprogram's goals, strategies, and some of its major accomplishments are described below.

Passenger and Commercial Vehicle Goals

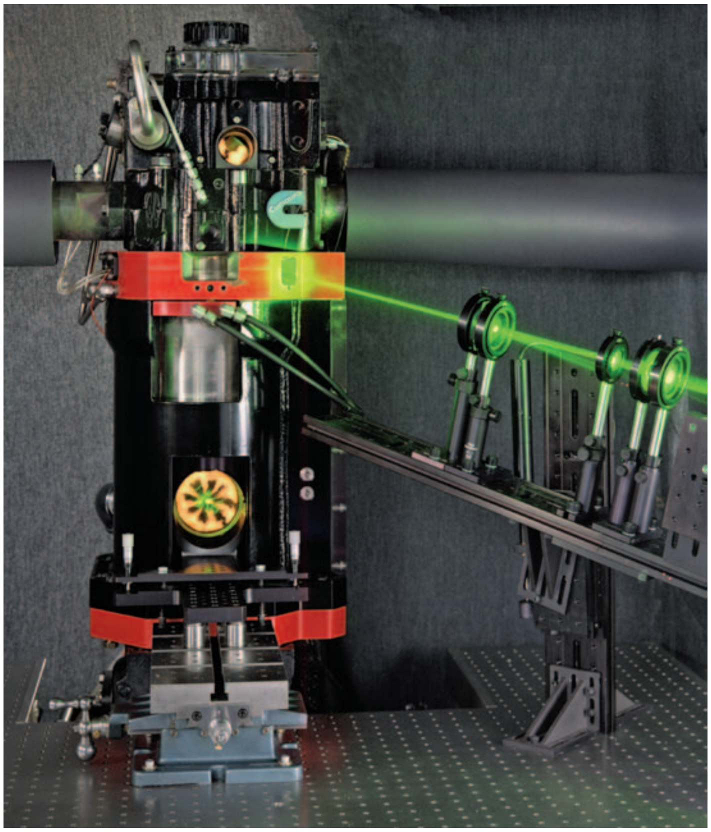
More than 230 million cars and light trucks consume three quarters of U.S. highway transportation fuel, mostly as gasoline. Our strategy for the passenger vehicle sector is two-pronged: 1) demonstrate cost-competitive, production-ready vehicles with advanced gasoline engines that are at least 25% more efficient than conventional engines by 2014; 2) demonstrate cost-competitive, production-ready diesel passenger vehicle engines based on high-efficiency clean combustion technologies that are at least 40% more efficient than current gasoline engines by 2014.

Goals

Improve passenger vehicle engine efficiency 25%–40% by 2014

Improve commercial vehicle engine efficiency at least 20% by 2014

Achieve commercial engine cost, durability, and emissions targets



Sandia National Laboratories

Advanced laser diagnostics of combustion in a modified Cummins engine

Although they account for fewer than 5% of highway vehicles, medium-duty and commercial vehicles account for a quarter of the fuel used. These vehicles are big, and they are driven constantly. The trucking industry's high fuel consumption and low profit margins give truck manufacturers a strong incentive to commercialize energy-efficient technologies. Over the past five years, commercial engine research and development (R&D) funded by VTP has saved more than 2 billion gallons of petroleum-based fuel, resulting in fuel cost savings many times greater than the federal investment. We aim to build on these results by demonstrating a 50%-efficient commercial engine in 2014, which represents a 20% improvement over today's engines. Successful commercialization of this advanced engine has the potential to save an additional 1 billion gallons of fuel annually by 2020.

Strategies for Developing Higher-Efficiency, Cleaner-Burning Engines

Our strategies for achieving higher engine efficiencies focus on three complementary technology pathways involving collaborative partnerships with vehicle and engine manufacturers, suppliers, national laboratories, and universities:

1. Improve the fuel economy of traditional spark-ignited gasoline engines by more than 25% using advanced technologies such as downsizing, variable compression ratio, and lean-burn engine operation.
2. Develop new combustion approaches that are more efficient than diesel combustion, but with near-zero emissions, which could enable engines to meet emissions regulations without the complicated and expensive equipment that is currently required.
3. Recover energy from the engine's exhaust to achieve a 10% or greater efficiency improvement using turbocompounding/turbocharging, bottoming cycles, and thermoelectric devices that convert heat to electricity for powering the vehicle and auxiliary loads.

Our well-balanced R&D efforts range from fundamental research to prototype demonstration, informed at each stage by industry partners who help identify critical barriers to technology commercialization. National laboratories and universities conduct fundamental and applied research aimed at understanding combustion processes, pollutant formation, and emissions reduction. The deep insights and accurate models developed through this research guide the development of advanced engine designs that allow expanded use of high-efficiency clean combustion strategies. Through competitive solicitations, we fund cost-shared applied R&D and demonstration activities with engine manufacturers that incorporate fundamental knowledge into production-ready engine designs. We also fund research to ensure that widespread commercialization of new technologies is safe for human health and the environment.

Top Accomplishments

The Advanced Combustion Engine R&D subprogram has led major advances in engine and vehicle development, efficient combustion strategies, emissions reductions, health effects, computer modeling, and exhaust heat recovery. The following are some of the top accomplishments to date.

Reaped a 60-Fold Return on Commercial Engine R&D Investments

VTP-sponsored R&D enabled engine manufacturers to improve diesel engine efficiency by 4%–5% since 2002. To date, this has saved 2.4 billion gallons of diesel fuel worth more than $7.6 billion—more than 60 times VTP's $123 million investment in commercial engine R&D from 1999 to 2007. In addition to the efficiency improvements, the R&D enabled the engines to meet 2007 regulations requiring a 90% reduction in particulate matter (PM) emissions and a more than 50% reduction in nitrogen oxides (NO_x) emissions.


International

Long-haul Class 8 truck

Made Diesel as Clean as Gasoline for Passenger Vehicles

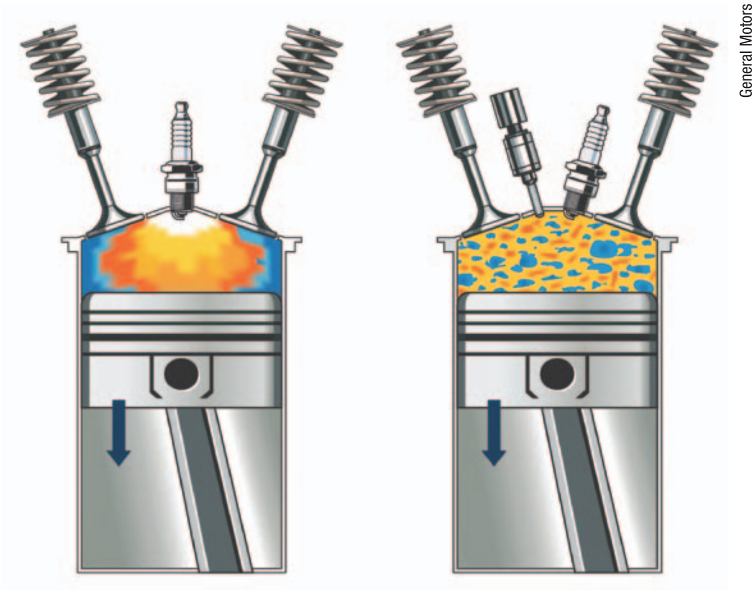
VTP spearheaded the development of clean diesel engine technologies for passenger vehicles in the 1990s, spurring the current reintroduction of highly efficient diesel vehicles into the passenger market. In the past, the inability of diesel passenger vehicles to meet U.S. Environmental Protection Agency (EPA) emission standards prevented them from entering the U.S. market. VTP-sponsored research demonstrated the ability of diesel passenger vehicles with advanced aftertreatment to meet EPA's stringent Tier II Bin 5 standards, representing an 83% reduction in NO_x and more than 87% reduction in PM emissions compared with the best-available diesel vehicles of the late 1990s. Cummins partnered with VTP to develop a diesel engine that meets the 50-state 2010 emissions standards while boosting vehicle fuel economy by 30% over comparable gasoline-powered vehicles. The Cummins engine is scheduled to debut in 2010 Chrysler sport utility vehicles and pickup trucks.


Daimler/Mercedes-Benz

Diesel passenger vehicle

Demonstrated Highly Efficient, Inherently Clean Combustion Techniques

VTP-sponsored R&D resulted in one of the first public demonstrations of homogeneous charge compression ignition (HCCI). HCCI is a high-efficiency clean combustion technology in which a fuel-air mixture is compressed until it spontaneously combusts. HCCI produces inherently low emissions, greatly reducing or eliminating the need for exhaust aftertreatment such as catalytic converters. In 2007, two General Motors (GM) concept cars using HCCI technology derived from VTP-sponsored R&D demonstrated up to a 15% fuel economy improvement over comparable spark-ignition vehicles. Ongoing R&D is expanding the range of engine load conditions available to HCCI operation.

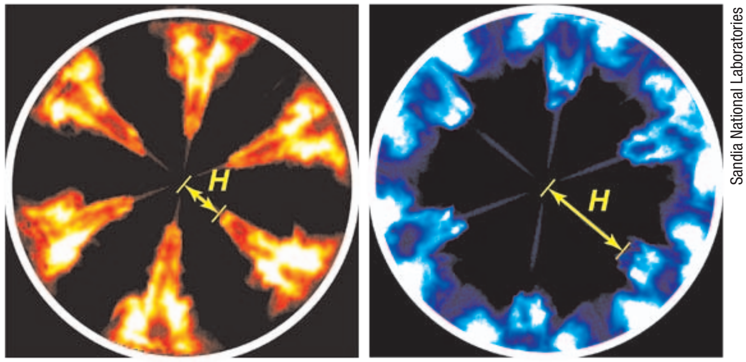


Illustrations of normal combustion (left) and homogeneous charge compression ignition (right)

Expanded the Fundamental Understanding of Combustion Processes

VTP established much of the fundamental knowledge about combustion processes and pollutant formation through funding R&D at national laboratories and universities. This R&D has guided the development of computer models that allow researchers to understand the impact of engine design changes on efficiency and emissions. Examples include the following:

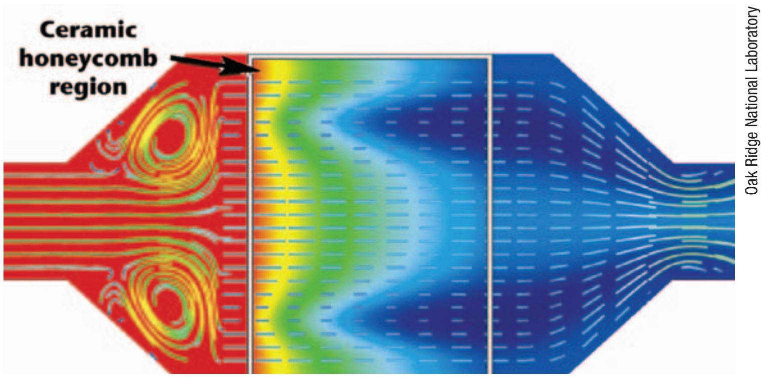
- Sandia National Laboratories developed a system of laser diagnostics and transparent cylinders that allows researchers to view and measure detailed combustion processes and emissions formation as they occur in real time.
- Argonne National Laboratory used x-rays from its Advanced Photon Source to image the fuel injection spray and its effect on combustion.
- Oak Ridge National Laboratory developed analytical and diagnostic methods to characterize the complex chemical processes that occur in the engine and exhaust catalyst systems. The laboratory's spatially resolved capillary-inlet mass spectrometer received an R&D 100 Award in 2008.
- Los Alamos National Laboratory contributed to the numerical framework for engine combustion models.
- Lawrence Livermore National Laboratory provided chemical kinetic models for combustion and emissions processes.
- Research at several universities helped develop and validate many diesel combustion sub-models.



In-cylinder images from normal combustion (left) and non-sooting, low-NO_x combustion obtained by lowering intake-gas oxygen content (right)

Established CLEERS Databases for Developing High-Efficiency Lean-Burn Engines

VTP collaborated with industry and university partners to initiate the Cross-Cut Lean Exhaust Emissions Reduction Simulation (CLEERS) R&D project in 2001. The CLEERS project is improving the simulation tools needed to develop lean-burn emission-control technologies. Lean-burn engines, in which fuel is combusted in the presence of excess oxygen, are expected to have higher efficiencies than traditional engines while producing fewer pollutants. This enables use of emissions aftertreatment technologies that are less complex and costly than current technologies. Car manufacturers have used the enormous amount of combustion and emissions data in CLEERS databases to develop commercial products. For example, GM developed new catalyst materials using lean-NO_x control data developed under CLEERS. Ford demonstrated the ability of urea and selective catalytic reduction systems to enable diesel engines to meet stringent emission standards. Ongoing CLEERS work focuses on reducing catalyst cost and increasing the efficiency of lean-burn gasoline and diesel engines.



Analysis of a catalytic converter during cold starting

Examined the Health Impacts of Clean Diesel Engines

VTP funds research to ensure that commercialization of its technologies will not produce unintended human health effects. This research was instrumental in revealing that diesel engines using low-sulfur (less than 15 ppm sulfur) fuel and equipped with catalyzed diesel particulate filters do not cause lung inflammation or pose other health hazards.

National Renewable Energy Laboratory PIX 01824

Laboratory analysis of emissions

Additional studies have indicated that clean diesel vehicles pose no more health risks than do conventional gasoline vehicles.

Developed Industry-Standard Engine Design Software

The KIVA family of modeling software—developed with VTP support and collaboration among national laboratories, universities, and industry—is used by all engine manufacturers as part of their engine design processes. The software predicts complex fuel and air flows as well as ignition, combustion, and pollutant-formation processes in engines. The KIVA models have been used to understand combustion chemistry processes, such as auto-ignition of fuels, and to optimize diesel engines for high efficiency and low emissions. Using the software, Cummins reduced development time and cost by 10%–15% in developing its high-efficiency 2007 ISB 6.7-L diesel engine that was able to meet 2010 emission standards in 2007. At the same time, the company realized a more robust design and improved fuel economy while meeting all environmental and customer constraints. Cummins credits this accomplishment to VTP-sponsored R&D efforts to understand and model the physical and chemical processes of combustion and pollutant formation.

Improved Fuel Economy Using Thermoelectric Generators

An engine loses 60%–70% of its fuel energy as waste heat from the combustion process. VTP has led efforts to convert this waste heat into useful electricity—and boost fuel economy—using solid-state thermoelectric generators (TEGs). In the 1990s, VTP worked with Hi-Z Technologies to demonstrate a 1-kW solid-state TEG on a commercial diesel engine that displaced electricity normally generated by the alternator. The TEG's on-highway capability was demonstrated in the exhaust system of a Class 8 truck for the equivalent of 550,000 miles. This successful demonstration spurred further VTP-sponsored R&D of prototype TEGs that meet performance and cost goals required for commercialization. BMW is scheduled to introduce a TEG developed by BSST in its model year 2015 5 and 7 Series cars with 3.0-L gasoline engines. Ford is developing a similar technology for its Escape Hybrid. GM is developing a TEG for the Chevy Suburban, with projected introduction of 200,000 TEG-equipped vehicles in model year 2015.

Hosted the Premier Advanced Diesel Conference

The VTP-sponsored Directions in Engine-Efficiency and Emission Research (DEER) Conference is the premier venue for exchanging information about diesel technology and emissions R&D. VTP initiated the DEER Conference in 1993 to accelerate U.S. introduction of diesel-powered passenger and commercial vehicles that are compliant with emissions standards. Since its inception, the conference's open forum has helped national laboratories, original equipment manufacturers, and suppliers better understand and overcome barriers to diesel commercialization. Conference attendance has grown from 50 attendees in 1993 to 1,200 attendees in 2008.

DEER 2009 DEARBORN
DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE
U.S. DEPARTMENT OF ENERGY

Driving into the Future

VTP's Advanced Combustion Engine R&D subprogram has made significant strides toward reducing U.S. petroleum consumption. By focusing our efforts on the three technology pathways described above and strengthening our collaborations with industry, universities, and national laboratories, we will continue to leverage R&D investments to achieve even greater petroleum displacement.

More Information

For more information about VTP's Advanced Combustion Engine R&D subprogram, contact Gurpreet Singh at *gurpreet.singh@ee.doe.gov.*

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