Heavy Vehicle Emissions Reduction Technologies

ENERGY EFFICIENCY AND RENEWABLE ENERGY

OFFICE OF TRANSPORTATION TECHNOLOGIES

Transportation

FOR THE 21ST CENTURY

Although significantly more efficient than gasoline engines, current diesel engines bring with them a number of environmental concerns, including the emission of particulate matter (PM) and nitrogen oxides (NO_x), a major contributor to urban smog. The Office of Heavy Vehicle Technologies (OHVT) conducts a customer-focused national program for research and development (R&D) on critical technologies that will enable the U.S. heavy vehicle transport industry to fully exploit the energy efficiency and alternative fuels capability of the diesel engine while simultaneously reducing highway vehicle emissions. Through this program, OHVT envisions the development of an energy-efficient, near-zero-emissions diesel engine technology for all of the following truck classes:

- Class 7&8: large, on-highway trucks;
- Class 3-6: medium duty trucks, such as delivery vans; and
- Class 1&2: pickups, vans, and sport utility vehicles (SUVs).

To achieve this goal, the OHVT strategy employs a two-pronged approach:

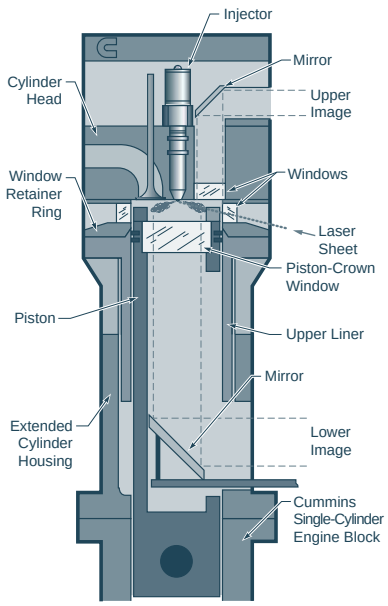
1. Improve the efficiency of Class 7 & 8 trucks by developing energy efficient diesel engines and systems technologies that improve the capability to use alternative fuels while reducing emissions to ultra-low or near-zero levels, and
2. Utilize the expertise of the world-class U.S. diesel engine manufacturing companies in developing highly efficient, ultra-low to near-zero emissions diesel engines that will be commercially competitive with gasoline engines in the multipurpose Class 1 & 2 truck market.

The technologies developed and advancements made in improving the efficiency of Class 7 & 8 vehicles will also be applied to Class 3-6 engines to reduce emissions and improve fuel economy. A separate, key technology applicable to Class 3-6 urban heavy vehicles is the hybrid electric propulsion system combining a diesel engine with the latest in electric vehicle technology.

Inherent in the OHVT strategy is the development of in-cylinder processes and exhaust aftertreatment technologies. Along with research into advanced petroleum-based fuels, as well as alternative, non-petroleum fuels, these technologies will ultimately help to deliver clean and efficient diesel-powered trucks. This integrated systems approach will allow the high efficiency of the diesel engine to be maintained while meeting future emissions standards.

Clean Combustion

Combustion related research and development focuses on an improved fundamental understanding of in-cylinder combustion processes in order to facilitate emissions reductions without sacrificing fuel efficiency. One of the critical challenges facing diesel engines is the tradeoff between emissions of NO_x and particulates. In advanced diesel engines, many in-cylinder strategies intended to reduce NO_x to very low levels, including exhaust gas recirculation and retarded injection timing, result in increased PM emissions. Conversely, some methods which reduce PM to very low levels, such as higher operating temperatures and more in-cylinder mixing, tend to increase NO_x emissions. Investigations are underway to explore the dynamics of fuel/air mixing. Researchers are examining the interactions between fuel spray and the piston/bowl walls, as well as the effects of fuel swirl on heat release rates and combustion processes. Also being examined are the effects of engine load conditions (gas temperature and density) and injection parameters (orifice diameter and injection pressure) on the evolution of combustion zones and emissions formation. Much attention is being focused on exhaust gas recirculation (EGR) to reduce NO_x emissions. This includes improving cylinder-to-cylinder distribution of exhaust gases and extending the limits of EGR while still maintaining combustion stability. Investigators are also exploring the possibility of injecting auxiliary air/oxygen during the diffusion phase of the combustion cycle to decrease soot



Single-cylinder, optically accessible Cummins engine for diesel research (Sandia National Laboratory).

formation, and developing diagnostic tools for real-time, in-situ characterization of particulates.

Advanced Fuels

More and more attention is being focused on the effects of advanced petroleum-based fuels on exhaust emissions. These fuels include mixtures blended with oxygenates, gas-to-liquid diesel fuels (Fischer-Tropsch), and diesel fuels which have a low sulfur content. Research up until now has shown that aggressive fuel reformulation may lead to reductions in engine-out emissions of up to 35% for particulates. Some studies have revealed a strong correlation between the reduction in particulates and the hydrogen/carbon ratio and oxygen content of the fuel. Researchers are examining the physical and chemical mechanisms which may lead to reductions in soot formation when oxygenated diesel fuels are burned. In addition, the use of low-sulfur fuels is being encouraged as a means of reducing the emission of sulfate particulates. Advanced fuels containing low sulfur can improve the durability and effectiveness of emission control systems and minimize the need for sulfur removal systems on board the vehicle. The role of lubricating oils in particulate formation is also being explored.

Emission Control Systems

Key emission control technologies being pursued are:

- NO_x adsorbtion
- Urea-based, selective catalytic reduction
- Plasma-assisted catalysis
- Particulate traps

Conventional NO_x reduction catalyst technology used on gasoline engines cannot be applied to diesel engines due to excess oxygen in the exhaust. NO_x catalyst R&D emphasizes improved NO_x conversion efficiencies, lower light-off temperature (for light duty applications), wider temperature operating ranges, and long-term durability. Efforts are focusing on an improved understanding of NO_x reduction mechanisms and the identification and preparation of new catalyst and support materials. Research efforts are centered around adsorbers which are proving to be highly effective in reducing NO_x, demonstrating about 90% conversion efficiency. Adsorbers, however, are very sensitive to sulfur and require improved regeneration techniques that will not impact on fuel economy. Technologies employing sulfur traps and sulfur tolerant catalysts, as well as operating schemes for desulfurization are also being explored. Recent research has emphasized the use of urea-based selective catalytic reduction (SCR) to reduce NO_x, where the urea replaces hydrocarbons from the diesel fuel as the reducing agent. New SCR catalysts with high activities are needed, as well as advances in the methods used to introduce the reducing agents. Although considered a longer-term option, non-thermal plasma-assisted catalysis shows promise for both NO_x and particulate reduction. Advances in the efficiency and design of plasma reactor systems, however, and the development of suitable high-activity catalysts are still required.

For particulate reduction, various catalyzed soot filters and periodically regenerated traps have demonstrated an effectiveness in excess of 80%. Further research is needed however, to reduce the pressure drop across the filter, improve regeneration, and broaden the thermal operating range so that fuel economy is not affected. Advances must also be made to improve durability and decrease costs.

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Gurpreet Singh
Office of Transportation Technologies
(202) 586-2333
gurpreet.singh@ee.doe.gov
http://www.ott.doe.gov

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