1.1.3 FUELS FOR ADVANCED COMBUSTION ENGINES

Technology Description

The Fuels for Advanced Combustion Engines activities are undertaken to enable advanced combustion regime engine technology, as well as identify practical, economic fuels and fuel-blending components with the potential to directly displace significant amounts of petroleum. A major focus of the fuels activities is to determine the impacts of fuel properties on the efficiency, performance, and emissions of advanced internal combustion engines. In the near term, these are expected – for the most part – to be direct-injection diesel engines and their associated emission-control systems.

A researcher uses a clean room to gather emissions data from future fuels.

System Concepts

- To enable current and emerging advanced combustion engines and emission control systems to be as efficient as possible while meeting future emission standards.
- To reduce reliance on petroleum-based fuels by supporting the introduction of fuels that displace petroleum.
- To reduce sulfur, particulate, and oxides of nitrogen emissions.

Representative Technologies—Fuels

- Low-sulfur diesel fuel that allows more efficient emissions control.
- Diesel fuel produced from expected heavier and sourer crude oil feedstocks.
- Diesel fuel produced from oil sands, shale oil, coal.
- Biodiesel produced from vegetable oils and waste fats.
- Fischer-Tropsch diesel produced from natural gas, biomass and coal.

Representative Technologies—Engines

- Direct-injection diesel engines equipped with emission controls such a diesel particulate filters (DPF), NOx Adsorber Catalysts (NAC), or Selective Catalytic Reduction (SCR) systems.
- Homogenous charge compression ignition (HCCI).
- Low-temperature combustion (LTC).

Technology Status/Applications

- Venezuelan and domestic heavy crude use in U.S. refineries is well established.
- Refining of synthetic crude derived from oil sands is growing in use in Canada, and expansion into U.S. petroleum pools is beginning.
- Fischer-Tropsch diesel fuels, synthesized from natural gas or coal (Coal-to-Liquids, CTL), have been studied in numerous engine tests to determine their impact on emissions and have been used as a blending material in California diesel fuels since 1993.
- Use of similar fuels derived from biomass – Biomass-to-Liquid (BTL) fuels – may increase in the future.
- Biodiesel (fatty acid methyl esters) produced from vegetable oils and waste fats has been used extensively as a blending component in Europe and its use in the United States is increasing.

Current Research, Development, and Demonstration

RD&D Goals

- By 2007, identify fuel formulations optimized for use in 2007-2010 technology diesel engines that incorporate use of nonpetroleum-based blending components with the potential to achieve at least a 5% replacement of petroleum fuels by 2015.
- By 2010, complete R&D to eliminate technical barriers to the achievement of the 5% petroleum

displacement goal for 2007-2010 engines, allowing these engines to meet key technical targets.

- By 2010, identify fuel formulations optimized for use in advanced combustion engines (2010-2020) providing high efficiency and very low emissions, and validate that at least 10% replacement of petroleum fuels could be achieved by 2025.

RD&D Challenges

To fully exploit the full potential of high-efficiency, clean advanced combustion regime engines, codevelopment of the engines and fuels is a necessity. Nearer term, understanding the compatibility of nonpetroleum-based fuels with 2007-2010 engines is critical for expanded use of these fuels. The technical barriers to achieving this are as follows:

- **Inadequate data and predictive tools for fuel property effects on combustion and engine optimization.** Existing data and models for engine efficiency, emissions, and performance – based on fuel properties and fuel-enabled engine designs or operating strategies – are inadequate. Also, the variability of refinery stream (blendstock) composition on the efficiency, performance, and emissions of engines appears to be significant but is poorly understood.
- **Inadequate data and predictive tools for fuel effects on emissions and emission-control system impacts.** The database on the extent to which petroleum fuel and nonpetroleum fuel components contribute to toxic emissions is inadequate and must be improved in order to optimize engine and aftertreatment systems from a fuel economy standpoint. The relationship between fuel properties and the formation of ultra-fine particles (i.e., particles of <0.1 nm in diameter) is not well established. Also inadequate are data on the effects of fuel properties (other than sulfur) on exhaust emission control systems; and widely accepted test procedures to measure these effects do not exist. Furthermore, suitable test equipment and universally recognized test procedures with which to generate this knowledge base are not available.
- **Long-term impact of fuel and lubricants on engines and emission-control systems.** The knowledge base is inadequate on the effect of fuel properties on the deterioration rates and durability of engine fuel system and emission-control system devices and components. The effects of lubricating oil on engine emissions and emission-control devices are not clearly understood, nor are the effects of nonpetroleum-based fuels on lubricating oil performance. Improved understanding is needed in developing approaches that mitigate any deleterious effects caused by fuel and lube oil components. Furthermore, new fuel formulations could require corresponding new lube oil formulations.

RD&D Activities

The fuels activities will test and evaluate a wide variety of fuels to develop a better understanding of the relationships between fuel properties, engine efficiency, system durability, and emissions. Exhaust emission-control devices are expected to be necessary to meet future emissions standards for diesel-powered vehicles. Fuels-compatibility testing will include such devices as they become available (through close collaboration with the Advanced Combustion Engine R&D activities).

Key deliverables from these activities will be test data and test-databased analyses of the sensitivity of the performance and emissions of engines and emission-control devices to fuel and lubricant properties. As data accumulate in the database, it will become increasingly feasible to predict fuel formulations with favorable properties to reduce emissions of NOx and PM. In addition, some emission-control strategies rely on reductants derived from the fuel to operate effectively, a fact that will be taken into account as required reductant properties are identified by the Advanced Combustion Engine R&D activities. Technical tasks include:

- Evaluation of fuels and lubricants to enable high efficiency engine operation while meeting 2007-2010 emission standards.
- Evaluation of fuel properties effects on advanced combustion regimes and on engine regulated and unregulated emissions while operating in these regimes.
- Evaluation of petroleum displacement fuels and fuel-blending components.

Recent Progress

- A major focus of the fuels activities is to determine the impacts of fuel properties on the efficiency, performance, and emissions of advanced internal combustion engines. A recently completed major contribution to clean, efficiency transportation was a multiyear effort to determine the effects of fuel sulfur on diesel emissions controls that helped lead to and support EPA's rulemaking for low-sulfur diesel fuel. In the near term, advanced internal combustion engines are expected to be mostly direct-injection diesel engines and their associated emission-control systems. There exists little understanding of the compatibility of the engine-emission-control system with renewable fuels such as biodiesel or BTL. Additional information is also required on performance and durability with fuels derived from heavy-crude, oil sands, shale oil, and coal.
- For the long term, focus is on fuels optimized for advanced combustion regimes, which include technologies that have the potential to provide diesel-like (or greater) efficiency with extremely low engine-out emissions. Combustion regime examples are homogeneous charge compression ignition (HCCI) and low-temperature combustion (LTC).
- While anecdotal evidence points to variations in performance and emissions in near-term (e.g., prototype MY2007) engines related to fuel-property variations, it is almost certain that future, advanced combustion engine technologies will show a greater sensitivity to such variations. As such, codevelopment of fuels and engines will be essential to ensure availability of fuels optimized for operation in advanced combustion regime engines in the post-2010 time frame. This necessitates an improved fundamental knowledge about fuel properties and composition and their impact on combustion phenomena. If fuel specifications need tighter definition for engine operation in advanced combustion regimes, close coordination between the Advanced Combustion Engine and Fuels activities will be essential.
- The expertise of the national laboratories is used for in-house research and development efforts, in "working group"-level interactions in government-industry consortia, and in technical management. In the near term, fuel issues associated with 2007-2010 engines and emissions-control systems are of concern. Near-term tasks support removing sulfur from the fuel at fueling stations or onboard the vehicle prior to combustion to provide a near-zero sulfur level, if necessary. An additional near-term focus is assessing the impact of renewable and nonpetroleum blending components such as biodiesel and BTL, and examining the impacts of fuels derived from heavy-crude. For the long term, the challenge is development of a fuel specification optimized for operation of advanced combustion regime engines up to full load and during transients. Other challenges include assessing the implications of the properties of newly developed fuels on engine performance and emissions, and identifying compatible lubricants for use with newly developed fuels.

Commercialization and Deployment Activities

- Guidance on the fuels testing and other tasks will come from industry, DOE, national laboratories, and others. Government/industry technical and supporting groups will make specific recommendations for tasks, data analyses, and overall direction.

Market Context

- **Infrastructure.** The lack of quality specifications, as well as distribution and fueling infrastructure is a major barrier for any nonpetroleum-based liquid fuel component that is not compatible with all current systems. This barrier must be addressed for non-fungible fuels to have a significant impact on reducing the transportation sector's dependence on petroleum-based fuels.
- **Cost.** There are insufficient public data on refinery economics and processing strategies to enable comparison of options for advanced combustion engine fuels. Also inadequate are the databases on the health, safety, and regulatory issues associated with most nonpetroleum fuel components that might be used to replace petroleum-based fuels, and the knowledge base on the technical and economic impacts of nonpetroleum fuel components on the distribution, storage, and fueling.