NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuels Performance

Navigating the Intersection of Fuels and Combustion

Cars and trucks in the United States burn through 3.2 billion barrels of gasoline each year. Putting more energy-efficient vehicles on the road—to displace oil consumption, decrease greenhouse gases (GHGs), and improve the nation's energy security—requires simultaneous advances in fuel formulation, combustion strategy, and engine design.

Researchers at the National Renewable Energy Laboratory (NREL), the only national laboratory dedicated 100% to renewable energy and energy efficiency, recognize that engine and infrastructure compatibility can make or break the impact of even the most promising fuel. NREL and its industry partners navigate the intersection of fuel chemistry, ignition kinetics, combustion, and emissions, with innovative approaches to engines and fuels that meet drivers' expectations, while minimizing petroleum use and GHGs.

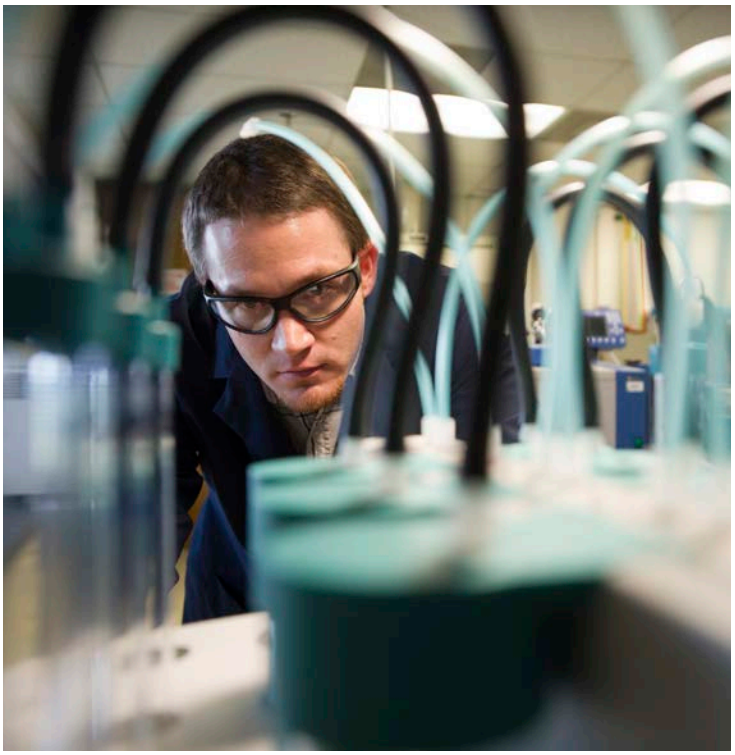
NREL research, development, and deployment (RD&D) explores how biofuels, advanced petroleum-based fuels, fuel blends, and natural gas (NG) perform in vehicles, fuel pumps, storage tanks, and distribution systems. This continuum of applied research takes a whole-vehicle-systems approach, examining not just co-optimization of low-carbon fuels and internal combustion engines, but also fuel production, infrastructure, handling, combustion, and emissions.

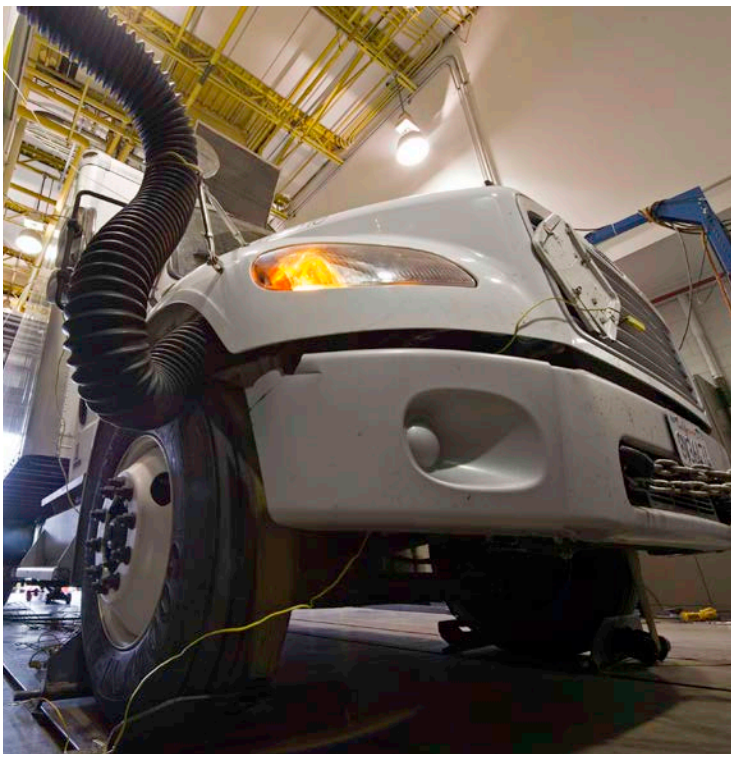
NREL and its automotive, biofuel, and petroleum industry partners work in collaboration to answer two primary questions: How can improved fuel chemistry lead to more efficient engine performance? And how can better engine design most effectively leverage fuel properties?

Study Reveals Key to Low-Temperature Biodiesel Performance

Research: An NREL study evaluated 140 biodiesel blend samples for the effects of composition on low-temperature fuel performance.

Impact: The findings debunk previously accepted wisdom by revealing the percentage of saturated monoglycerides is the largest factor affecting cold-weather performance, pointing industry toward new strategies for producing and blending wintertime biodiesel.





NREL RD&D explores how biofuels and advanced petroleum-based fuels perform in vehicles, fuel pumps, storage tanks, and distribution systems. *Photos by Dennis Schroeder, NREL 32106 (top) and 22772 (bottom)*

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL researchers develop and characterize a wide range of renewable and advanced petroleum-based fuels. *Photo by Dennis Schroeder, NREL 32107*

Accelerating the Development of New Fuels

NREL research has played a pivotal role in accelerating the development of bio-based renewable fuels. At the same time, the lab recognizes that petroleum will continue to be an important source of transportation fuel, and works to improve the performance of gasoline and diesel fuels. Both types of fuel need to be paired with compatible engines to optimize performance.

It is forecast that biofuels have the potential to displace as much as 30% of the gasoline and diesel markets by 2050. Any meaningful progress toward this target will require studying the chemistry of biofuels in tandem with combustion to assess properties, behavior, and quality at the whole-vehicle level. NREL's focus on how biofuels interact with engines, emission control systems, and infrastructure feeds industry development of new fuels and vehicle components, as well as agencies' establishment of fuel quality standards.

Biomass offers the most readily available, sustainable alternative to petroleum-derived gasoline and diesel on a scale that is impossible for other renewable fuels to match. The projected 2030 annual supply of more than 1.3 billion tons of biofuel feedstock—in the form of corn stover, wheat straw, switchgrass, and forestry byproducts—is 5 times the amount of corn grain available for conversion into ethanol. NREL's advanced biofuels research and development (R&D) is exploring the potential of drop-in cellulosic ethanol biofuel blends that can be easily introduced into existing vehicle technology and infrastructure and deliver better water tolerance, energy content, and performance properties than corn ethanol.

Looking at new fuels, blends, additives, and lubricants alongside heavy-duty and light-duty vehicle technology makes it possible to provide developers with requirements to meet ASTM standards and perform strongly in engines, in addition to identifying areas of potential difficulty.

Overcoming Barriers for New Fuels

NREL researchers help overcome technical barriers for new fuels by:

- Developing and characterizing research-grade reference fuels, surrogate fuels, and advanced alternative/renewable blending streams
- Measuring fuel quality and performance properties in relation to chemical composition
- Comparing behavior, performance, and emissions impacts of different alternative fuels and fuel blend levels
- Studying combustion-related fuel properties
- Evaluating fuel compatibility with engines, emissions control catalysts, and infrastructure materials.

NREL studies effects of new fuel properties on performance and emissions in advanced engine technologies. *Photo by Dennis Schroeder, NREL 23588*

Pairing New Fuels with Improved Engine Technologies

NREL's combustion R&D bridges fundamental chemical kinetics and applied engine research to investigate how new engine technologies can be co-developed with fuels and lubricants to maximize energy-efficient vehicle performance. Researchers examine what happens to fuel inside the engine, how fuel interacts with equipment, and what emissions are produced. Results from and tools developed by the lab guide engine manufacturers in developing equipment and controls.

Engine studies at NREL's Renewable Fuels and Lubricants (ReFUEL) Laboratory pick up where fuel chemistry testing leaves off. Evaluations progress from initial screening of fuel candidates to bench-scale research and single-cylinder engine studies, and then scale up to assessments involving multi-cylinder engines and complete vehicle systems. Test engines based on production engines are operated over a range of conditions to optimize potential for real-world application.

NREL's emissions and fuel economy testing and analysis, conducted primarily at the ReFUEL Laboratory, helps combat GHGs by advancing the development of new fuels and engines that deliver both high efficiency and reduced emissions. Industry partners rely on the laboratory's expertise to advance low-carbon fuels and high-efficiency engine technology while maintaining operations in compliance with emissions regulations. A chassis dynamometer capable of putting vehicles as large as Class 8 semi-trucks through their paces is used to evaluate whole-vehicle systems, including engines and emission control equipment.

NREL conducts both bench experiments and modeling simulations of fuel ignition kinetics performance. NREL's flexible research platform based on an ignition quality tester (IQT) complements fundamental research, examining combustion across a wide range of temperatures, pressures, and levels of dilution.

Paired with the lab's Peregrine supercomputer, IQT-based experiments make it possible to validate kinetic models for automakers in hours rather than weeks. The IQT tool's independent control system allows researchers to conduct ignition experiments examining low-volatility fuels in engine-relevant conditions and at small volumes, which often pose severe challenges to traditional testing devices.

Optimizing Engine Performance

NREL combustion and engine research activities include:

- Developing experimental and simulation research platforms to enable efficient combustion and diversification of fuel options
- Collaborating with partners to develop and refine accurate, efficient kinetic mechanisms for fuel ignition
- Determining the effect of fuel properties on combustion and engine efficiency optimization
- Using engine-based studies to correlate data for experimental and simulation efforts.

Alternative Fuel in Every Form

Rather than taking a silver-bullet approach to petroleum displacement and energy efficiency, NREL is exploring multiple pathways to transportation sustainability. This includes characterization of the chemistry and properties of the full spectrum of commercially available fuels, fuels in development, and compounds under consideration for future fuel formulation. Fuels currently under investigation include:

Biofuels for Diesel Engines

- Biodiesel
- Hydro-isomerized fats and oils
- Biomass pyrolysis-derived diesel
- Cellulose-derived oxygenates.

Biofuels for Spark-Ignited Engines

- Ethanol
- Butanol and long-chain alcohols
- Biomass pyrolysis-derived gasoline
- Cellulose-derived oxygenates.

Natural Gas

- Compressed
- Liquefied
- NG-derived gas-to-liquids.

Infrastructure

Infrastructure compatibility can present major hurdles to commercialization of low-carbon fuels and fuel blends. NREL works with equipment certification authorities, manufacturers, and service station and refinery operators to examine requirements for components, including:

- Service station pumps
- Delivery equipment
- Distribution lines and meters
- Storage tanks.

Projects Introduce Natural Gas Engines for Medium- and Heavy-Duty Vehicles

Research: NREL, along with state agency and industry partners, helped bring to market the first 2010 emissions-compliant 11- to 13-liter NG engine for medium- and heavy-duty vocational vehicles and long-haul freight trucks.

Impact: The new 11.9-liter NG engine, combined with the surge in U.S. NG discoveries, make this a competitive option for commercial vehicles, including the trucks that transport 18.3 billion tons of freight each year.

NREL researchers assess fuels over a range of conditions to optimize potential for real-world application. *Photo by Dennis Schroeder, NREL 20112*

NREL's Sustainable Transportation RD&D

As the only national laboratory solely dedicated to renewable energy and energy efficiency, NREL spearheads the RD&D needed to put sustainable transportation solutions on the road. The laboratory's innovative and integrated approach helps government, industry, and other partners develop and deploy the components and systems needed for market-ready, high-performance, low-emission, fuel-efficient passenger and freight vehicles, as well as alternative fuels and related infrastructure.

For more information on NREL's transportation RD&D capabilities and successes, go to www.nrel.gov/transportation.

Contact us to explore opportunities for collaboration on fuels performance RD&D: 303-275-4273.

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Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

BR-5400-63147 • November 2014

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