



# Transforming **ENERGY** through **SUSTAINABLE** Mobility

Expanding Energy-Efficient  
Mobility Options





**AS THE NATION'S PREMIER FACILITY FOR ENERGY-EFFICIENT TRANSPORTATION R&D SOLUTIONS**, NREL blazes new trails with novel approaches that combine vehicle, building, and infrastructure connectivity and automation to optimize mobility and increase energy efficiency.

## NREL IS EXPLORING

new options for high-performance fuels and advanced combustion engines to maximize energy efficiency and on-road vehicle performance, while minimizing harmful emissions, enhancing energy security, increasing U.S. jobs, and lowering drivers' costs.

For the typical American, transportation is the second greatest expense after housing, and the average commuter wastes about 42 hours a year stuck in traffic. New, innovative, and integrated mobility strategies have the potential to transform the movement of people and goods, enhance national energy security, boost the domestic economy, and save individuals and businesses both time and money.

As the nation's hub for cutting-edge transportation research and development (R&D), the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) provides the scientific building blocks needed to spur innovation through fundamental research and engineering. In turn, this acts as a catalyst to help industry bring to market affordable, high-performance, energy-efficient passenger and freight vehicles, as well as domestic alternative fuels and related infrastructure.

NREL's sustainable transportation R&D efforts are not limited to vehicles, fuels, roads, and fueling stations. The lab also explores ways to enhance the nation's mobility options, boost transportation energy efficiency, and minimize harmful emissions by integrating technology advancements with a range of domestic energy resources, power grids and building systems, urban planning, and fleet operations.

Researchers collaborate closely with research, government, and industry partners, using a whole-systems approach to design better batteries, drivetrains, and engines, as well as thermal management, energy storage, power electronic, fuel, combustion, and emission systems. Unbiased expert research and guidance—backed by credible data and analysis, as well as proven systems, tools, and processes—empower partners to make informed sustainable transportation decisions.





**NREL IS DEVELOPING** a “mobility energy productivity” metric to quantify the overall quality of mobility in a given area with respect to time, cost, and energy.

## CROSS-CUTTING INITIATIVES

A truly sustainable transportation future will rely on widespread adoption of numerous solutions, including domestic alternative fuels, more fuel-efficient internal combustion engines, electric-drive vehicles (EDVs)—hybrid, plug-in hybrid, and fully electric battery and fuel cell vehicles—new approaches to fueling and charging, innovative systems of vehicle connectivity, and a grid powered by a variety of renewable and conventional energy sources. In addition to research spanning a broad spectrum of technologies and complex analyses leveraging high-performance computing capabilities, NREL’s expertise has established the laboratory as a national trailblazer in a wide range of cross-cutting areas.

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### **Sustainable, Affordable & Efficient Mobility Systems**

Rapid proliferation of automated vehicle technologies and connected, on-demand mobility services, coupled with lightning-speed advances in communications and control technologies, are revolutionizing today’s transportation system. NREL’s Sustainable Mobility Initiative approaches transportation as a network of travelers, services, and environments, rather than just vehicles and roads, using connectivity and automation to optimize mobility and overall system efficiency. In light of the plethora of burgeoning technologies, researchers are developing a “mobility energy productivity” metric to quantify the overall quality of mobility in a given area with respect to time, cost, and energy.

### **Fuel, Engine & Infrastructure Co-Optimization**

New fuels, engines, and infrastructure will be required to meet ambitious energy-saving goals. NREL is leading a multi-lab collaborative effort, simultaneously exploring new options for high-performance fuels and advanced combustion engines to maximize energy efficiency and on-road vehicle performance, while minimizing harmful emissions, enhancing energy security, increasing U.S. jobs, and lowering drivers’ costs.

### Thermal Management Research

Optimized thermal management can increase electric vehicle battery power by more than 20%, enable electric drivetrains with 10-fold higher power density, and decrease climate control systems' energy demands by as much as 68%. NREL research focusing on energy storage, power electronics, electric machines, and climate control system operating temperature aims to improve vehicle performance, range, reliability, lifespan, and affordability.

### Transportation Data, Analysis & Tools

NREL serves as the nation's most credible and complete transportation energy-efficiency clearinghouse for validated, up-to-date statistics, data, and tools, pairing information from government and private-sector partners with expertise in analysis and applications. NREL's analytical and data science prowess—bolstered by world-class computational science and high-performance computing capabilities—plays a vital role in accelerating the pace of research advancements in cross-cutting areas such as intelligent mobility system technologies, optimized passenger and freight mobility, and much more.

## OPTIMIZED THERMAL MANAGEMENT

can increase electric vehicle battery power by **MORE THAN 20%**

### ELECTRIC VEHICLE SYSTEMS AND COMPONENTS

must perform reliably in a wide range of conditions to meet consumer expectations.

### Reliability & Durability Research

Electric vehicle systems and components must perform reliably in a wide range of conditions to meet consumer expectations. NREL R&D focused on improving the reliability and extending the lifespan of power electronics, energy storage, and hydrogen infrastructure components and systems makes EDVs more viable in the marketplace.

### Vehicle Technology Integration and Evaluation

Technology integration projects encourage adoption of emerging technologies by identifying and breaking down barriers that end users face. NREL experts provide technical assistance, convene forums to identify industry-wide research needs and priorities, and collect and share data on the real-world impacts of new technologies.

### Vehicle-to-Grid Integration

Vehicle-to-grid technology can balance intermittent renewable resources, enhance grid stability, reduce peak-hour electricity demand, and address electric vehicle driving-range limits. NREL researchers are developing and evaluating fully integrated systems that connect cars, power grids, and renewable energy sources. In tandem, NREL is examining opportunities and impacts associated with a full range of charging technologies—from home-based Level 1 charging to extreme fast charging.



## AS THE COUNTRY'S RECOGNIZED LEADER

in battery thermal management research, NREL conducts modeling, simulation, and system evaluation activities to assess and optimize energy storage components.



## INNOVATIVE VEHICLE, FUEL, AND INFRASTRUCTURE R&D

While EDVs are rolling off assembly lines in ever-growing numbers, they currently command a relatively tiny market share. NREL researchers are exploring ways to optimize the internal combustion engine technology that will continue to power the majority of vehicles on U.S. roads for decades to come, while simultaneously developing EDV and infrastructure technologies and fuels to effectively leverage domestic energy resources. This R&D touches nearly every type of automotive system and class of on-road vehicle at scales ranging from component materials to vehicle fleets.

### Fuels & Engines

Substantial advances in engine technologies and fuel components are needed to reduce energy consumption, lower drivers' costs, and reduce harmful emissions. By focusing on the intersection of fuel physical and chemical properties, ignition and soot formation mechanisms and kinetics, and combustion in engines, NREL is supporting coordinated development of high-performance fuels, advanced combustion engines, and fueling infrastructure. Research spans from laboratory fuel property experiments,

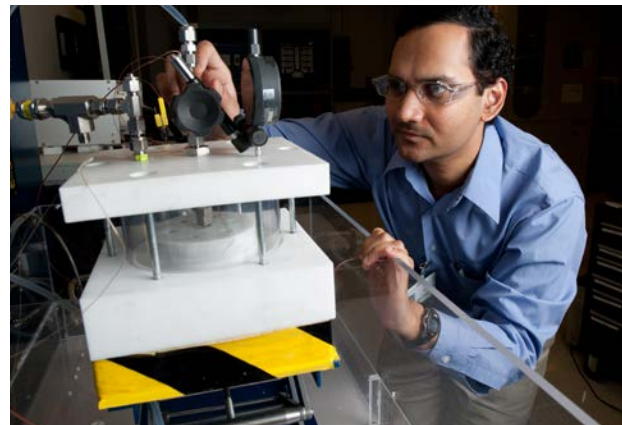
fundamental research into the chemical mechanisms and kinetics of ignition and soot formation, and modeling fuel combustion at the molecular level, to analyzing engine performance and evaluating emissions from all classes of vehicles.

### Energy Storage

Batteries are the most expensive EDV component. To meet market demand for long-range, fast-charging, safe, and inexpensive options, energy storage systems must be able to withstand high heat. As the country's recognized leader in battery thermal management research, NREL conducts modeling, simulation, and system evaluation activities to assess and optimize energy storage components at the materials, cell, pack, and systems levels. NREL's battery materials expertise enables new battery chemistries for anode and cathode materials in this critical area of thermal control. In partnership with other national labs, NREL is investigating the use of silicon as an anode material to improve energy density and reduce costs while also developing critical-material-free energy storage technologies to support the integration of electric vehicle fast chargers, photovoltaic generation, stationary energy storage, building systems, and the electric grid. Additionally, NREL is spearheading ways to repurpose and recycle batteries when they are no longer useful in vehicles.



TRUCKS MOVE more than  
**13 BILLION TONS**  
of freight across the United States each year.



**NREL R&D** is making wide-scale EDV acceptance more feasible by developing more robust and affordable power electronics and electric motor technologies.

## INNOVATIVE VEHICLE, FUEL, AND INFRASTRUCTURE R&D, CONTINUED

### Power Electronics & Electric Machines

While power electronics help run a wide range of systems in conventional gas-fueled vehicles, EDVs rely even more heavily on these components. NREL R&D is making wide-scale EDV acceptance more feasible by developing power electronics and electric motor technologies and components with greater dependability, efficiency, and durability, while dramatically decreasing costs. This work has established the lab as a vital resource for reliability and thermal management of motor controllers, inverters, and traction motors.

### Hydrogen & Fuel Cells

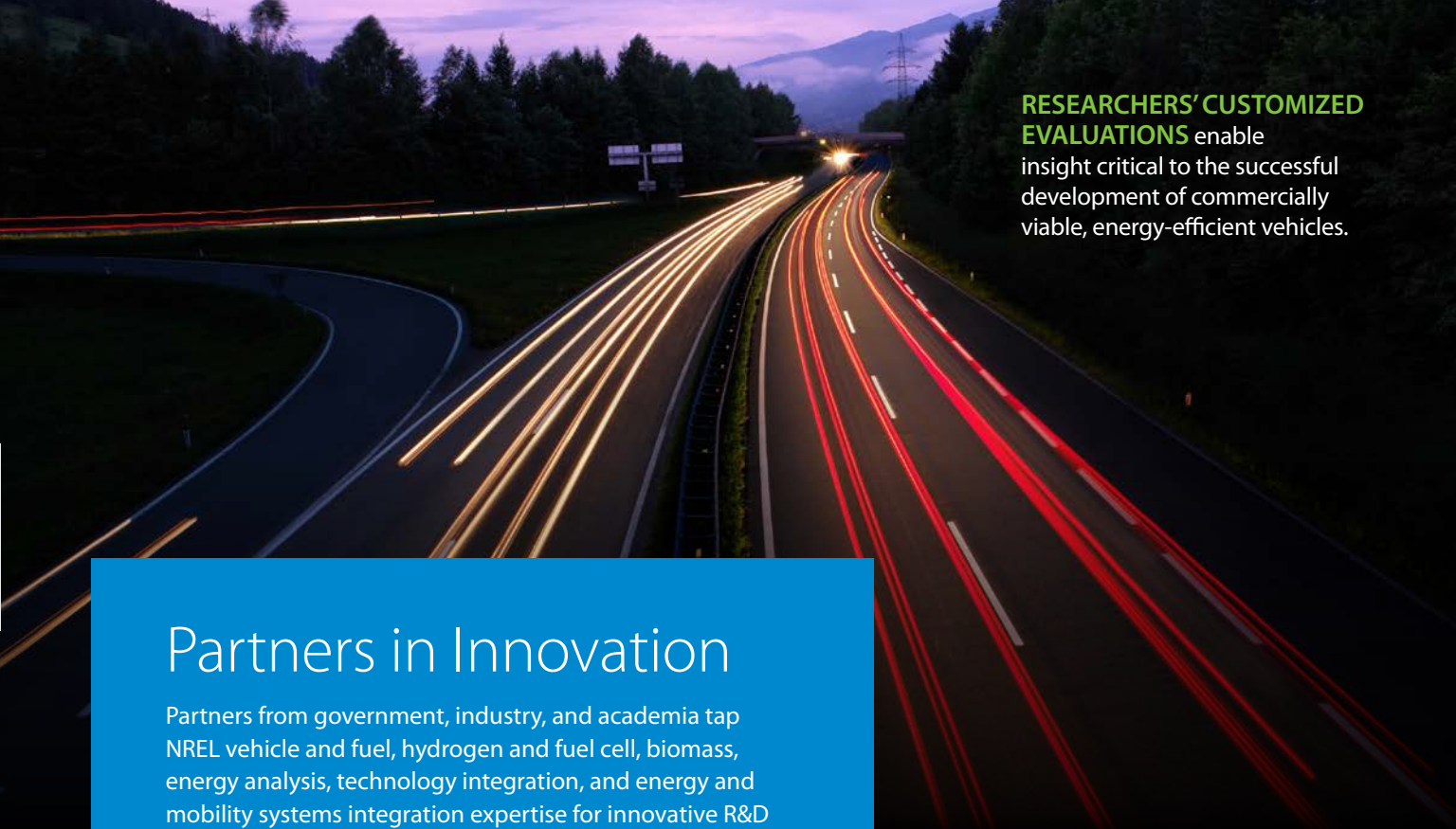
NREL researchers advance the science behind emerging hydrogen and fuel cell technologies and develop and validate new cost-effective, high-performance storage and delivery systems for transportation and other applications. Projects

range from fundamental research to achieve technical targets; manufacturing process improvements to enable high-volume fuel cell production; systems analysis to guide R&D and stakeholder decisions; and R&D to improve hydrogen fueling infrastructure, safety, and system integration.

### Commercial Vehicle Technologies

Trucks move more than 13 billion tons of freight across the United States each year. NREL helps truck manufacturers and fleet managers pinpoint fuel-efficient strategies to reduce operating costs while meeting performance requirements across vehicle vocations. Researchers' customized evaluations—of conventional and advanced vehicles, infrastructure, operational practices, and implementation considerations—along with NREL's suite of validated online tools, enable insight critical to the successful development of commercially viable, energy-efficient vehicles.





**RESEARCHERS' CUSTOMIZED EVALUATIONS** enable insight critical to the successful development of commercially viable, energy-efficient vehicles.

## Partners in Innovation

Partners from government, industry, and academia tap NREL vehicle and fuel, hydrogen and fuel cell, biomass, energy analysis, technology integration, and energy and mobility systems integration expertise for innovative R&D in support of:

- Biofuels, hydrogen, natural gas, propane, and petroleum-based fuels
- Electric, hybrid, fuel cell, and conventional vehicle technologies
- Charging and fueling infrastructure
- Vehicle connectivity, automation, and mobility systems.

For information on sustainable transportation partnership opportunities, visit [www.nrel.gov/transportation/working-with-us.html](http://www.nrel.gov/transportation/working-with-us.html).



### LEARN MORE

To learn more about NREL's sustainable transportation R&D, visit [www.nrel.gov/transportation](http://www.nrel.gov/transportation)



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