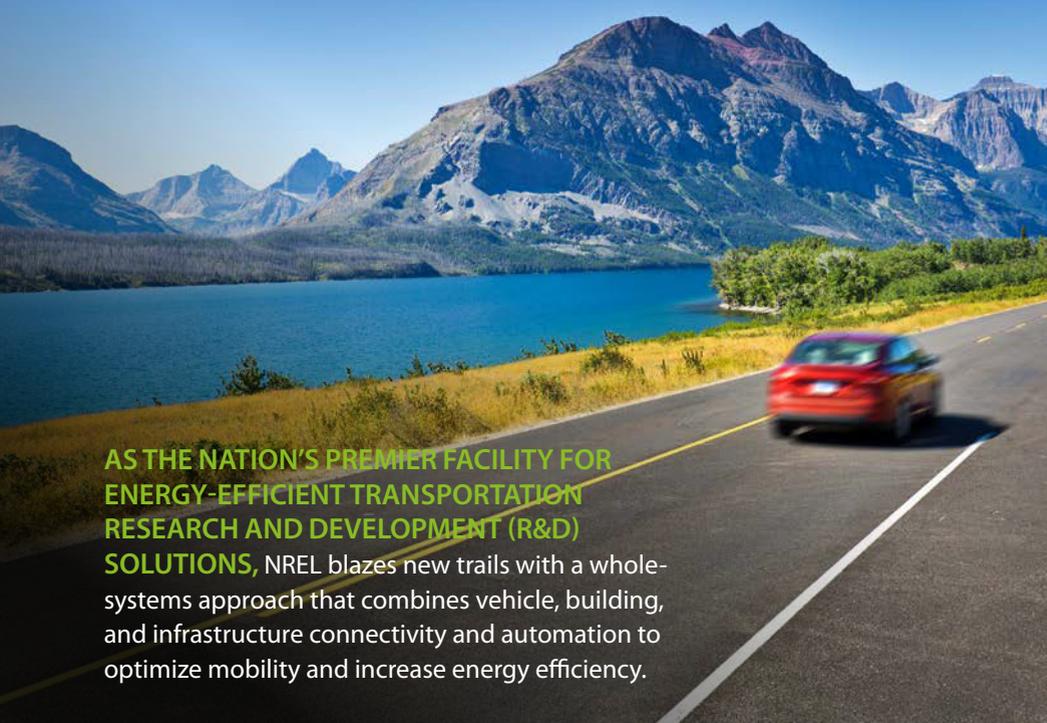




Transforming  
**ENERGY** through  
**SUSTAINABLE**  
Mobility

Expanding Energy-Efficient  
Mobility Options



**AS THE NATION'S PREMIER FACILITY FOR ENERGY-EFFICIENT TRANSPORTATION RESEARCH AND DEVELOPMENT (R&D) SOLUTIONS**, NREL blazes new trails with a whole-systems approach that combines 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 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 99 hours per 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 R&D, the 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 and fuels. The lab also explores ways to enhance the nation's mobility options, boost transportation energy efficiency, and minimize 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. The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy's Vehicle Technologies Office and Hydrogen and Fuel Cell Technologies Office support this work.



**NREL's** “mobility energy productivity” metric quantifies a given area’s ability to connect individuals to services and activities with respect to time, cost, and energy, while a new freight metric quantifies the ease of shipping goods between cities or states via various modes.

## 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.

**FOR MORE THAN 40 YEARS, NREL** has expanded American leadership and prosperity through research advances in energy efficiency, sustainable transportation, and renewable power technologies.

### **Sustainable, Affordable, and 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 approaches transportation as a network of travelers, services, and environments, using connectivity and automation to optimize mobility and overall system efficiency. NREL’s mobility energy productivity metric, or MEP for short, quantifies a given area’s ability to connect individuals to services and activities with respect to time, cost, and energy. Likewise, the Freight MEP quantifies the ease of shipping goods between cities or states via various modes and—when applied to major attractors such as airports (dubbed the Airport MEP)—measures the ease of accessing an airport from anywhere in a city.

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

New fuels, engines, and infrastructure will be required to meet ambitious energy-saving goals. NREL is a founding member of the Co-Optimization of Fuels and Engines initiative, a multi-lab collaborative effort, simultaneously exploring new options for high-performance fuels and advanced combustion engines to maximize

## CROSS-CUTTING INITIATIVES, CONTINUED

energy efficiency and on-road vehicle performance while minimizing 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 tenfold 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

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 advancements in cross-cutting research areas such as intelligent mobility system technologies, optimized passenger and freight mobility, fueling infrastructure, 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 and 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.

### Sustainable Transportation Integration and Evaluation

Transportation 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 industrywide research needs and priorities, and share data, tools, and information about emerging mobility technologies and strategies.

### 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 vehicles, power grids, renewable energy sources, and behind-the-meter storage options. 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 for passenger and freight vehicles.



## AS PART OF THE SILICON ANODE CONSORTIUM,

NREL is partnering with other National Labs to investigate the use of silicon as an anode material to improve energy density and reduce costs.



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

Although EDVs are rolling off assembly lines in ever-growing numbers, they currently command a relatively small 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.

### Fuel Chemistry and Combustion Science

Substantial advances in engine technologies and fuel components are needed to reduce energy consumption, lower drivers' costs, and reduce 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

To meet market demand for long-range, fast-charging, safe, and affordable EDV batteries, energy-storage systems must be able to manage high heat levels. 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. NREL is partnering with other National Labs as part of the Silicon Anode Consortium and the Behind-the-Meter Storage Consortium. The former investigates the use of silicon as an anode material to improve energy density and reduce costs, while the latter develops 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's "science of safety" research examines lithium-ion batteries under abuse conditions. NREL also spearheads ways to repurpose and recycle batteries when they are no longer useful in vehicles.

### Power Electronics and Electric Machines

While power electronics help run a wide range of systems in conventional gas-fueled vehicles, EDVs and high-power charging equipment rely even more heavily on these components. NREL R&D is making widescale EDV acceptance more feasible by developing power electronics and electric motor technologies



TRUCKS MOVE nearly  
**12 BILLION TONS**  
of freight across the United States each year.

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

and components with greater dependability, efficiency, and durability, while dramatically decreasing costs. This work, steeped in modeling and experimentation, has established the lab as a vital resource for reliability and thermal management of motor controllers, inverters, and traction motors, as well as sensors for mobility, energy-efficiency, and renewable-energy applications.

#### Fuel Cell and Hydrogen Technology Engineering and Analysis

NREL researchers advance the science behind emerging hydrogen and fuel cell technologies and develop 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; resource assessments, techno-economic comparisons, and financial modeling to guide stakeholder decisions; and R&D to improve hydrogen fueling infrastructure reliability and performance while reducing costs.

#### Mobility Behavior Science

Focusing on the interactions among people, mobility, the built environment, and energy systems, NREL's behavioral science R&D illuminates travel behavior and consumer choice, enabling the design of transportation systems that save consumers time and money. Research efforts improve our collective understanding of



**NREL's BEHAVIORAL SCIENCE RESEARCH**  
illuminates travel behavior and consumer choice,  
enabling the design of transportation systems that save  
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how people will respond to technology transitions and dynamic new mobility service offerings across spatial and temporal scales.

#### Intelligent Vehicles and Mobility Systems

NREL's intelligent vehicles and mobility systems R&D fuses the laboratory's world-class simulation and analysis tools with researcher expertise and a deep understanding of rapidly evolving mobility technology options, vehicle electrification, connected and automated vehicle technologies, and the underlying data infrastructure. Modeling and analysis activities focusing on advanced vehicle powertrains enable real-world and "off-cycle" fuel-efficiency impact assessments of thermal management technologies, driving behavior, eco-routing, eco-driving, and more.

#### Commercial Vehicle Technology Development and Evaluation

Trucks move nearly 12 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 such as freight delivery, public transit, port drayage, yard tractors, airport shuttle service, and more. Researchers' customized evaluations—of conventional and advanced vehicles, infrastructure, operational practices, and implementation considerations—along with NREL's suite of validated online tools, enable insights critical to the successful development of commercially viable, energy-efficient vehicles.



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

## Partners in Innovation

Partners from government, industry, and academia tap NREL expertise in vehicles and fuels, hydrogen and fuel cells, biomass, energy analysis, sustainable technology integration, and energy and mobility systems integration 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)



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

## Expanding Energy-Efficient Mobility Options

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