NATIONAL
LABORATORY
OF THE ROCKIES

VEHICLE TECHNOLOGIES

FISCAL YEAR 2025
ANNUAL REPORT

Contents

Fueling the Future:
NLR'S Transportation R&D Strengthens U.S. Leadership, Delivers Economic Impact

America's transportation and energy systems are at a crossroads—evolving faster than ever and becoming inseparable in their impact. With demand for energy surging and innovation accelerating, the opportunity before us is clear: not simply to adapt, but to lead.

At the National Laboratory of the Rockies (formerly known as NREL), our transportation research is driven by a simple conviction—that the hardest problems are worth solving. We are reimagining supply chains to reduce risk and strengthen resilience. We are unlocking new materials to make batteries dramatically cheaper and more capable. We are harnessing advanced, high-performance computing power to accelerate the development of domestically produced fuels. And we are applying artificial intelligence (AI) to ensure both people and goods move across America's vast infrastructure more reliably, affordably, and faster than ever before. Each of these efforts is bold on its own. Together, they chart a course toward an energy and mobility system that powers not just our economy, but our future.

And while we are firmly fixed on the future, it's also important to highlight the journey. Over the past year, the NLR team has accomplished milestones worthy of recognition—earning titles such as "World's first," "NASA Invention of the Year," and "R&D 100 Finalist," while achieving breakthroughs like "95% cost savings" and a "400% increase in power density." These are markers of momentum.

With a clear focus on innovation and impact in mobility and energy systems—at NLR, we are just getting started.

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NLR AT-A-GLANCE

4 CAMPUSES • 4,000+ EMPLOYEES

World-Class Research Expertise In:
- Energy Systems Integration
- Transportation and Fuels
- Buildings and Industry

1,100+ Partnerships With:
- Industry
- Academia
- Government

GOLDEN CAMPUS

FLATIRONS CAMPUS

FAIRBANKS, ALASKA, CAMPUS

WASHINGTON, D.C., OFFICE

NLR'S FY25 VEHICLES PROGRAM BY-THE-NUMBERS

Equivalent of **130 full-time staff** spanning **every NLR research organization** supporting VTO projects.

100+ projects with private industry, academia, and state and local governments that leverage and enhance VTO research outcomes.

$60.38M in vehicles-related industry and research partnership agreements with **91** unique organizations.

40 active licensing agreements, 31 records of invention, 2 patents granted, and **10 patent applications** initiated.

243 peer-reviewed publications were produced, including **75 journal articles** (**up 8.7%** from 2024). Of these, **17 articles** were published in journals with an **impact factor above 10.**

The U.S. Department of Energy's Vehicle Technologies Office is the largest single user of NLR's high-performance computing (HPC) capabilities, accounting for **over 1/4 of all HPC utilization** and enabling large-scale computing and AI-informed research.

LEADERSHIP HIGHLIGHTS

NLR Expertise Bolsters Cost-Effectiveness of Advanced Mobility Technologies

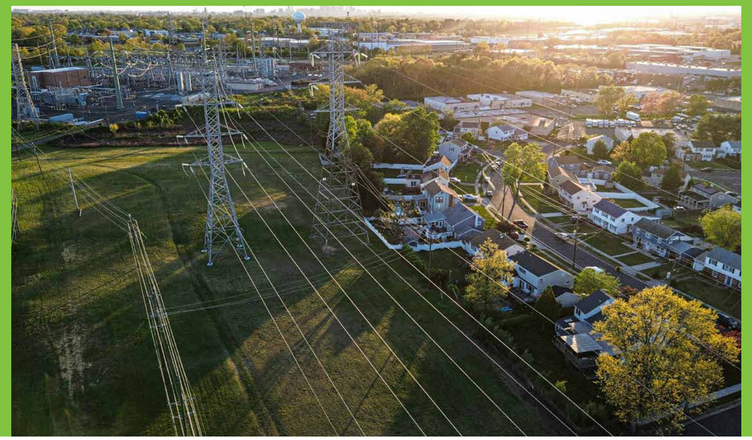
Conducting thoughtful analysis and devising useful tools and models are all in a day's work for National Laboratory of the Rockies (formerly known as NLR) researchers striving to develop and de-risk innovative transportation technologies and ensure that America's energy system can support those advancements into the future.

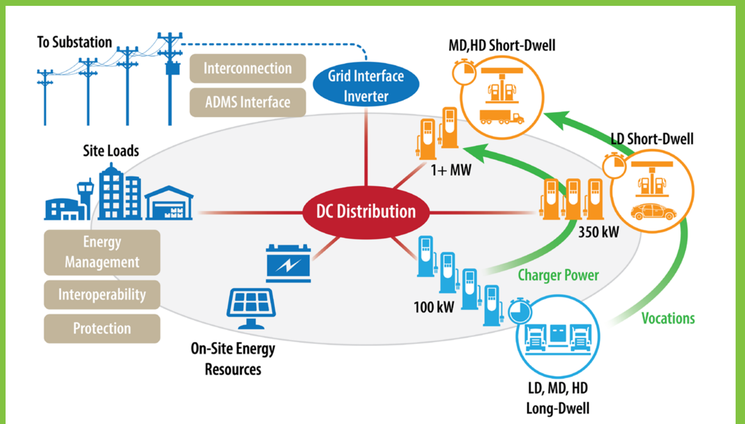
Ensuring energy security and reliability of vehicles and the grid are top of mind, from advancing new approaches for strengthening the energy grid to support the needs of data centers and various transportation applications, developing standards for high-power charging of long-haul heavy-duty electric trucks, and more. Researchers are also exploring pathways to boost strategic adoption of domestic critical material sources to strengthen manufacturing, build a resilient supply chain, and lower costs for consumers.

These front-line NLR efforts are driving resilience and securing the long-term future of America's transportation and energy innovation.

Diagnostics for Degradation: Advanced Characterization Techniques Are Helping NLR Researchers Build Better Batteries

- **A Closer Look:** Energy experts are using NLR's state-of-the-art X-ray nanoscale computed tomography (nano-CT) scanner to reveal hidden flaws in battery materials that may impact their performance. Combined with NLR's Microstructure Analysis Toolbox, this imaging allows researchers to quickly assess battery health, charging systems, and recycling processes.
- **Faster Analysis:** NLR researchers have developed industry-leading AI models and machine-learning methods to improve the way we diagnose battery health, predict battery degradation, and optimize battery designs. These tools include a physics-informed neural network that can predict battery health nearly 1,000 times faster than traditional models.
- **The Big Picture:** NLR's expertise in electrochemical characterization is driving innovation throughout battery lifetimes, from safer battery systems to end-of-life resource recovery.





High-Power Charging and Control Strategies Boost Grid Performance

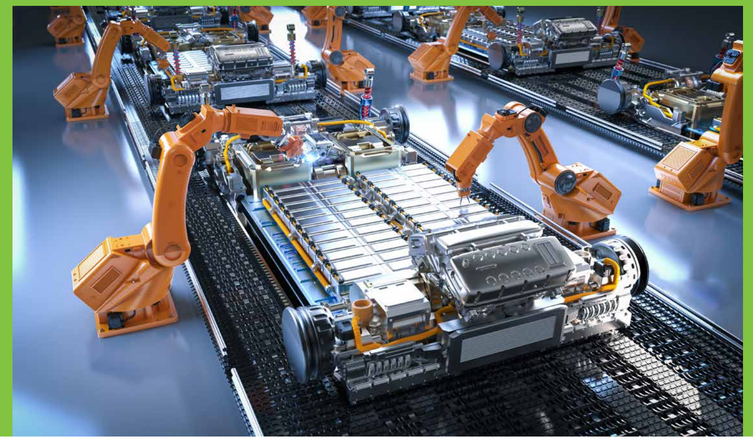
- **What To Know:** NLR researchers are identifying and de-risking solutions to enable next-generation technologies that reliably integrate transportation with the grid. NLR is proactively developing the equipment and technical specifications needed to accommodate large electric loads from industries such as trucking, rail, mining, and advanced aviation applications.
- **High-Powered Solutions for Complex Energy Challenges:** NLR is supporting efforts to develop the Megawatt Charging System to facilitate reliable, interoperable charging capacity of up to 3.75 MW—a power level that is necessary for energy-intensive applications like medium- and heavy-duty on-road, off-road, and nonroad applications. This year, NLR installed three custom direct-current (DC-DC) charging systems to convert from an 800-V DC hub to up to 1,000 V DC.
- **Strengthening the Grid for What's Next:** NLR's upcoming Megawatt Charging Emulator at the lab's Flatirons Campus will enable researchers to assess and design charging technologies and control strategies that operate up to 10 MW, with megawatt-scale generation and storage, a megawatt-scale battery emulator, a DC-as-a-service microgrid, and megawatt-level charging evaluation to boost the grid's performance rather than placing it under strain.

NLR Enables Major Utility To Evaluate Charge Management Strategies With Real Data

- **The Partnership:** NLR partnered with Xcel Energy to analyze options for the utility to reduce potential grid infrastructure expansion expenses while ensuring affordability for ratepayers by absorbing additional electric vehicle (EV) charging loads through smart charge management (SCM) strategies.
- **Streamlining Decision-Making:** NLR researchers used the lab's Electric Vehicle Infrastructure – Distribution System Integration Tool (EVI-DiST) to reduce the burden on Xcel Energy to identify solutions. The team found that that SCM strategies allowed for the full completion of over 94% of charging events on the existing distribution networks of the regions studied and would notably reduce utility upgrade costs.
- **A Resource for All Utilities:** NLR is expanding access to EVI-DiST by launching an open-source version of the tool. Any utility planner will be able to input their unique service area data from the transformer and feeder levels and view in high-resolution detail how different SCM strategies would meet customer needs and impact any needed utility upgrades.

Project Unlocks Potential for High-Efficiency DC-Based Microgrids

- **Innovative Design for Many Applications:** Instead of converting alternating-current (AC) power from grid transformers to DC power at locations like high-power charging sites, a DC-based hub can handle conversions at the site level, streamlining power delivery, cutting costs, reducing energy loss, and boosting efficiency. This approach not only applies to high-power charging sites, but also supports DC microgrids for energy storage, data centers, mining operations, and other critical facilities—unlocking scalable, multisector benefits. DC hubs also reduce the copper used in power distribution, reducing strain on critical minerals.
- **How NLR Is Making It Happen:** Through the High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP) project, NLR, in partnership with Argonne National Laboratory (ANL) and Oak Ridge National Laboratory (ORNL), is investigating the power and control hardware and software needed to develop a DC charging hub for high-power charging. The project is validating the design at NLR's Energy Systems Integration Facility and has the potential to scale up to the megawatt level.
- **What's Next:** NLR researchers will demonstrate advanced grid interactions using a DC hub test platform and real-time simulations to explore control approaches, including distributed controls for enhanced resiliency. The platform will validate controllers with newly acquired DC-DC high-power chargers and a 1-MW grid-tie inverter, while simulations assess scalability and site reliability.



NLR Models Drive Integrated Insights Across Complex Energy and Mineral Supply Chains

- **What To Know:** NLR researchers are exploring innovative, data-driven approaches to maximize the efficient and strategic use of domestic resources. Expert analysts continue to track the global flow of raw materials and critical minerals from mineral extraction to application in key vehicle components such as motors and batteries.
- **Digging Deeper:** The NLR-developed Lithium-Ion Battery Resource Assessment Model (LIBRA) evaluates how rising demand for lithium-ion batteries presents opportunities to grow domestic manufacturing and build a resilient and robust supply chain. LIBRA explores the technological advances and market signals that could affect global supply of raw materials, primary and recycled batteries, and EVs.
- **On the Horizon:** New research—supported by DOE's newly established Office of Critical Minerals and Energy Innovation (CMEI)—builds upon LIBRA's success to create an end-to-end modeling framework for interconnected energy supply chains. This integrated analysis provides a holistic view of mining, refining, processing, manufacturing, and resource recovery to meet rising energy demands.

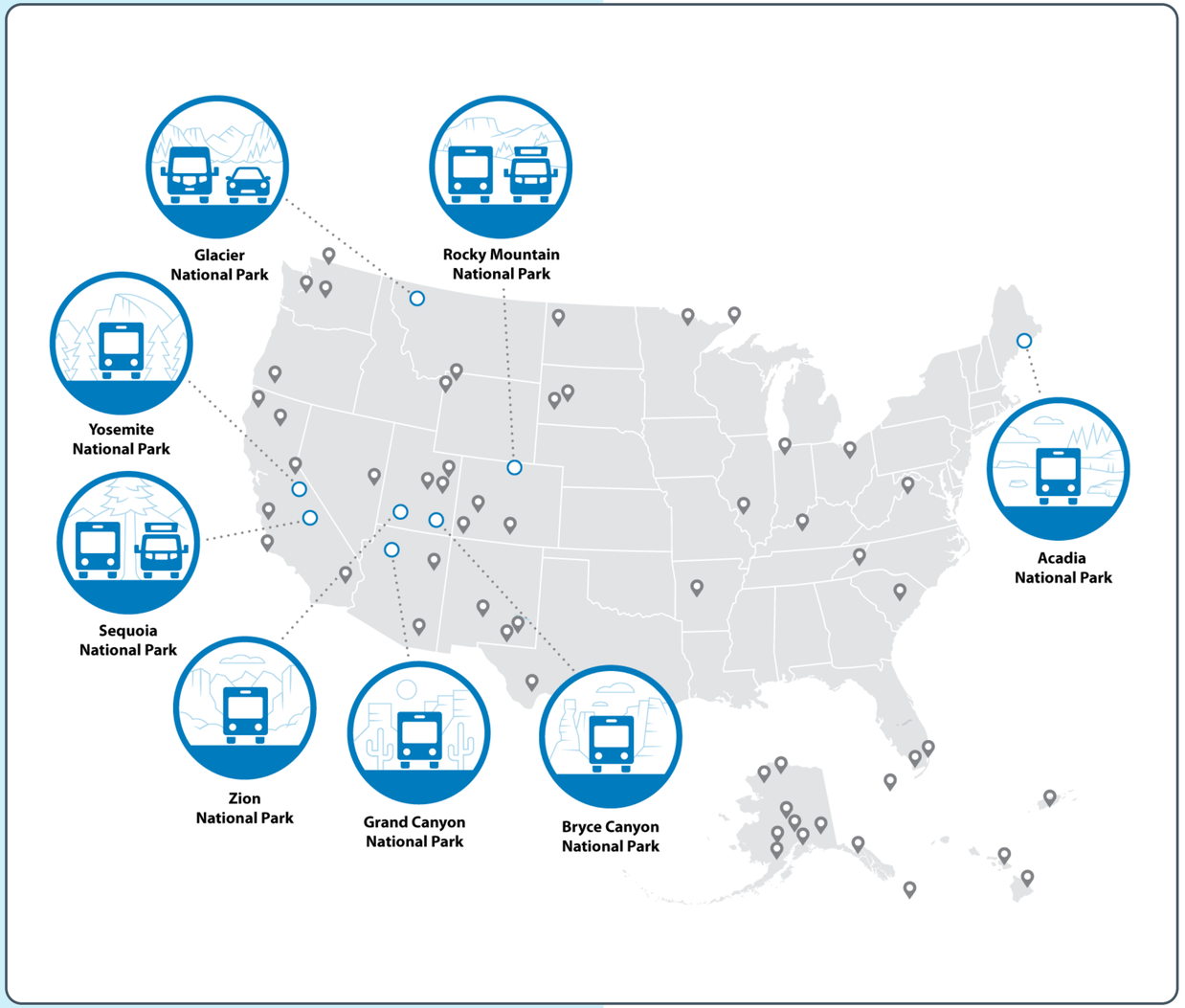
Strengthening U.S. Battery Supply Chains: NLR Research Enables Rapid Materials Validation

- **Core Info:** The Enhanced Validation of Advanced Battery Supply Chains (EVALS) consortium, supported by NLR, is developing methods that accelerate the adoption of domestic materials sources to strengthen manufacturing. Rapid throughput assessments can increase access to crucial battery minerals by streamlining the process to bring new material sources online.
- **The Details:** A key component of the EVALS consortium is enhancing our understanding of material purity impacts to determine acceptable purity levels that maintain battery performance while driving down costs. This year, NLR's team developed a novel synthesis process for LiFePO4 battery cathodes tailored to low-cost precursors available in the United States—laying the groundwork for more competitive domestic battery production and leading to an NLR record of invention. The team also created a machine-learning model that predicts battery degradation from early data, enabling faster, cheaper performance assessments that will reduce costs for product development and operations.
- **Zooming Out:** Coordinated testing, prediction, and modeling tools developed at NLR facilitate rapid source validation, giving manufacturers confidence in emerging materials suppliers, and illuminating new production pathways and techniques.

NLR Analysis Drives Cost Savings and Operational Efficiencies at 8 National Parks

While NLR researchers have worked with dozens of national parks over decades, their efforts at Zion, Yosemite, Bryce Canyon, Grand Canyon, Acadia, Rocky Mountain, Sequoia, and Glacier National Parks have focused on upgrading the 20- to 60-foot buses and small shuttles that bring visitors to popular park destinations.

Researchers analyzed the potential for these parks to modernize their fleets. Higher-performing, cost-saving shuttles can reduce operational costs for parks, lower noise levels, and reduce traffic and crowding in our nation's most beautiful places.



Port and Freight Optimization Drives U.S. Economy Forward

The United States relies on a vast freight transportation network to keep the economy—and the nearly 20% of U.S. gross domestic product that flows from exports and transportation services—humming. With more goods traversing our ports, highways, railroads, waterways, and skies each year, strengthening our freight systems is critical.

NLR research bolsters each link in these complex chains, from accelerating new vehicle and equipment technologies to streamlining freight logistics. With our expertise, complexity becomes efficiency—and the United States prospers from lower shipping costs, faster delivery times, and resilient systems that work in concert to drive our economy forward.

First-Ever National Intermodal Freight Modeling Tool Nears Completion

- **How Intermodal Freight Improves Shipping:** Steel and aluminum containers packed full of goods—which aren't unpacked between destinations—can be seamlessly transported via truck, ship, train, or plane. Deliveries can be tuned to offer low shipping costs, fast delivery times, fuel savings, and other desirable attributes.
- **NLR's Breakthrough:** NLR is developing the INtermodal Freight Optimization for a Resilient Mobility Energy System (INFORMES) framework to support a national rollout of intermodal freight transportation. INFORMES will be the nation's first-ever modeling tool for coast-to-coast intermodal freight movement, infrastructure planning, and logistics refinement. The publicly accessible tool is slated for completion in 2026.
- **Why INFORMES Matters:** It will give ports, railroads, trucking companies, shipping agencies, and other stakeholders access to a tool that can lower costs, speed deliveries, and help route shipments around accidents and disruptions—on a national scale. By streamlining our freight shipments, INFORMES will give the United States a competitive economic edge.

Aeroportal Puts Optimization Tools in Airports' Hands

- **Why Airports Need Energy Expertise:** Airports are sprinting to improve their ability to transport record numbers of travelers to, through, and from terminals. While they seek to adopt advanced transportation and operational equipment, they need to ensure they make informed, strategic, coordinated, and comprehensive decisions to avoid increased costs or stress on the grid.
- **How Aeroportal Helps:** NLR is putting its airport modernization tools directly into the hands of airports nationwide through the Aeroportal. An offshoot of the Athena project, the Aeroportal will give airports access to modeling tools that can show the best strategies for managed charging that minimize electricity costs, optimize vehicle and equipment performance, and bolster the stability of the grid.
- **Looking Ahead:** Fifteen major airports have partnered with NLR to develop the Aeroportal. Athena is using machine learning to provide airports with the full power of NLR's high-powered computing capabilities, to perform high-fidelity analysis and modeling in a nimble, responsive, web interface package.

T3CO Equips Fleets With the Most Sophisticated Cost Insights Available

- **Why Total Cost of Ownership Is Complex:** Thanks to lower maintenance, operating, and energy costs, next-generation vehicles can save commercial fleets and businesses money. But these vehicles are far less standardized than their diesel counterparts, making their full life cycle costs harder to calculate.
- **The T3CO Difference:** NLR's Transportation Technology Total Cost of Ownership tool, known as T3CO, enables fast analyses that provide insights into the full lifetime costs of advanced vehicles, from upfront investments to the opportunity costs presented by recharging and refueling.
- **Why T3CO Is Groundbreaking:** The user-friendly T3CO tool and its web-based dashboard T3CO-Go provide ownership cost analysis with a level of detail that hasn't been possible in the past. T3CO is a major component of the Federal Transit Administration's (FTA) new Transit Bus Selection Tool, which allows transit agencies to make vehicle purchasing decisions based on total cost of ownership estimates.

ÆNodes Shows Regional Airports How To Become Local Energy Suppliers

- **On-Site Energy Generation Helps Airports:** Regional airports have a win-win opportunity: investing in local energy generation and storage. Not only can they sell electricity back into the grid—they can also serve as a local source of grid stability by providing backup energy.
- **NLR and NASA Are Accelerating the Opportunity:** Through the Airports as Energy Nodes (ÆNodes) project, NLR and NASA are investigating how airports can leverage energy generation and storage infrastructure to sell energy back to their local grids, thereby boosting regional energy reliability. The findings will inform a repeatable research model available to the United States' 5,000 public airports.
- **How ÆNodes Helps:** The ÆNodes model will show regional airports how to configure their electrical systems for local use—as a source of energy backup and potential economic revenue. These findings can boost profits and cut costs for smaller airports, as well as increase grid reliability in surrounding regions.

ALTRIOS-LIFTS Details Energy Use Inside a Freight Terminal's Gates

In 2024, the United States shipped $2 trillion of exported products around the world—all thanks to the nation's port system. To sharpen the nation's economic edge, researchers at NLR and the University of Texas at Austin are building a new module within the Advanced Locomotive Technology and Rail Infrastructure Optimization System (ALTRIOS) called ALTRIOS-LIFTS (Line-haul Intermodal Freight Terminal Simulator).

ALTRIOS-LIFTS allows users to model every movement of a container within a freight terminal. With fine-grained detail, it tracks:

- The energy required by each step of a container's journey through the port.
- The actions taken by every piece of equipment—from miles driven by a yard tractor to lifts completed by a crane.
- The time associated with each step.
- A terminal's total energy consumption in real life or during hypothetical scenarios.

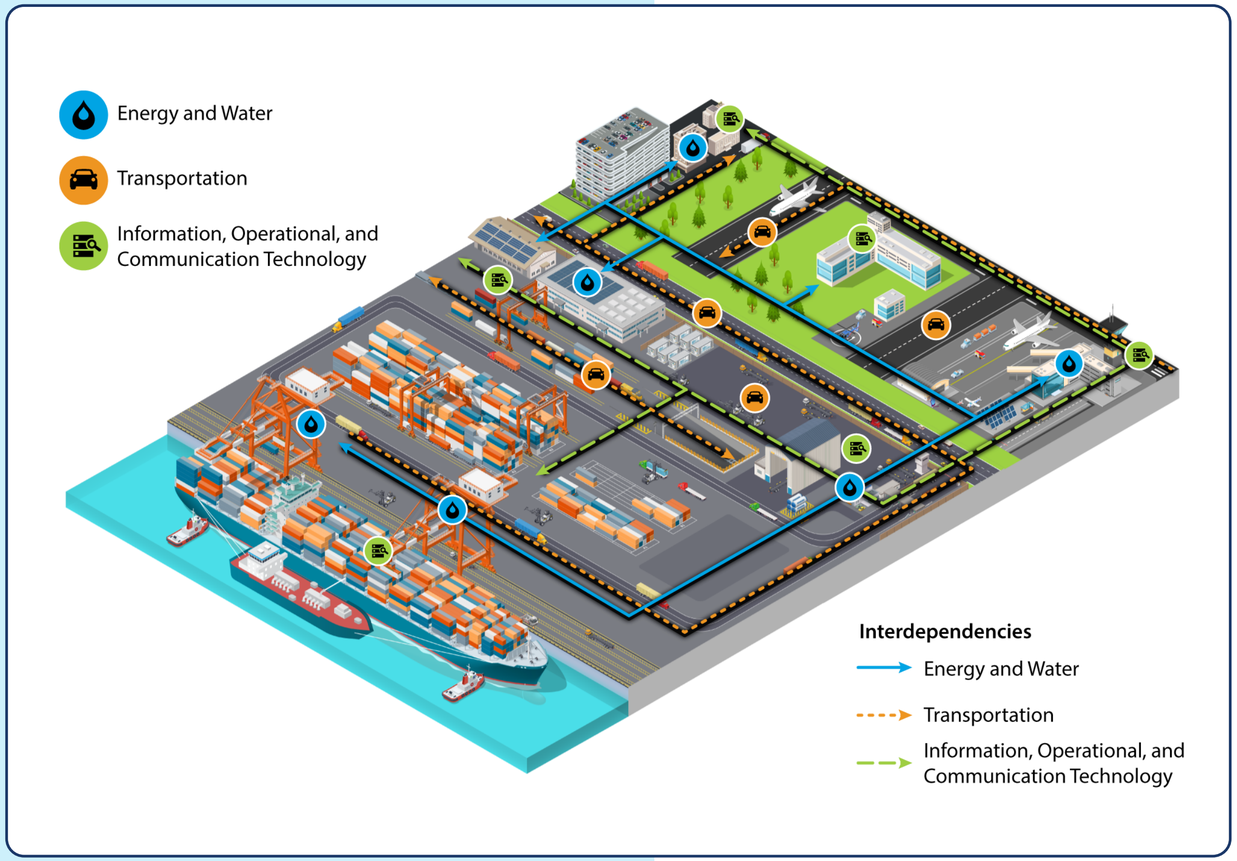
Like a high-resolution camera, ALTRIOS-LIFTS gives users both a clear, big-picture view of a terminal's operations and a crisp, "zoomed-in" understanding of minute actions by single pieces of equipment.

Users can look at the impacts of automation and electrification within a terminal, see where terminal operations are creating bottlenecks, and pinpoint areas where optimization is needed to achieve faster, more affordable freight transportation.

Resilient Ports Strengthen U.S. Supply Chains, Trade, and Manufacturing

If goods are the lifeblood of American trade, ports are the nation's arteries. These critical nodes are integral to the nation's prosperity and security. Modernizing and reinforcing the energy systems and operational strategies of the United States' airports, seaports, and inland ports can strengthen domestic supply chains and sharpen the nation's economic edge.

NLR's integrated port modernization strategy leverages abundant sources of domestic energy coupled with flexible energy storage solutions. In turn, the laboratory charts the path to affordable, secure, and modernized ports.



Planes, Trains, and Off-Road Vehicles Reach New Performance Heights at Lower Costs

When it comes to the heaviest vehicles on Earth—planes, trains, and off-road equipment—even minor improvements to powertrains and components can create significant cost, energy, and time savings. But NLR's research extends far beyond minor improvements. Our off-road and nonroad transportation research reimagines vehicles and systems from the ground up to unlock new efficiencies, advance American industry, and strengthen our global economic edge.

NLR's ALTRIOS Tool Enables Fast, Flexible Freight Rail Deliveries in the Heart of Georgia

- **The Details:** Over the past 3 years, NLR has helped disruptive rail manufacturer Parallel Systems successfully reimagine the centuries-old concept of a train—shifting from a miles-long, rigid procession of railcars to highly efficient, self-propelling cars that can quickly connect and disconnect. Most recently, NLR leveraged the ALTRIOS software to simulate the operations of Parallel Systems' next-generation rail vehicles along sections of Genesee and Wyoming's 177-mile Heart of Georgia rail line.
- **How?** ALTRIOS shows Parallel's rail vehicles can reduce the energy costs of rail shipments by more than 75% and can increase locomotive safety by reducing stopping distances by 90%. And together with an optimized dispatching strategy, Parallel can slash container delivery times by nearly 70%.
- **Rolling Out:** NLR's evaluations formed the basis of Parallel Systems' successful petition for a Federal Railroad Administration-approved pilot of the self-propelled rail vehicles, slated for completion in 2026. The technology has the potential to make short-line railroads more competitive with the trucking industry. It could create opportunities to open new rail markets, allow for reinvigorated traffic on rural rail lines, and reduce congestion on the nation's busiest highways, creating economic opportunity for communities along the way.

Silicon Carbide Inverter With "Never-Before-Seen" Performance Set for Commercialization at John Deere

- **The Breakthrough:** In partnership with John Deere, NLR researchers helped craft a silicon carbide (SiC) traction inverter for heavy-duty vehicles with never-before-seen performance. The inverter is capable of roughly 400% greater power density than previous silicon-only designs.
- **How It Works:** NLR researchers developed a custom thermal management design that simplifies the inverter's architecture, reduces its size and weight, and allows for reduced fuel use at a lower manufacturing cost. Extensive evaluation in John Deere's heavy-duty 644 K hybrid loader showed the inverter can operate at high temperatures, under high pressure, and at a lower cost, thanks to significant fuel reductions.
- **Looking Ahead:** The traction inverter is set to be adopted into a production-intent program at John Deere. The manufacturer is now poised to commercialize the first off-road SiC inverter.

NLR Combustion Simulations Equip Aviation Industry To Accelerate Next-Generation Jet Fuel

- **What To Know:** Powered by more than 50 years of DOE's applied mathematics research, NLR leverages its Pele combustion modeling suite to model complex reacting flows—including the operations of NLR's "virtual jet engine." The computations require massive throughput: When NLR researchers ran Pele's combustion calculations on ORNL's exascale computer, Frontier, they used more than three-quarters of its 9,000 compute nodes. The collaboration, made possible due to the two laboratories' unique capabilities, is now informing simulation of an experimental aviation combustor.
- **New Research Taking Flight:** The simulations generated at NLR are now being used to model an experimental combustor for advanced aviation fuel at the Georgia Institute of Technology. The results will validate NLR's conventional jet fuel computations and generate new data on the performance of emerging jet fuels. Combined, the data and NLR's ability to simulate new formulations of jet fuels will help advance cost-effective new aviation fuels and assist in modernizing ASTM D1655, the jet fuel originally developed in 1959.
- **Creating Affordable, Safe, Scalable SAF:** NLR's ultra-detailed models can predict how advanced jet fuels perform during flight and help identify which fuel properties can be advanced while preserving safety and performance. These SAF simulations equip the aviation industry with tools to accelerate the development of next-generation jet fuels and avoid costly surprises during approval processes by organizations like ASTM International.

AI Allows Farm Tractors To Harness 50% More Hydraulic Efficiency

- **The Background:** Most modern tractors use a hydraulic system to move their cylinders and pistons, but can only pump hydraulic fluid at a single pressure, requiring tractors to throttle back unneeded pressure. In response, researchers at Purdue University developed a new system that can provide three different levels of hydraulic pressure to farm tractor components.
- **NLR's Novel Controls System:** In a major refinement of Purdue's three-pressure system, NLR researchers unveiled an innovative controller that can precisely calibrate the hydraulic pressure that reaches each tractor component. It is equipped with a machine-learning system that allows it to adjust its operations in real time, creating maximum hydraulic efficiency.
- **Why It Matters**: Increasing the amount of hydraulic energy converted to useful work presents an immediate opportunity to increase farm vehicles' productivity while also lowering fuel costs for farmers across the country. And the novel controls framework NLR developed has applications in nearly every off-road sector—from freight rail to marine vessels and aviation.

Strategic Transportation Partnership Projects Lend World-Class Expertise to Today's Technology Challenges

NLR brings world-class research, leading technical experts, and real-world solutions to strategic transportation partnerships. In FY 2025, NLR worked with numerous industries, government agencies, and research organizations on projects that examined the techno-economic impacts of emerging energy technologies, removed technical barriers to transportation projects, and enabled new use cases with advanced energy technologies.

NLR Helps U.S. Army Double Range of Combat Vehicles With Next-Generation, Highly Efficient Technology

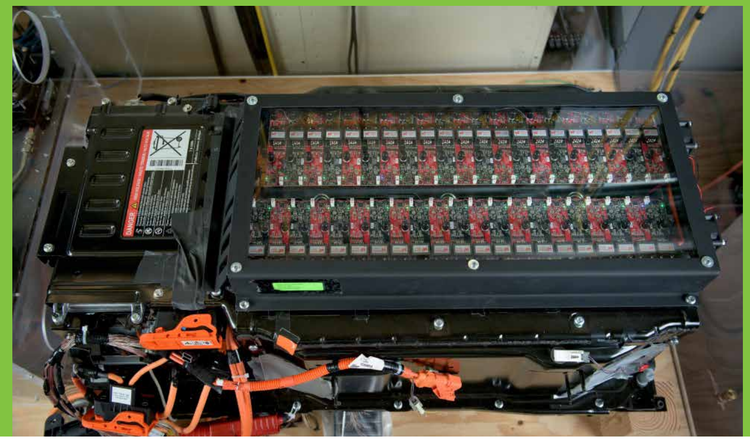
- **The Details:** The U.S. Army is hybridizing combat vehicles to extend range and achieve tactical advantages against enemy vehicles. At their Combat Capabilities Development Command Ground Vehicle Systems Center, a compact, 200-kW, high-temperature traction inverter can be mounted directly on the traction motor and significantly improve ground combat vehicle range.
- **The Challenge:** While compact traction inverters achieving power density such as 100 kW/L at 70°C have been demonstrated, maintaining high power density at high ambient temperature (105°C) using only radiator coolant is extremely challenging. The PICHOT power inverter overcomes this by linking to the existing engine coolant system, allowing full-power operation in 105°C environments without the need for additional coolant loops.
- **Delivering Real-World Impact:** The PICHOT inverter doubles the range of U.S. military ground combat vehicles and saves 53% on fuel. This unique project has NLR developing real hardware for combat vehicles, with the design blueprint to be licensed to defense contractors for mass production.

Massachusetts Port Authority Taps NLR Combustion Research To Bring SAF to Market

- **What To Know:** NLR researchers are conducting modeling and analysis to identify potential feedstocks and pathways to produce SAF in New England. Researchers are also evaluating jet fuel logistics to determine how to blend and move SAF within the region.
- **The Details:** After learning about NLR's combustion research capabilities and a study the lab performed for the Port Authority of New York and New Jersey, the Massachusetts Port Authority (Massport) requested a SAF analysis for the New England region. Massport launched a Massachusetts and New England SAF Regional Hub in June 2025 for collaboration across industry and sectors and aims to catalyze SAF adoption. NLR is conducting a SAF resource assessment, techno-economic analysis, and logistics assessment to inform and guide investments in SAF.
- **Zooming Out:** The Massport project positions Massachusetts and New England at the forefront of aviation innovation. NLR will help Massport prepare the New England region, an area with a population of more than 15 million, to distribute, produce, and use SAF.

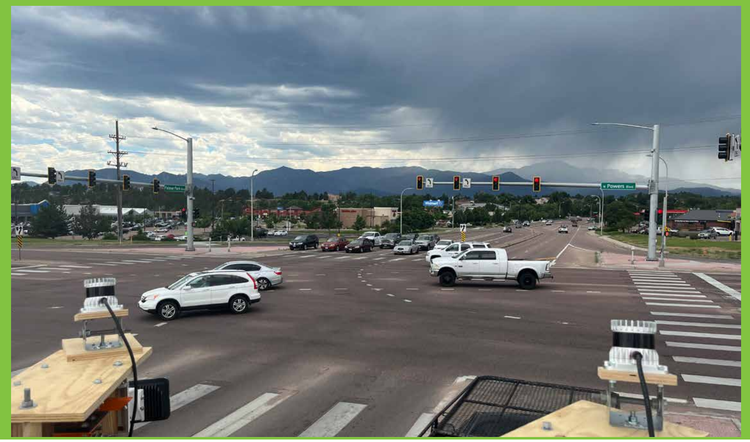
Advanced Technologies To Enable V2X Capabilities for Military and Commercial Fleets

- **The Background:** NLR and Eaton Corporation are developing a DC power system architecture to enable safe, reliable, and cost-effective megawatt-scale operations in military and commercial applications. This system supports scalable, grid-resilient charging infrastructure, with advanced bidirectional fast chargers and techno-economic analysis to demonstrate benefits across military and commercial applications.
- **What's Happening:** NLR is partnering with Eaton Corporation to validate high-power controller hardware and software solutions by integrating Eaton site controller hardware into a DC high-power charging test bed at the lab's Energy Systems Integration Facility. Using NLR's open-source site energy management system for protocol translation, the project enables SCM, vehicle-to-grid (V2G) capabilities, and flexible charging operation use cases that seek to enhance reliability and affordability of mobile and stationary assets.
- **Why It Matters:** Advanced DC-based charging infrastructure modeling, simulation, and hardware testing integrate new technologies into a commercially viable solution that simplifies moving innovations from lab to market, validates end-to-end performance, lowers cost of operation, and improves safety.



NLR Analysis and Validation Supports NHTSA Initiatives for Safer Vehicle Battery Management Systems

- **The Work:** NLR is collaborating with the National Highway Traffic Safety Administration (NHTSA) to evaluate vehicle safety with high-voltage batteries. The laboratory is leading and executing all aspects of a multifaceted project that spans computer modeling, battery cell validation, EV battery management system validation for fault protection, evaluation and analysis of market tools related to battery safety state assessment, discharging battery stranded energy after a vehicle incident, and emergency responder outreach, education, and training.
- **What's Happening?** This work focuses on the distinct safety challenges and risk reduction strategies related to high-voltage battery systems in vehicles. NLR's tool evaluation and analysis, alongside EV battery management system vehicle validation, represents developing efforts aimed at supporting NHTSA regulatory programs and assisting emergency responders in managing field incidents.
- **Why It Matters:** Validating functionality of vehicle battery management systems ensures their safety on the roads and provides valuable insights into other battery applications. Although vehicle fires involving high-voltage batteries are rare, they present distinct challenges for firefighters, as one approach is to use significant amounts of water and extended time to extinguish, while accounting for a risk of reignition. As more vehicles with high-voltage batteries drive on the roads, it's crucial to better understand battery safety and improve how responders assess, manage, and transport these vehicles after incidents occur.



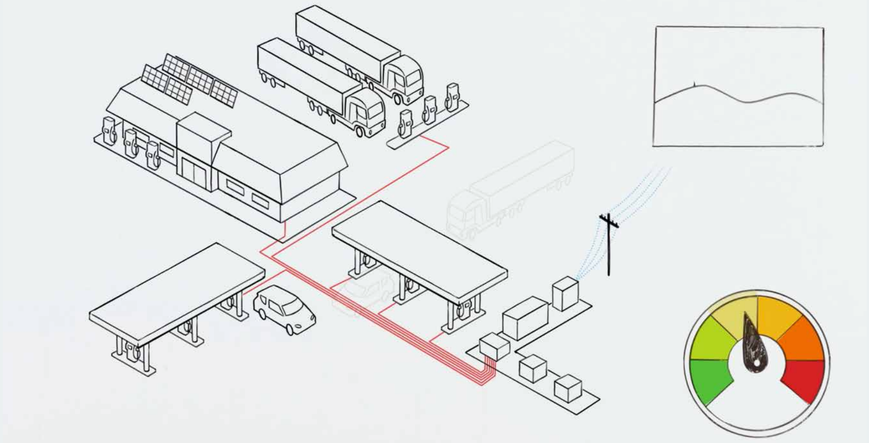
City of Colorado Springs Partners With NLR To Optimize Sensor-Based Traffic Management

- **The Project:** NLR's expertise in infrastructure perception and control helped the city of Colorado Springs implement adaptive traffic management solutions through the use of sensors at traffic intersections. The project focused on demonstrating how data from various types and numbers of sensors at intersections across the city could be collected and combined, with a goal to improve understanding of the city's traffic patterns. NLR's data collection spanned radar, LiDAR, image processing, and connected vehicles using RTK GPS.
- **The Need:** The city's existing intersection sensors typically serve only one application, which limits how much data can be collected and analyzed. NLR researchers introduced a new approach that provides a framework to leverage the unique attributes of each type of sensing, along with connected vehicles to develop a digital twin—or a virtual replica of a real sensor—to analyze multiple application goals including safety, efficiency, and travel time.
- **Scaling Traffic Data Enables Informed Improvements:** More robust and comprehensive data collection demonstrated proof that sensor fusion was possible for the city of Colorado Springs, thereby supporting informed local decision-making for future intersection improvements. NLR's findings provide a pathway for critical traffic safety applications at scale in a city with nearly 500,000 residents.

NLR Institutional Investments in Support of VTO

State-of-the-Art Facilities Power Progress, Capabilities Expansion

NLR's facilities are evolving to meet the nation's most pressing energy challenges—advancing the performance of today's technologies, while pioneering the solutions of tomorrow. By harnessing America's abundant energy resources, these upgrades are improving the affordability, security, reliability, and scalability of energy systems. As the nation's premier energy systems integration laboratory, NLR is fueling economic growth and strengthening America's position as a global leader in energy innovation through collaborations with industry, academia, and government partners.



ARIES Platform: Supercharging Grid and Transportation Integration

NLR's Advanced Research on Integrated Energy Systems (ARIES) platform leverages the laboratory's world-class capabilities across research assets and facilities to study and develop optimal strategies for coordinating electric loads from vehicles with buildings, the power grid, and other energy systems. As part of ongoing ARIES investments, NLR is enhancing transportation and grid DC integration capabilities, including expanded high-power charging capabilities, added advanced testing equipment, and strengthened cross-sector integration to accelerate innovation in transportation–grid coordination that will be necessary to put downward pressure on energy prices while maintaining grid reliability.

- **DC-Fed Charging Systems:** NLR installed three custom DC-DC charging systems to convert from an 800-V DC hub to up to 1,000 V DC for North American Charging Standard and Combined Charging System charging. This platform will curb energy loss from AC-DC conversion and allow NLR to evaluate DC-DC solutions to reduce interconnection, improve efficiency, and lower the cost of electricity for charging.
- **Higher-Power Charging:** Continued construction of the Megawatt Charging Emulator at NLR's Flatirons Campus will enable researchers to run complex grid emulations—informed by real-world operating data—of how a grid and the infrastructure connected to it will function while handling up to 10 MW of electricity.
- **Site-Level Energy Controls:** Further expansion of NLR's large-scale emulation capabilities includes progress on a behind-the-meter storage system, complete with megawatt-scale generation and storage, a megawatt-scale battery emulator, a DC-as-a-service microgrid and fast chargers, and megawatt-level charging evaluation. Behind-the-meter storage systems are crucial to lowering operational costs and reducing grid impacts for energy-intensive industries.

The ARIES transportation and grid DC integration capabilities are expected to be formally commissioned with research beginning in 2026.

EMAPS Facility: Scaling Breakthrough Materials for Real-World Impact

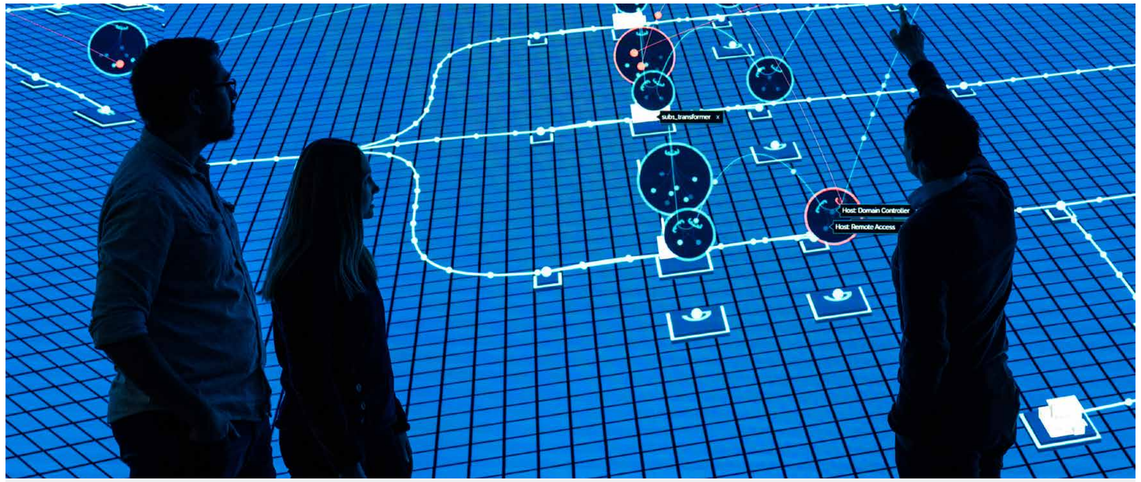
Currently under construction, NLR's Energy Materials and Processing at Scale (EMAPS) facility will bridge the gap between lab-scale materials innovation and pilot-scale production—accelerating the development of advanced energy materials and processes. With the final steel beam placed, this 127,000-square-foot facility is on track to meet its scheduled completion in 2027. Planned capabilities within EMAPS will create a direct path for market-ready solutions in energy storage, advanced manufacturing, grid modernization, and fuels for transportation and industrial applications.

- **Tailored Grid Support:** Additional hardware capabilities within EMAPS will enable NLR to focus on battery management system designs and DC microgrid integration, allowing researchers to tailor battery solutions for increasing energy demands from data centers and high-power charging stations.
- **Design to Deployment:** The facility will feature dedicated equipment for designing, prototyping, and validating advanced power electronics modules under realistic operating conditions. Researchers will be able to study thermal, fluid, electrical, and mechanical performance to enable faster optimization of designs for efficiency, durability, and manufacturability.
- **Ensuring Reliability:** EMAPS will enable long-term reliability evaluation of electronics, power electronics, electric machines, and electric-drive systems under controlled—but realistic—mechanical and thermal stresses. A new dynamometer system will allow researchers to evaluate performance across a variety of applications, from EVs to industrial systems, while gathering data on efficiency, failure modes, and operational limits.

IPC Laboratory: Transforming Mobility With Next-Generation Sensing and Controls

NLR's Infrastructure Perception and Control (IPC) lab advances the sensing, modeling, and computational controls needed for safer, more efficient movement of vehicles and people—both on the road and in large facilities. New tools expand NLR's capabilities in multimodal sensing, simulation, and augmented reality for transportation research.

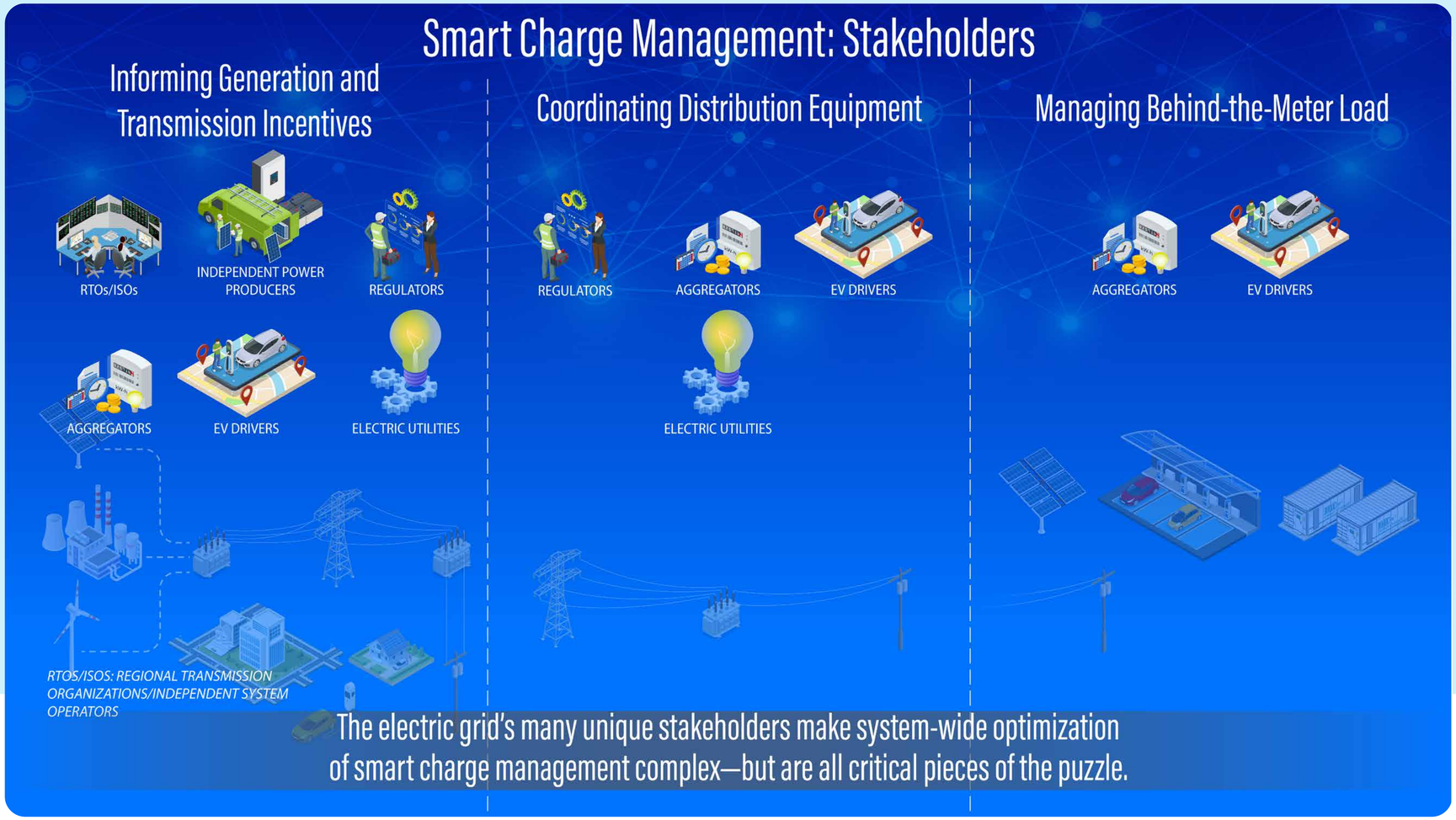
- **Immersive Visualization:** Two new Meta Quest 3 devices will provide affordable augmented reality capabilities to bridge the gap between human-readable and machine-readable data. These state-of-the-art mixed-reality devices can offer immersive simulations to enhance surveying and analysis of transportation systems.
- **Sensors for Smarter Vehicles:** NLR developed and refined multimodal sensing and perception capabilities for cellular vehicle-to-everything (C-V2X) modeling to improve how smart vehicles communicate with their surroundings. These capabilities will contribute to the safety and reliability of autonomous vehicles.
- **On-Road Data Collection:** NLR's C-V2X models were developed after several rounds of field data collection in both urban and rural settings using the IPC mobile trailer. Sensors used for data collection include Econolite's EVO RADAR units, Ouster's OS1 LiDAR units, and Axis camera units.



ARIES Cyber Range: A Virtual Environment for High-Fidelity, At-Scale Evaluation

The ARIES Cyber Range is a state-of-the-art cyber-physical modeling, simulation, and emulation platform to study and advance the cybersecurity of energy systems. Combining power grid-scale hardware with emulation and simulation approaches, the ARIES Cyber Range can faithfully replicate modern energy systems to ensure secure integration of our nation's electric power and transportation systems.

- **Powerful Computing:** The ARIES Cyber Range spans multiple data centers to leverage the breadth of NLR's high-performance computing power to simultaneously emulate entire utility networks while running multiple large-scale power system experiments. This platform combines real operating systems, networks, and applications that appear within live grids to precisely replicate their behavior.
- **World-Class Connections:** The ARIES Cyber Range connects to world-class hardware across NLR's Energy Systems Integration Facility and Flatirons Campus. In addition, users can reserve assets from the emulation library, access the catalog of laboratory devices, or integrate their own devices for a flexible and easily configurable approach to meet unique research needs.
- **Dynamic Visualizations:** Interactive ground truth visualizations show how the power system and digital communication systems dynamically interact throughout a given scenario, providing real-time awareness, historical analysis, and future planning and operation support.



Smart Charge Management Across the Energy System Offers Resilience and Affordability Benefits

Responsive and integrated energy management strategies are critical to reduce risk and increase reliability as growing numbers of data centers, EVs, residential and commercial buildings, and more, increase strain on the American power grid. Smart charge management (SCM) can proactively mitigate the potential stress from this growing demand—and improve grid resilience and energy security—by leveraging flexible EV loads. SCM coordinates EV charging with transportation needs and grid capabilities to optimize the use of current infrastructure and intelligently manage the flow of electricity needed for charging. Merging transportation energy demand with grid operations requires broad stakeholder coordination to de-risk new technologies and target high-value opportunities and markets. Though complex, optimized SCM can make both electricity and transportation more affordable.

Smart Charge Management: Benefits Across All Levels of the Grid

Informing Generation and Transmission Incentives

CHALLENGE: Higher costs due to increased peak demand energy generation caused by high energy demand and uneven loads.

SOLUTION: The capability to forecast demand and develop responsive generation, and optimize vehicle charging, reduces transmission congestion—**lowering energy costs for all consumers.**

Coordinating Distribution Equipment

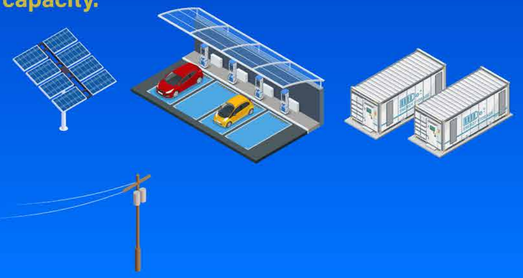
CHALLENGE: Coincident peaks straining distribution equipment, risking equipment overloads and increasing equipment upgrade costs.

SOLUTION: Gaining real-time understanding of grid operations and equipment capacity reduces the likelihood of blackouts and the cost of upgrading capacity, allowing for more **cost-effective, proactive equipment management.**

Managing Behind-the-Meter Loads

CHALLENGE: High peak demand and low grid capacity reducing the availability and usability of electric vehicle charging sites.

SOLUTION: Predicting energy load and responsive energy generation, while reducing time pressure, using solar, battery, and vehicle-to-grid resources reduces site energy costs and upgrade **costs, supporting cost-effective charging site management and resilience using current capacity.**



Smart charge management across all three levels of the electric grid frees up grid capacity and provides energy, cost, convenience, and time savings benefits to consumers and American energy providers.

Laboratory Directed Research and Development (LDRD) Projects

Science of the Supply Chain: Tuning Processes for Domestic Materials and Faster Validation

Domestic materials are essential for building resilient, independent supply chains for advanced energy technologies, including batteries. However, these raw materials often differ in composition and availability compared to international sources. This project invests in early-stage R&D to develop smarter synthesis and validation methods that reduce costs and enable faster, broader adoption of U.S.-sourced materials in energy manufacturing.

- **The Hurdles:** Manufacturers hesitate to adopt U.S. materials due to unknown impurity profiles, limited processing know-how, and the cost of extensive validation. Purifying materials to match arbitrary standards may be both unnecessary and economically unsustainable. Instead, we need tools to identify which impurities matter, how to tune processes to U.S. ores and precursors, and how to quickly predict whether new materials will perform in real-world devices.
- **Key Breakthroughs:** This year, NLR's team developed a novel synthesis process for LiFePO4 battery cathodes tailored to low-cost precursors available in the United States—laying the groundwork for more competitive domestic battery production. A record of invention has been submitted for this process. They also created a machine-learning model that predicts battery degradation from early data, enabling faster, cheaper performance assessments.
- **Related News:** In parallel, NLR researchers advanced understanding of how impurities in CdCl2 treatments affect photovoltaics performance, informing sourcing and purification decisions in manufacturing. This project has spun off to form a new VTO-funded, multi-lab consortium with Idaho National Laboratory and ANL: the EVALS consortium.
- **What's Next:** Battery research will continue under the EVALS consortium, with further development of synthesis and validation tools to support U.S. production. Looking ahead, the multi-lab team is exploring how both materials-tuned processing and fast validation can be applied across other critical materials to unlock broader opportunities for domestic manufacturing.

ARIES by NATIONAL LABORATORY OF THE ROCKIES

Scaling Energy Systems R&D With the ARIES Virtual Emulation Environment

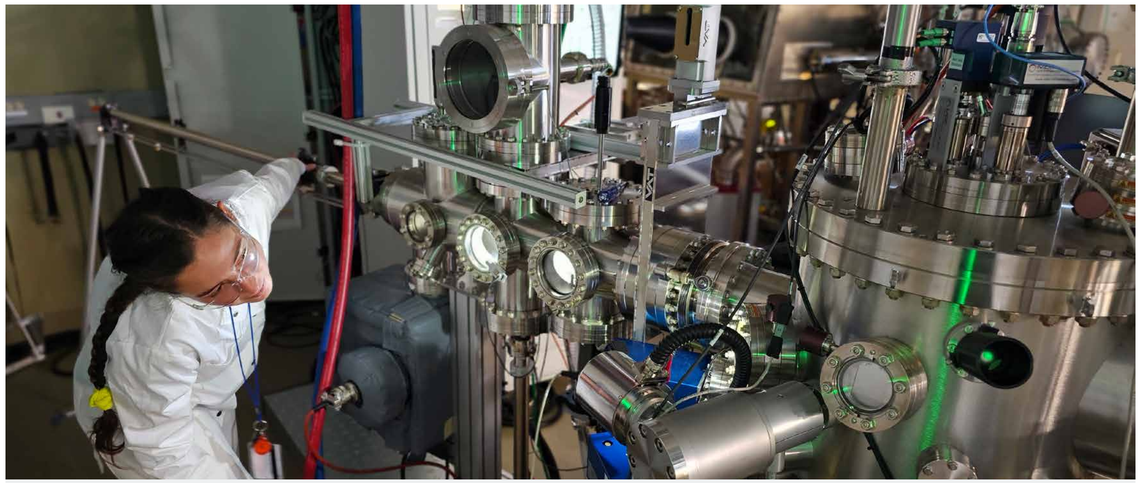
The ARIES virtual emulation environment aims to break through the current limitations of physical testing by creating a digital research platform that can simulate, emulate, and analyze energy systems at scale. By leveraging AI, machine learning, and advanced computing, this project builds the foundation for future energy system planning, validation, and resilience at a national scale.

- **The Hurdle:** Today's energy research infrastructure is limited by the scale, cost, and complexity of physical assets. As integrated energy systems grow to include millions of distributed devices or more, traditional experimentation cannot keep pace. ARIES is DOE's most advanced energy systems platform, but it needs the virtual emulation environment to transform complex data into actionable knowledge. That requires combining simulation models, physical assets, real-world data, and AI-driven analytics in entirely new ways.
- **Key Breakthroughs:** In FY 2025, NLR researchers demonstrated the ARIES virtual emulation environment capabilities through a real-world use case with Verrus, a company developing flexible data centers designed to act as grid assets. The data center demonstration—featured during NLR's Partner Forum—showcased the ability to link physical operations with high-fidelity virtual simulations and analytics. This proof of concept validated the approach as a powerful tool for system design and de-risking data centers.
- **Next Steps:** Additional upcoming capabilities include energy system planning and design, incident response, and resiliency analysis. This project lays essential groundwork for R&D at a scale that matches the complexity of tomorrow's energy challenges.

Probing the Effect of Preferential Evaporation on the Performance of Jet Turbine Combustors

Understanding how complex jet fuels behave during combustion is critical for the development and qualification of next-generation aviation fuels. This project invests in foundational R&D to explore how individual fuel components evaporate during spray combustion—an effect that is poorly understood but has major implications performance and fuel design.. The goal is to generate experimental data and modeling tools that can improve predictive accuracy and reduce uncertainty for fuels in early-stage development.

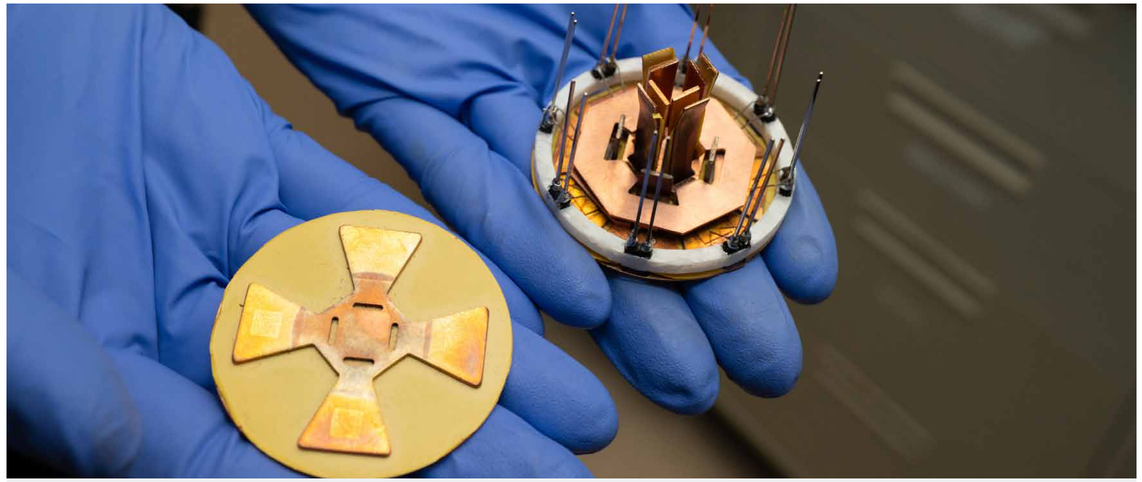
- **The Hurdles:** Jet turbine combustion is a complex process involving spray breakup, evaporation, mixing, and combustion. Real fuels are mixtures of many components, and lighter fractions tend to preferentially evaporate, altering evaporation rates, droplet dynamics, and combustion behavior. This complexity is not represented well in existing models, and no experimental setup currently exists to directly measure individual fuel droplets. Model validation is especially difficult for new fuels, often available only in small quantities.
- **Key Breakthroughs:** The NLR team completed the design, assembly, and safety review of a first-of-its-kind experimental setup to study preferential evaporation in realistic conditions. In parallel, researchers also developed a physics-informed evaporation model and began validating it using simple fuel surrogates that represent the main chemical classes found in aviation fuels.
- **What's Next:** Researchers will experiment on simple fuel mixtures to verify the setup and compare results with model predictions. This validated approach will then be applied to increasingly complex and emerging synthetic fuels—even those available only in small volumes. By improving our understanding of preferential evaporation, this work will enable more accurate modeling, reduce the time and cost of fuel testing, and support long-term innovation in next-generation aviation.



Developing Ultrawide-Bandgap $InBO_3$ Materials and Devices for Power and Extreme Environment Electronics

Up to 80% of all generated electricity will flow through power electronics within the next decade, making power electronic device efficiency a critical area of research. Ultrawide-bandgap materials offer transformative potential for high-efficiency, high-voltage power electronics. This NLR project, in collaboration with the Colorado School of Mines, assumes the challenge of experimentally validating $InBO_3$—an ultrawide-bandgap semiconductor material that could outperform today's leading materials like gallium nitride (GaN), SiC, and gallium oxide (Ga_2O_3) by more than an order of magnitude.

- **The Hurdles:** Most commercial power electronics rely on SiC or GaN, but these materials are approaching their performance limits. Theoretical studies suggest that Group III borates, especially indium borate ($InBO_3$), could deliver superior performance thanks to their high bandgap, mobility, and dopability. However, no one has demonstrated functional devices using these compounds.
- **Key Breakthroughs:** In its first year, the project team has commissioned, installed, and calibrated a custom molecular-beam epitaxy system in NLR's cleanroom facilities. This system is tailored to grow high-quality oxide crystals, and initial $InBO_3$ films are now being synthesized. Parallel efforts are incorporating zirconium dopants into $InBO_3$ grown by pulsed laser deposition. On the theoretical side, the team computed the electronic structure and band alignments for $InBO_3$, gallium borate ($GaBO_3$), and aluminum borate ($AlBO_3$), and identified promising metal and oxide contact candidates for both ohmic and Schottky interfaces—critical inputs for device design.
- **What's Next:** The project team will continue exploring the complicated molecular-beam epitaxy growth space of ternary oxides to create high-quality thin-film crystals, as well as dope them with zirconium. They will also calculate alloy properties of $GaBO_3$ and $InBO_3$, including electronic structure and dopability. The ultimate goal is to fabricate and test rudimentary devices—like Schottky diodes and field-effect transistors—to demonstrate $InBO_3$'s viability as an ultrawide-bandgap semiconductor. If successful, this work could open entirely new pathways for power electronics that are more efficient, more compact, and capable of withstanding extreme conditions.



Ultra-Low Inductance Smart (ULIS) Silicon Carbide Power Module

NLR researchers have developed a groundbreaking SiC power module—dubbed ULIS—that achieves ultra-high efficiency and ultra-low inductance at a low cost. By rethinking conventional module design, ULIS offers five times greater energy density and significantly reduced parasitic inductance, making it promising for data centers, power grids, advanced vehicles, and other high-demand applications.

- **The Hurdles:** Conventional power modules suffer from high parasitic inductance, limiting switching speed, efficiency, and overall performance. High-efficiency SiC modules are typically expensive and difficult to manufacture, limiting their widespread adoption.
- **Key Breakthroughs:** NLR's ULIS power module is capable of achieving five times greater energy density than predecessor designs in a smaller package, making it possible for manufacturers to build and power more efficient, compact, and lighter technologies. The 1,200-volt, 400-amp power module boasts parasitic inductance seven to nine times lower than any current state-of-the-art SiC power module. Its ultrafast, ultraefficient switching of electrical current into usable forms allows ULIS to "squeeze" more usable power out of the electricity supply.
- **What's Next:** NLR will continue to scale up performance validation in real-world applications such as EVs, data centers, and energy systems, as well as explore pathways to commercialization with industry partners. Continued research will aim to further enhance cooling, durability, and manufacturability.

STRATEGIC HIRES

Cybersecurity Strategist Specializes in Secure, Interoperable Infrastructure for Energy and Mobility Systems

As America's transportation system grows smarter and integrates with our electric, communications, and building infrastructure, prioritizing cybersecurity and interoperability is essential. A secure and interoperable transportation and energy system ensures that American individuals and businesses have cost-effective, safe, and reliable mobility options.

NLR's advanced transportation and grid integration research puts cybersecurity and interoperability at the forefront. To strengthen this focus and reinforce NLR's role as a strategic thought leader, NLR's Center for Integrated Mobility Sciences welcomed Sarah Hipel in June 2025. As a senior researcher in the center, Hipel leads the lab's mobility cybersecurity strategy with an emphasis on resilient transportation deployments at scale. She is also a nonresident fellow at Carnegie Mellon University's Institute for Strategy and Technology, contributing to national security and digital infrastructure strategy.

Previously, Sarah served as acting chief technology officer at the Joint Office of Energy and Transportation, where she led efforts to standardize and secure EV charging infrastructure integrating cybersecurity, public key infrastructure, and system resilience into federal programs and shaping standards such as J3400. In the private sector, she held leadership roles at Rivian and Ford, advancing secure EV infrastructure and digital trust frameworks. She also chaired SAE's OpenPKI Consortium and has contributed to U.S. and international standards on cyber-physical system security.

Other VTO-Relevant NLR LDRD Projects

- Adaptive Computing (PI: Marc Day)
- Operando to Operation at Scale (PI: Katie Jungjohann)
- Integration Science for Next-Generation E-Fuels (PI: Randy Cortright)
- Low-Solvent, High-Loading, Silicon Anode Scalable Extrusion-Based Manufacturing (PI: Francois Usseglio-Viretta)
- Reclaimed PET and Fiber Composites for Lightweight, Decarbonized, and Circular Vehicle Components (PI: Robynne Murray)
- ARCADE: Active Response Control Around Disruptive Events (PI: Eliza Hotchkiss)
- Proactive and Automated Failure Management in Connected Energy Systems (PI: Malik Hassanaly)
- Accelerating Scientific Knowledge Discovery in Material Degradation Using Explainable AI (PI: Juliette Ugirumurera)
- Systemic Control Paradigm for Flexible Resource Integration (SysCo-Flex) (PI: Bala Kameshwar Poola)
- Biphasic Materials as Novel Electrodes for Sodium-Ion Batteries (PI: Joseph Stiles)

AWARD RECOGNITION

Photo by Gregory Cooper, NLR 93239

Alicia Birky Received Outstanding Performance Award for Leadership in Commercial Transportation Analysis

Alicia Birky, a systems engineer at NLR, received an Outstanding Performance Award at NLR's Staff Awards ceremony for her leadership and expertise in applying large-scale data and techno-economic analysis to commercial transportation challenges—from trucks and buses to trains, planes, and vessels. Known as a go-to expert in the field, Birky provides guidance and mentorship while leveraging complex transportation data to advance commercial vehicle performance and efficiency.

Photo by Dennis Schroeder, NLR 38991

Margo Melendez Honored With Lifetime Distinguished Achievement Award

Margo Melendez, chief engineer at NLR, received the VTO Lifetime Distinguished Achievement Award for more than 20 years of leadership in DOE's Technology Integration program and the Clean Cities and Communities (CC&C) partnership, which advances transportation energy choices through more than 75 coalitions nationwide. The award recognizes her strategic role in guiding NLR teams that provide critical technical assistance to CC&C, as well as her role in strengthening connections among DOE, NLR, and stakeholders across the alternative fuel and advanced transportation sectors. Melendez was also honored for leading major projects to advance natural gas vehicle technologies in California.

Photo by Werner Slocum, NLR 82622

Rajneesh Chaudhary Elevated to IEEE Senior Member

Rajneesh Chaudhary, a senior mechanical engineer at NLR, has been elevated to senior member of the Institute of Electrical and Electronics Engineers (IEEE). This recognition reflects his significant contributions to the field of power electronics, particularly in developing novel thermal fluids and multiphysics solutions for advanced power electronics, electric machines, and electric-drive systems.

Photo by Agata Bogucka, NLR 93821

Xuhui Feng Receives Outstanding Performance Award, Elevated to IEEE Senior Member

Xuhui Feng, a senior mechanical engineer at NLR, was elevated to an IEEE senior member in recognition of his significant contributions to the thermal management of power-dense systems. His research explores novel cooling solutions for power electronics and electric machines across a range of applications, including EVs, electrified aviation, grid-tied power converters, and nuclear power conversion systems. Additionally, Feng was honored with an Outstanding Performance Award at NLR's Staff Awards ceremony in recognition of his pioneering research, innovation, and leadership in thermal management and materials characterization for power electronics and electric machines.

Photo by Werner Slocum, NLR 83566

Bidzina Kekelia Named ASME Fellow and IEEE Senior Member

Bidzina Kekelia, a senior mechanical engineer, has been named a fellow of the American Society of Mechanical Engineers (ASME) in recognition of his exceptional engineering achievements and contributions to the profession. His research at NLR focuses on developing novel cooling solutions for power electronics, electric machines, and integrated electric traction drives for both on-road EVs and electrified aviation applications. Kekelia's innovative work was also recognized with his elevation to an IEEE senior member.

Photo by Bryan Bechtold, NLR 85248

Sreekant Narumanchi Honored With IEEE Best Associate Editor Award

Sreekant Narumanchi, manager of NLR's Advanced Power Electronics and Electric Machines group, received the Best Associate Editor Award for his outstanding contributions to the *IEEE Transactions on Components, Packaging and Manufacturing Technology* journal. The annual honor recognizes editors who show exceptional commitment to upholding the journal's high standards through careful peer review and efficient manuscript processing.

Photo by Gregory Cooper, NLR 89733

Xiaoling Li Wins IEEE Award for Paper on Advances in Medium-Voltage Power Module Design

The IEEE Power Electronics Society has recognized **Xiaoling Li**, senior power electronics researcher at NLR, with its 2024 First Place Prize Paper Award for her lead authorship of "A 10 kV SiC MOSFET Power Module with Optimized System Interface and Electric Field Distribution," published in *IEEE Transactions on Power Electronics*. Co-authored by Yuxiang Chen, Hao Chen, Riya Paul, Xiaoqing Song, and H. Alan Mantooth—all from organizations outside NLR—the paper examines trade-offs in insulation, parasitic inductance, common-mode capacitance, and fabrication complexity in medium-voltage power modules. It presents design improvements that enhance module performance and support broader application. The award recognizes papers for originality, technical contribution, analytical and experimental support, and clarity of presentation.

Photos (left to right) by Gregory Cooper, NLR 97884; Agata Bogucka, NLR 96986; Dennis Schroeder, NLR 89393; Shashi Peddireddy; Agata Bogucka, NLR 92366; and Agata Bogucka, NLR 96984

RouteE and FASTSim Developers Receive VTO Team Award

NLR teams that developed the Route Energy Prediction (RouteE) tools and the Future Automotive Systems Technology Simulator (FASTSim™) received a VTO Team Award for their ingenuity, collaboration, and technical expertise. These tools support energy optimization, powertrain simulation, and technology impact assessment across all vehicle classes. The award also recognizes their integration of new research methods and ongoing partnerships, including contributions to Google Maps' energy-efficient routing feature. Honored team members include **Chad Baker**, **Robin Steuteville**, **Nick Reinicke**, **Jeff Gonder**, **Shashi Peddireddy**, Balashanmuga Priyan Rajamohan, Ananta Shrestha, Kyle Carow, **Jacob Holden**, **Rob Fitzgerald**, **Joshua Hoshiko**, and former NLR intern Natalie Schultz.

Photos (left to right) by Werner Slocum, NLR 74669; Alejandro Henao; Werner Slocum, NLR 50030; and photo courtesy Sailesh Acharya

Award-Winning Paper Highlights Impact of On-Demand Transit Systems

The Transportation Research Board's executive committee awarded NLR researchers **Bonnie Powell**, **Alejandro Henao**, **Stanley Young**, and **Sailesh Acharya**—along with former NLR colleagues Rick Grahn and Ruqayya Zakaria—with the William W. Millar Award for the best paper in public transportation. Their paper, "Mobility Energy Productivity Evaluation of On-Demand Transit: A Case Study in Arlington, Texas," is part of a broader series of NLR case studies exploring innovative mobility services, including on-demand transit systems. Leveraging NLR's Mobility Energy Productivity (MEP) tool, the study demonstrates the substantial mobility benefits these systems can offer, particularly in communities where traditional fixed-route transit is not viable.

Photos by Agata Bogucka, NLR 96986 (left) and Gregory Cooper, NLR 89276

Multi-Lab Cooperative Driving Automation Research Recognized With VTO Team Award

NLR research software engineer **Nick Reinicke** and computational transportation scientist **Qichao Wang** were honored alongside collaborators from Lawrence Berkeley National Laboratory (LBNL), ORNL, and ANL with a VTO Team Award for advancing the understanding and implementation of cooperative driving automation (CDA). The team developed novel software, algorithms, and hardware to quantify the energy impacts and sensitivities associated with various communication frameworks, as well as with specific CDA and active traffic management applications. CDA allows vehicles and road users to communicate and coordinate actions, enhancing safety and improving traffic flow.

Photos by Werner Slocum, NLR 74521 (left), and Dennis Schroeder, NLR 49988

NASA Recognizes Matt Keyser and Ahmad Pesaran With 2025 Invention of the Year Award

Researchers **Matt Keyser**, senior energy storage engineer, and **Ahmad Pesaran**, chief engineer, have received NASA's 2025 Invention of the Year award for their development of an internal short-circuit device used to make batteries safer. The device, designed by NLR and NASA, is implanted into a battery manufacturer's cell to investigate the thermal behavior of a battery under abuse conditions. Once the insulating wax in the device is melted, a hard short circuit results in the cell, replicating a single-point manufacturing defect failure and allowing battery researchers to evaluate the safety design of their battery systems.

Photo by Bryan Bechtold, NLR 83826

PeleLMeX Developer Marc Day Honored as 2025 Fellow of the Combustion Institute

Marc Day, manager of the Scalable Algorithms, Modeling, and Simulation group at NLR, was **named a 2025 fellow of the Combustion Institute** for "pioneering algorithmic and software advances enabling multiphysics direct numerical simulation of turbulent combustion in laboratory-scale configurations." He led the development of the low-Mach-number adaptive mesh code PeleLMeX, which is being used to model synthetic aviation turbine fuel combustors at Georgia Tech as part of NLR's VTO-funded project on bio-derived jet fuels. PeleLMeX is part of the **Pele combustion simulation suite** and was developed in collaboration with the DOE Exascale Computing Project.

Photo by Gregory Cooper, NLR 97859

Yukihiro Hatagishi Appointed Vice Chair of SAE Task Force Dedicated To Establishing EV Communication Protocols

Yukihiro Hatagishi, a senior researcher specializing in EV–grid integration, was appointed vice chair of the **SAE Hybrid Communications and Interoperability Task Force**. The group establishes use cases, communication protocols, and security and interoperability standards for EV technologies, including smart charging, fast charging, wireless charging, V2G, and diagnostics. Hatagishi brings to this role his pioneering work on the first V2G onboard charger and his continued efforts to advance EV–grid interoperability, helping position EVs as responsive, integrated grid assets.

Photo by Gregory Cooper, NLR 89285

Nikita Dutta: Characterizing Long-Life Lithium-Ion Cells With Earth-Abundant Cathodes

Nikita Dutta, a materials science researcher, has made significant technical contributions to the VTO-funded Earth-Abundant Cathode Active Materials project, applying advanced nanoscale mapping techniques to study manganese dissolution in lithium- and manganese-rich (LMR) cathodes—work that has been accepted for publication in *ACS Applied Energy Materials*. In parallel, she mentored a graduate student with no prior battery experience, guiding her to co-first authorship on the journal article and supporting her successful application for a DOE Office of Science Graduate Student Research Fellowship. Dutta's efforts have advanced key project goals and demonstrated strong leadership in both research and workforce development.

Photo from Sailesh Acharya

Sailesh Acharya: Leading High-Impact Projects and Mentoring Interns for Success

Sailesh Acharya, a postdoctoral data science researcher, has consistently exceeded expectations across multiple projects. He serves as the technical lead for the VTO-funded National Impacts of Community-Level Strategies to Improve Convenience of Mobility project—overseeing Transportation Energy & Mobility Pathway Options (TEMPO™) modeling, scenario design, high-volume data processing, and troubleshooting. Additionally, he has made substantial contributions to the MEP Core Tools project and several related collaborative efforts. Beyond his technical work, Acharya has mentored interns, several of whom have advanced to postdoctoral positions at NLR.

Photo from Allie Danner

Allie Danner: Providing Technical Support for EV Infrastructure and Battery Safety

Allie Danner, an electrical engineer, has played a key role in two VTO technical assistance projects, leading technical case study reviews and contributing to related strategy development for the Alternative Fuels Data Center (AFDC), as well as supporting battery safety efforts for micromobility applications. She has also provided technical leadership on electric vehicle supply equipment (EVSE) projects and supports NLR's collaboration with the National Highway Traffic Safety Administration to evaluate battery "safety state" tools and develop best practices for field use. Danner brings a can-do, will-learn attitude to her work and applies her technical knowledge in practical ways that address both engineering challenges and real-world constraints, such as cost and utility limitations.

Photo from Polina Alexeenko

Polina Alexeenko: Driving Efficiency in Transportation Electrification

Polina Alexeenko, a postdoctoral researcher, consistently pushes the boundaries of applied research in transportation electrification and grid integration. She has led pioneering efforts to apply grid data to energy use timing and charging optimization strategies combined with in-use duty cycle data—advancing solutions that improve system-level efficiency. Alexeenko combines rigorous technical analysis with visionary thinking, demonstrating not only deep expertise, but also creativity, a collaborative spirit, and a strong drive to tackle new challenges.

Photo from Francisco Trejo Morales

Francisco Trejo Morales: Elevating Impact of Transportation Projects

Francisco Trejo Morales, a postdoctoral researcher, has made meaningful contributions to several transportation projects under the CC&C program. As a bilingual researcher, he has played a key role in translating materials from English to Spanish, helping to broaden the reach of NLR's work. Morales is a thoughtful and creative collaborator who consistently brings forward ideas that strengthen the impact of NLR research.

Photo from Cemal Akcicek

Cemal Akcicek: Steering Strategic Data Collection and Platform Expansion

Cemal Akcicek, a data science researcher, has delivered exceptional performance on the Travel Demand Management and National Impacts projects while also effectively managing the Transportation Secure Data Center. He leads extensive transit-focused research efforts, including the processing and analysis of large volumes of General Transit Feed Specification data, and is spearheading efforts to validate the TEMPO model's transit ridership by mapping National Transit Database summaries to the county level. In addition to overseeing data collection for the Transportation Secure Data Center and coordinating the integration of new data and analyses into the Livewire Data Platform, Akcicek has contributed to business development and mentored interns who have gone on to postdoctoral and research positions at the lab.

Photo by Bryan Bechtold, NLR 79832

Shuofeng Zhao: Advancing High-Performance Power Modules With ULIS Technology

Shuofeng Zhao, an electrical engineer, played a key role in the design of NLR's patent-pending Ultra-Low Inductance Smart (ULIS) power module, an innovation considered one of the lab's top technological advancements of the year. ULIS is a cutting-edge power module enginCMEld for high-frequency switching applications. It delivers a 7–9 times performance improvement compared to commercially available modules, setting a new benchmark in power electronics.

Photo by Gregory Cooper, NLR 95864

Nina Prakash: Leading Innovation in Machine Learning and Open-Source Tools

Nina Prakash, a data science researcher, has contributed significantly to NLR through her expertise in machine learning, software development, and cross-disciplinary research, particularly in energy storage systems. She played a pivotal role in the development of impactful machine-learning tools for microscopy and diagnostics, contributed to major VTO projects, and published open-source software supporting scientific research. With multiple manuscripts submitted or in preparation for top journals, Prakash's technical work reflects a deep commitment to advancing science in the areas of battery health diagnostics, early-life performance assessment, and materials characterization.

R&D HIGHLIGHTS

Battery Technologies

eXtreme Fast Charge and Cell Evaluation of Lithium-Ion Batteries (XCEL) Program Makes Progress in Fast Charging Technologies

Impact & Significance: *NLR researchers advanced battery charging technologies by integrating novel materials and electrode designs that enabled energy-dense lithium-ion cells to reach more than 80% charge in just 12 minutes for 800 cycles.*

As part of DOE's XCEL program, NLR is establishing benchmark designs demonstrating how emerging technologies can achieve extreme fast charging of batteries. Achieving this in energy-dense batteries (≥4 mAh/cm^2) requires an in-depth understanding of internal resistances and rate-limiting mechanisms within battery systems. This quarter, the XCEL team made significant progress in fast charging battery technologies. These advancements include integrating single-walled carbon nanotubes into cathode materials to enhance conductivity, laser-ablating electrolyte "highways" into the anode to improve lithium transport and mitigate harmful lithium plating and formulating novel electrolytes with superior lithium-ion transport properties. A recent study demonstrated that these innovations enabled the development of energy-dense cells (3.3 mAh/cm^2) capable of achieving more than 80% charge in just 12 minutes for 800 cycles, with minimal capacity fade of only 13%. Although the XCEL program has concluded, this groundbreaking work will be disseminated in several manuscripts slated for publication early in FY 2026, including studying ultra-energy-dense cells (3.62 mAh/cm^2, designed to charge in 10 minutes, and 4.37 mAh/cm^2, designed to charge in 15 minutes).

Machine Learning Helps Predict Aging Behavior of Silicon Batteries

Impact & Significance: *Improved machine-learning models developed at NLR can now predict silicon battery lifetime and resistance growth months in advance with high accuracy, significantly reducing the cost and time for validation, while providing cost-saving insights into the performance and lifetime of energy storage solutions.*

Lithium-ion batteries with silicon anodes have high energy density but poor calendar lifetimes. Improving the calendar life of silicon batteries requires many iterations of testing, which is prohibitively slow and resource consumptive. The ability to accurately predict aging early in testing is crucial to minimize the cost of improving silicon batteries. Previously developed machine-learning pipelines were improved by including information about cell chemistry and test conditions as additional inputs, as well as by reducing dimensionality of correlated features. An initial model was also developed to predict resistance growth. After 1 month of calendar testing, the models can predict lifetime with 1.4-month average error, capacity retention 12 months into the future with 5% average error, and resistance growth after 12 months with 17% average error. Predicting the aging behavior of batteries with silicon anodes is critical to minimize the cost of testing new designs toward improved calendar life. Incorporating additional cell information as model inputs provides insight into their relationship with lifetime and the evolution of capacity and resistance over time. The machine-learning pipeline will be used to validate physics-based hypotheses for calendar life. Next steps include quantifying prediction uncertainty and incorporating uncertainty into the decision-making process when projecting lifetime.

Kestrel Enhances VTO's AI-Powered Research

Impact & Significance: *VTO is the largest sponsor of R&D that utilizes NLR's high-performance computing capabilities. The expansion in AI-accelerated capacity on Kestrel for VTO projects enables increased capabilities for large-scale AI and accelerated computing workloads, which is critical to supporting VTO research.*

High-performance computing, particularly AI and machine learning, are critical to enhancing predictive modeling and optimizing complex systems. In VTO, advanced AI techniques are employed to train models that predict battery behavior and degradation, enabling more accurate and faster assessments of battery life and performance, among other applications. Machine learning is used to discover new materials with desirable properties by predicting phase stability and electrochemical performance. Projects across the VTO portfolio are taking advantage of the new VTO "buy-in" on Kestrel, which completed installation in January 2025. The Kestrel buy-in provides priority access to 10 million allocation units of Kestrel GPU node capacity to VTO projects. This expansion in capacity for VTO provides projects with increased capabilities for large-scale AI and accelerated computing workloads, which is critical to supporting VTO's growing computing needs. In addition, Kestrel's overall availability for FY 2025 was greater than 95%, and VTO's buy-in usage was at full capacity most days, showing excellent transition of VTO work to Kestrel's advanced AI architecture. With the Kestrel GPU nodes fully deployed, the next steps involve completing transition of codes to Kestrel, exploring new accelerated computing techniques, and supporting and maintaining all computing needs.

Redox Mediator Relithiation Successfully Restores Cycle Performance of End-of-Life Cathode Materials

Impact & Significance: *NLR researchers demonstrated how redox mediator relithiation restores end-of-life cathode performance to levels comparable with pristine material. This achievement supports scalable, cost-effective recycling that strengthens the domestic battery supply chain.*

NLR researchers are developing approaches to scale up direct recycling of cathode materials using redox mediator relithiation—a process that seeks to restore inactive lithium and extend the life of battery materials within the domestic supply chain. Relithiated cells must demonstrate excellent cycle performance to ensure this method can successfully reintroduce recycled batteries into the marketplace. Researchers evaluated nickel manganese cobalt (NMC) 622 material from commercial cells cycled to 20% capacity loss to determine how the altered surface chemistry and structural degradation of a cycled NMC cathode material affects lithium restoration efficiency. The results show that full cell cycle performance of redox mediator relithiated NMC materials was comparable to pristine NMC performance. Researchers will continue to explore opportunities to decrease costs associated with this technique by analyzing the reusability of the redox mediator solution through multiple applications. In addition, researchers plan to verify this method can apply to additional compositions of end-of-life commercial cathodes, such as lithium iron phosphate.

Advanced Characterization To Guide and Validate the Design of Long-Life, Earth-Abundant Cathode Active Material Lithium-Ion Cells

Impact & Significance: *Using multimodal tomographic imaging, NLR researchers revealed how structural and chemical degradation limits the performance of LMR cathodes. These insights guide the design of cobalt-free batteries that can reduce supply chain risks.*

The lithium-ion batteries widely used today depend on critical minerals, such as cobalt, that are susceptible to supply chain bottlenecks and volatile pricing. New battery designs, such as LMR electrodes, use widely available materials to avoid supply concerns and ensure long-term viability of future battery technologies. However, LMR electrodes are currently unable to achieve the same performance as commercial electrodes. NLR researchers are using multimodal tomographic imaging to evaluate morphological and chemical changes causing degradation in LMR electrodes. Results show that LMR particles undergo significant damage during manufacturing and cycling, including severe cracking, crushing, and dissolution of transition metals during operation. Next, researchers will use X-ray diffraction to evaluate crystallographic degradation before publishing the complete results of these characterization efforts.

Researchers Optimize Fabrication Techniques To Create Ideal Microstructures for High-Performance Solid-State Battery Cathodes

Impact & Significance: *By optimizing microstructures through advanced imaging and analysis, NLR researchers established key design techniques for high-performance solid-state cathodes.*

All-solid-state batteries (ASSBs) replace the liquid electrolyte in traditional lithium-ion batteries with solid material, offering potential improvements in energy density, lifespan, and safety. However, microstructure defects in ASSB catholytes, such as poor material dispersion and voids, can leave active material underutilized and block lithium-ion transport, degrading both capacity and rate performance. NLR researchers are exploring opportunities to optimize fabrication techniques and catholyte composition for higher-performing ASSBs. The team developed a robust manufacturing pipeline for ASSB catholytes, incorporating X-ray nano-CT and custom in-house image analysis software to characterize the resulting microstructures. This process allowed researchers to identify two key parameters for optimization—the particle size distribution of the NMC active material and the solid electrolyte—which were shown to correlate with higher rate capability and capacity in electrochemical tests. This work lays the foundation for high-loading ASSB cathodes, a critical step toward achieving the energy density advantages enabled by solid-state technologies. These findings will be used to predict and experimentally test the theoretical limits for active material loading in ASSB cathodes.

New Modeling Frameworks Provide Uncertainty Analysis in Lifetime Prediction of Silicon Batteries

Impact & Significance: *New modeling frameworks developed by NLR quantify uncertainty in early-life signals to enable more reliable predictions of silicon battery aging. This approach supports better-informed design choices to extend battery life and accelerate innovation.*

Silicon anodes are a promising advancement for lithium-ion batteries due to their high energy density, but batteries with silicon anodes typically demonstrate calendar lives of <2 years, far below the 10-year industry standard for commercialization. The NLR-led Silicon Consortium Project is leveraging integrated modeling and machine learning using early-life signals to predict calendar aging. However, experiments have cell-to-cell variability and contain noise, presenting a challenge for accurate predictions. In response, researchers are developing two expanded frameworks for early-life prediction based on parametric trajectory modeling to quantify uncertainty. The first predicts power law fade parameters using high-dimensional electrochemical features from early testing, with uncertainty quantification based on quantile loss, bootstrapping, and conformal intervals. The second uses Bayesian regression to quantify uncertainty using power law fade parameter distributions. By effectively capturing the effect of measurement noise, dataset variability, and lack of representative data on the resulting predictions, researchers can enable robust and well-informed decision-making on design iterations that influence calendar life.

Plasma-Enhanced Silicon Anodes for Roll-to-Roll Battery Manufacturing Demonstrate Promising Feasibility for Market Success

Impact & Significance: *NLR scaled a plasma-synthesized silicon anode material and demonstrated its compatibility with roll-to-roll battery manufacturing. This milestone brings next-generation silicon anodes closer to commercial success with the potential for decadelong lifetimes.*

The NLR-led Silicon Consortium Project is working to scale up a novel silicon anode active material synthesized via plasma-enhanced chemical vapor deposition (PECVD) of silane gas, followed by polyethylene oxide (PEO) surface modification. Early full cell results from single-layer pouch cell batteries with this PECVD-PEO silicon material project more than 10 years of calendar life, making it a strong candidate for next-generation batteries. NLR researchers successfully synthesized and delivered more than 200 grams of PECVD-PEO silicon to the Cell Analysis, Modeling, and Prototyping (CAMP) Facility at ANL. Although this was enough material for several roll-to-roll coatings, further work is required to enable a high-loading electrode print of the anodes. Demonstrating the feasibility of scaling PECVD-PEO silicon using conventional manufacturing methods is an important step in enabling the market success of silicon anodes. Additionally, achieving consistent area loading of silicon anodes using roll-to-roll processing will allow for full cell matching and further calendar life studies to optimize battery designs.

Blended Electrolyte Additives Improve Stability of Earth-Abundant Battery Cathodes.

Impact & Significance: *A new approach to blending complementary electrolyte additives improved long-term cycling stability of cobalt-free cathodes by 28%.*

Today's lithium-ion batteries rely on cobalt, which is expensive, toxic, and geographically restricted, with 70% of cobalt mined in the Democratic Republic of Congo. Earth-abundant alternatives—such as LMR lithium nickel manganese oxide cathodes—offer high energy densities but fail to demonstrate stability during long-term cycling. In collaboration with ANL, NLR scientists used cryogenic scanning transmission electron microscopy with electron energy loss spectroscopy to investigate how electrolyte additives influence battery performance. The team found that blending two common additives—2 wt % lithium difluoro(oxalate)borate plus 1 wt % tris(trimethylsilyl) phosphite—achieved a 28% improvement in battery capacity over the baseline electrolyte after long-term cycling. These additives complement each other, mitigating manganese dissolution to stabilize the cathode surface and enhancing the structure and chemistry of the cathode-electrolyte interphase. By using advanced electron microscopy to uncover key nanoscale mechanisms, these insights can guide new approaches to electrolyte engineering that support the development of more affordable and reliable energy storage.

Machine Learning Optimizes Mechanical Processing for High-Performance Recycled Graphite

Impact & Significance: *Researchers combined experimental design, advanced characterization, and machine-learning models to optimize a scalable and low-cost milling method to mechanically shape natural and recycled graphite. As a result, the morphology and high-rate performance of recycled battery graphite was dramatically improved.*

Although graphite is an essential component of lithium-ion batteries, it is often undervalued in recycling and frequently treated as waste. Even when recovered, recycled graphite is often not structurally optimized to meet modern performance requirements. A low-cost and materially efficient shaping method is critical to upgrade the structure of recycled graphite and make recycled graphite competitive with virgin sources. In collaboration with Orbia, researchers at NLR demonstrated a scalable mechanical shaping process for both natural flake and recycled graphite. Using a machine-learning optimization framework paired with advanced image analysis, the team quantified how processing parameters impact graphite morphology and electrochemical performance. This data-driven approach guided the rational design of optimized milling conditions that significantly improved high-rate performance across diverse recycled graphite feedstocks. This breakthrough establishes a robust quantitative framework linking mechanical processing conditions to graphite properties and electrochemical performance, while providing a pathway to enhance the economic value of recycled graphite. Future efforts will extend this framework to mixed feedstocks and integrate additional characterization into the machine-learning model for further optimization.

Atmospheric Microplasma Increases the Value of Aged Battery Cathodes

Impact & Significance: *NLR researchers have successfully demonstrated the use of an atmospheric microplasma to recover 30% of lost performance of aged cathode materials without the need for high-temperature processing, enabling the reuse of cathodes that contain rare, valuable, and critical metals.*

Conventional NMC lithium-ion batteries contain metals that are difficult to obtain domestically. Unfortunately, rehabilitating these critical end-of-life cathode materials is often cost-prohibitive, requiring high-temperature treatments that limit reuse. For the first time, researchers at NLR have demonstrated that an atmospheric argon microplasma can restore capacity in aged NMC532 cathode material while avoiding high-temperature processing. The cathode's discharge capacity increased from 110 mAh/g to 143 mAh/g—recovering about 30% of lost performance and approaching pristine levels (approximately 153 mAh/g). In addition, system throughput increased from about 15 mg/h to 1,000 mg/h, highlighting the potential for practical stability. By eliminating the need for complex thermal infrastructure, this compact and modular process lowers both capital and operating costs while enabling domestic recovery of critical materials. Next, the team will scale the system from 2 to 10 tubes and tune parameters to enable relithiation of end-of-life material and potential upcycling of older NMC cathodes.

Updated Lithium-Ion Battery Supply Chain Database Surpasses 1,000 Company Entries

Impact & Significance: *This extensive resource, managed by NLR, is a valuable tool for tracking the depth and growth of the lithium-ion battery supply chain. Nearly 300 new entries were added across two updates in FY 2025.*

NLR completed two significant updates to the Lithium-Ion Battery Supply Chain Database managed in collaboration with NAATBatt International and Avicenne Energy US, adding nearly 300 new entries to bring the total to 1,022 companies and 1,178 facilities. In addition, the team added or updated entries on new plants, construction progress, production timelines, production capacity volumes, and relevant details, such as cathode chemistries, cell formats, offtake agreements, and more. This multiyear project is tracking industry growth across the lithium-ion battery supply chain in North America, including mining, material processing, electrode/cell/pack manufacturing, cell component production, and recycling/repurposing, as well as supporting infrastructure, such as equipment makers, startups, services, consulting, product distributors, and professional services. This open-access resource is available online with the option to download the database file, where viewers can use interactive features to map, filter, and search the entries. More than 5,000 registrants have accessed the website and downloaded the database file.

Electrification Technologies

Accelerated Reliability Evaluations Demonstrate Effectiveness of Low-Cost Power Electronics Material

Impact & Significance: *NLR's power electronics researchers are investigating whether sintered copper, a lower-cost material for power modules, is as effective and reliable as higher-cost sintered silver. They have begun validating its performance, which could help lead to lower-cost, highly effective wide-bandgap devices.*

Using NLR's world-class experimental facilities, researchers have begun to investigate if a lower-cost material for power modules called sintered copper can be as effective and reliable as its higher-cost counterpart, sintered silver. NLR researchers partnered with CuNex GmbH and Microchip to evaluate power modules incorporating both materials in NLR's laboratories. Experimentation began with power cycling, a durability and reliability evaluation that involves automatically turning a piece of hardware off and on again. Having power cycled the modules 75,000 times each, exceeding the 50,000-cycle lifetime typical of power modules for automotive applications, researchers will next power cycle the sintered silver and sintered copper modules until failure and examine the impact excess heat may have on the eventual failure mechanisms. These evaluations are critical to establish a thorough comparison of the performance and reliability of sintered silver and sintered copper, and to understand if sintered copper can support lower-cost advanced power electronics packages for wide-bandgap devices.

NLR Research Accelerates High Torque Motors Free of Rare-Earth Materials

Impact & Significance: *A groundbreaking motor design could enable the production of rare-earth-free motors, which could rapidly improve the profitability, affordability, and availability of advanced propulsion systems for high-torque vehicle applications.*

In collaboration with ORNL, NLR researchers are designing a cooling strategy that can enable permanent-magnet-free motors in high-torque applications where excess heat can cause demagnetization and permanent loss of performance. Using heat transfer modeling, NLR researchers have determined that a twin approach is needed: aggressive oil cooling of the internal machine, complemented by traditional automotive coolant for the outside stator. Having delivered an effective concept, NLR researchers will now fine-tune the design's cooling channels, flow rates, and coolant pumping requirements. The finished design will enable high-performance motors without the need for rare-earth magnets. This breakthrough will improve profit margins for medium- and heavy-duty vehicles while

removing the need for highly volatile imported minerals. This project is part of VTO's Electric Drive Technologies Program.

New Cooling Method for Motors Can Help Break U.S. Dependence on Foreign Critical Materials

Impact & Significance: *A powerful cooling system for a rare-earth-free motor design has accelerated progress toward electric-drive vehicles that don't rely on foreign supply chains.*

American automotive manufacturer BorgWarner is preparing to fine-tune and commercialize a wound-rotor motor made possible by NLR's thermal management expertise. Wound-rotor vehicle motors eliminate the need for expensive, scarce rate-earth magnets, but because their DC-powered rotors generate so much heat, they need powerful cooling mechanisms. In collaboration with BorgWarner, and as part of VTO's Electric Drive Technologies Program, NLR researchers have not only designed thermal management strategies for this cutting-edge technology, but also built in recyclability and reclamation strategies for several elements within wound-rotor motors. BorgWarner is now poised to bring the novel motor to life.

New Substrate Material Enables Highly Manufacturable Power Modules

Impact & Significance: *A new substrate material called aluminum oxynitride can offer superior electrical insulation, high thermal conductivity, excellent adhesion, and minimal stress on power modules, paving the way to higher-performing, lower-cost, and more reliable electric-drive vehicle systems.*

Next-generation power modules face a challenge: As wide-bandgap technologies push their power densities higher, they need to withstand ever-increasing temperatures. Under VTO's Electric Drive Technologies Program, NLR researchers have devised a strategy that can pave the way for higher performance, lower costs, and enhanced reliability—with applications in electric-drive systems. The strategy centers on the ceramic substrate that insulates power electronics components from the rest of the package, while bonding to copper to enable electrical and thermal conductivity. In collaboration with industry partners Nitride Global, CuNex, and CMS Circuits, researchers successfully demonstrated that an aluminum oxynitride (AlON) substrate can bond strongly to copper. With a unique combination of high electrical insulation and low thermal resistance in layers only tens of microns thick, AlON can help remove heat from electronic devices up to 80 times faster than other materials, helping devices use less power and extending their lifespans. Most importantly, it enables affordable and highly manufacturable power modules. Next, NLR researchers will evaluate the new substrate over 1,000 cycles in the accelerated thermal cycler to ensure its long-term reliability. Power modules using AlON substrates will then be designed and prototyped.

NLR Clears the Path to Enabling V2G Innovation

Impact & Significance: *By converting the requirements of UL 1741SC—a new critical standard to support V2G AC bidirectional power transfer—into a set of specific test cases and conformance criteria, NLR is streamlining efforts for manufacturers to develop advanced equipment to reduce costs and strain on the American electric grid.*

V2G AC transforms an EV into a distributed energy resource with the potential to stabilize the grid and lower costs for EV drivers and ratepayers. UL 1741SC is a critical new standard to enable connecting V2G AC-capable vehicles into the electric grid, defining requirements for V2G AC-capable EVSE to support important grid safety functionality, such as voltage and frequency trip requirements of the connection between the grid and the EV. However, EVSE manufacturers must have a clear set of test cases and conformance criteria by which to evaluate their equipment and confirm it complies with UL 1741SC. NLR researchers identified 39 sets of conformance test procedures for them. Additionally, the team converted requirements outlined in UL 1741SC into EVSE requirements, which can be used by EVSE manufacturers when developing and evaluating V2G-capable EVSE. Next, researchers will install a prototype V2G AC EVSE that will be constructed and delivered by an industry partner, expand NLR's existing test bed to include V2G AC features identified during this work, and assess the EVSE using the conformance criteria and evaluation procedures developed during this effort.

Research Helps Quantify Value of Smart Charge Management Solutions To Support Affordability and Reliability

Impact & Significance: *By using NLR's advanced analysis and computational resources, the EV-CENTS project's value proposition analysis framework will support informed decision-making by consumers and industry stakeholders by identifying the cost-saving potential of advanced transportation and energy technologies.*

Quantifying the potential cost savings of SCM and V2G solutions is critical to ensure that these technologies can support energy affordability and help utilities avoid costly infrastructure upgrades. But the variability of transportation and charging demands and range of distribution capacities can make it challenging for consumers to calculate impacts and savings. For the EV-CENTS project, NLR researchers developed two metrics to summarize evaluation results for EV charging, grid impacts, and SCM performance into a simple financial framework to quantify the value proposition for drivers and all ratepayers. The analysis framework includes metrics for cost of charging and cost of electricity. The annual cost to charge an EV will account for a wide range of costs and different use cases, identifying the motivation for a driver to consider solutions like SCM. The cost of electricity for average residential and commercial consumers will incorporate elements such as energy rates, demand charges, and fees, identifying the universal benefit to all ratepayers that new technologies will provide through downward pressure on utility rates. The team will next develop baseline results for each metric by leveraging grid studies from past projects that incorporate technology evaluation results that include cost savings and value potential.

New DOE Website Empowers Users To Leverage National Lab Vehicle–Grid Capabilities

Impact & Significance: *The new VGI Toolkit site on Energy.gov will offer cutting-edge software for stakeholders to use to study vehicle–grid integration (VGI) in their area with customized inputs and assumptions. Providing these resources in a single location streamlines informed decision-making by allowing stakeholders to identify the tools that best meet their specific needs.*

The upcoming launch of the VGI Toolkit will improve near-term accessibility to national laboratory tools for cost-effective and reliable grid integration of EVs. The tools, which allow users to develop detailed models for studying EV adoption, charging infrastructure, grid impacts, and financial outcomes, were previously hosted in a variety of locations, with varying degrees of accessibility to the public. Often, these individual sites lacked information on how tools across the DOE complex complement one another, or which tools were best suited to their individual use case. The VGI Toolkit was built through a collaboration among NLR, LBNL, ANL, Pacific Northwest National Laboratory, and ORNL. The ability for users to quickly access tools, run custom scenarios, and visualize results in an interactive setting is a huge improvement over conventional means of disseminating research insights. The VGI Toolkit is not only a step forward for DOE in supporting stakeholders making decisions about EVs, but also a model of how laboratories can develop user-friendly tools at scale and communicate their work to the public. Next steps include adding new tools to the website, with funding to support development of user-friendly interfaces specifically designed for each application.

New Transportation Load Profile Datasets for Four Vehicle Segments Fill Critical Gap

Impact & Significance: *An NLR research team has published new datasets estimating electricity demand for four traditionally overlooked EV segments: transit buses, government fleets, port cargo-handling equipment, and airport ground support equipment. These datasets provide critical data to support decision-making by utilities and energy planners.*

This project addresses a gap in energy planning by estimating potential electricity load profiles for underrepresented EV segments. The nationally representative, highly spatially resolved data support informed decisions on grid integration and infrastructure investments across the nation. The datasets and accompanying documentation are available in the NLR Data Catalog and will be included in a future update of the Electric Power Research Institute's eRoadMap data platform. Next, the team will further refine these datasets and develop similarly detailed load profiles for electric construction vehicles.

Site Assessment Tool Streamlines Charging Infrastructure Planning Process for Public and Government Users

Impact & Significance: *NLR's Electric Vehicle Infrastructure – Locally Optimized Charging Assessment Tool and Estimator (EVI-LOCATE), a virtual site assessment tool used to estimate the cost of installing EV charging stations, is now available to public users in addition to government users. By allowing users to get site assessment estimates without the time and costs of bringing in outside experts, the tool is improving the efficiency and cost-effectiveness of deploying charging stations.*

Since its public release, EVI-LOCATE has been used to conduct more than 1,700 site assessments—each taking about 7 minutes—for public users. Developed in collaboration with DOE's Federal Energy Management Program, the Joint Office of Transportation and Energy, and the U.S. Department of Defense, the tool provides an avenue for fleet operators, facility managers, and any infrastructure planning stakeholder to gather location-specific, site-specific, and user-specific cost estimates and site layouts. The NLR team combed the National Electrical Code standards, component-level cost data, and thousands of invoices from EV charging infrastructure projects to develop the tool. Researchers have also implemented insights and information from multiple stakeholders, including utility organizations, federal agencies, and EVSE installation businesses, improving the breadth and depth of the tool's site assessment capabilities. Next, the NLR team will incorporate findings from the EVSE soft costs benchmarking analysis to improve the tool's accuracy.

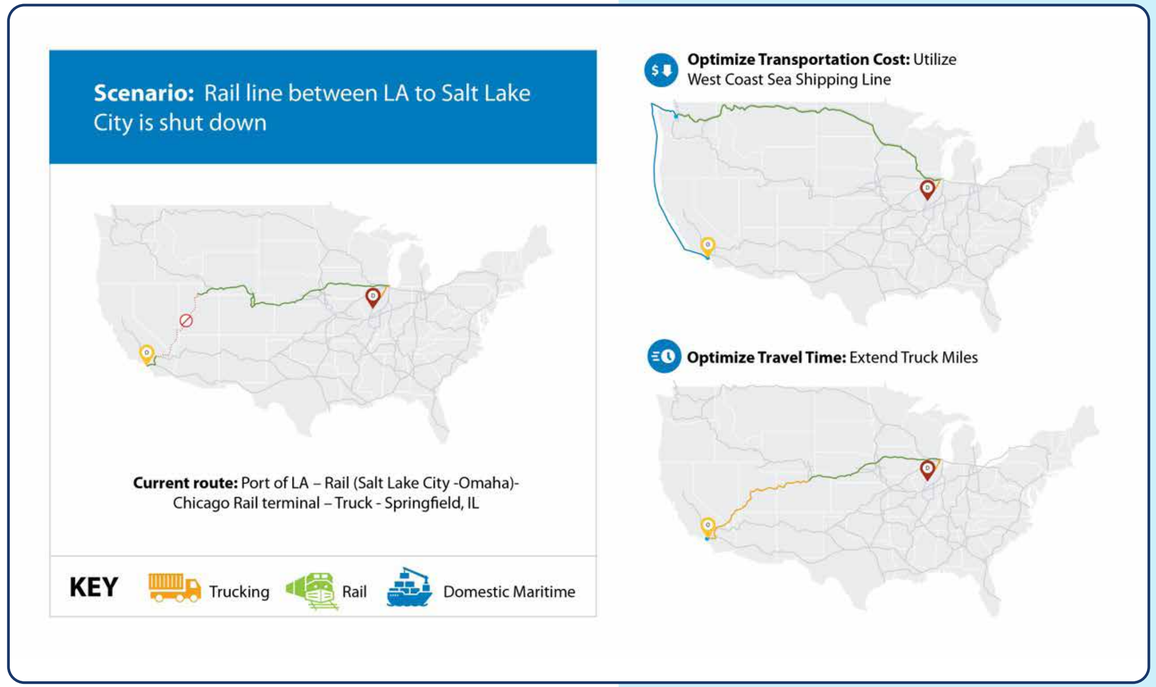
Analysis of Infrastructure Costs Enables Efficient Deployment of Charging Stations

Impact & Significance: *NLR developed a benchmarking analysis of the soft costs—capital and time—related to the installation of EVSE, as well as a tool that streamlines the EVSE permitting process. The analysis provides insights into EVSE interconnection and permitting, proposing solutions designed to improve efficiency, curtail delays and costs, and ensure uniformity in code enforcement for permitting.*

The benchmarking analysis describes the costs associated with the installation of EV charging stations and the time required for each stage of a typical installation process. Using data collected from over 4,000 project build-out invoices, the analysis reveals that approximately 30% of EVSE costs are allocated to non-hardware components. The team identified areas for more streamlined permitting and interconnection processes using insights collected from stakeholder interviews, large language model analysis of EVSE permitting procedures, and a workflow depicting the process of EV charger permitting and connection. NLR's permitting tool, a framework for streamlining EVSE installation, will improve the permitting process by evaluating a project's compliance with code specifications based on user input, calculations, and logic referencing national code. The tool will reduce the time needed to review, verify, or interpret compliance for high-frequency and low-complexity projects. NLR will publish the soft costs analysis, stakeholder engagement report, and permitting tool to improve EV stakeholder understanding of processes and ease the installation of EVSE. The team will also integrate benchmarking cost information into NLR's EVI-LOCATE tool, which generates charging station deployment plans, to enhance accuracy. NLR will extend the benchmarking analysis to include medium- and heavy-duty charging infrastructure and partner with DOE to explore chances to convert the permitting tool into automated software adapted for local codes.

Embedded Ceramic Layer in Power Electronics Package Will Transform Future Designs

Impact & Significance: *Integrating electrical insulation and liquid cooling into the ceramic layer of power electronics packages allows for dramatically more flexible and powerful designs. NLR's design has the capacity for four times greater power density than conventional power modules, which could enable next-generation aircraft, vehicles, and grid and energy systems.*



INFORMES Tool Poised To Unlock Intermodal Freight's Potential

Intermodal freight shipping can leverage the best of each mode of freight transportation: the size and cost-effectiveness of cargo ships, the efficiency of freight trains, the speed of aircraft, and the flexibility of trucks. But each node in the logistics chain adds complexity, and the process can quickly become inefficient.

NLR's INtermodal Freight Optimization for a Resilient Mobility Energy System, called INFORMES, will be the first-ever national-scale intermodal freight modeling tool. INFORMES can help freight operators route shipments around disasters, find the most cost-effective delivery strategy, and optimize delivery times. Slated for public release in 2026, the tool will support a strategic national rollout of intermodal freight technologies and guide optimized operations nationwide.

NLR researchers have discovered a transformative solution that could accelerate the development of compact, high-performance power electronics—widely regarded as critical to next-generation aircraft, electric-drive vehicles, grid infrastructure, and energy systems. The solution, developed with Synteris and Packet Digital under the Advanced Research Projects Agency–Energy (ARPA-E) OPEN 2021 project, involves integrating electrical insulation and liquid cooling into the ceramic layer commonly used for insulation and thermal conduction within power electronics packages. By embedding cooling channels directly into the ceramic substrate, researchers can circumvent the challenges a ceramic layer typically poses and design a more reliable package capable of nearly 500% greater power density. This year, NLR researchers fine-tuned the design using computational fluid dynamics and finite element analysis optimization, then demonstrated its capacity for power density four times greater than conventional models. With additional funding, the team could construct a prototype module, validate its performance, and demonstrate its effectiveness when integrated into transportation and energy systems.

3D-Printed Cooling System Can Enable Next-Generation Aerospace Propulsion

Impact & Significance: *A powerful motor using a 3D-printed cooling system could lay the foundation for advanced aircraft and aerospace vehicle powertrains, which require lightweight, low-cost, and extremely power-dense electric motors.*

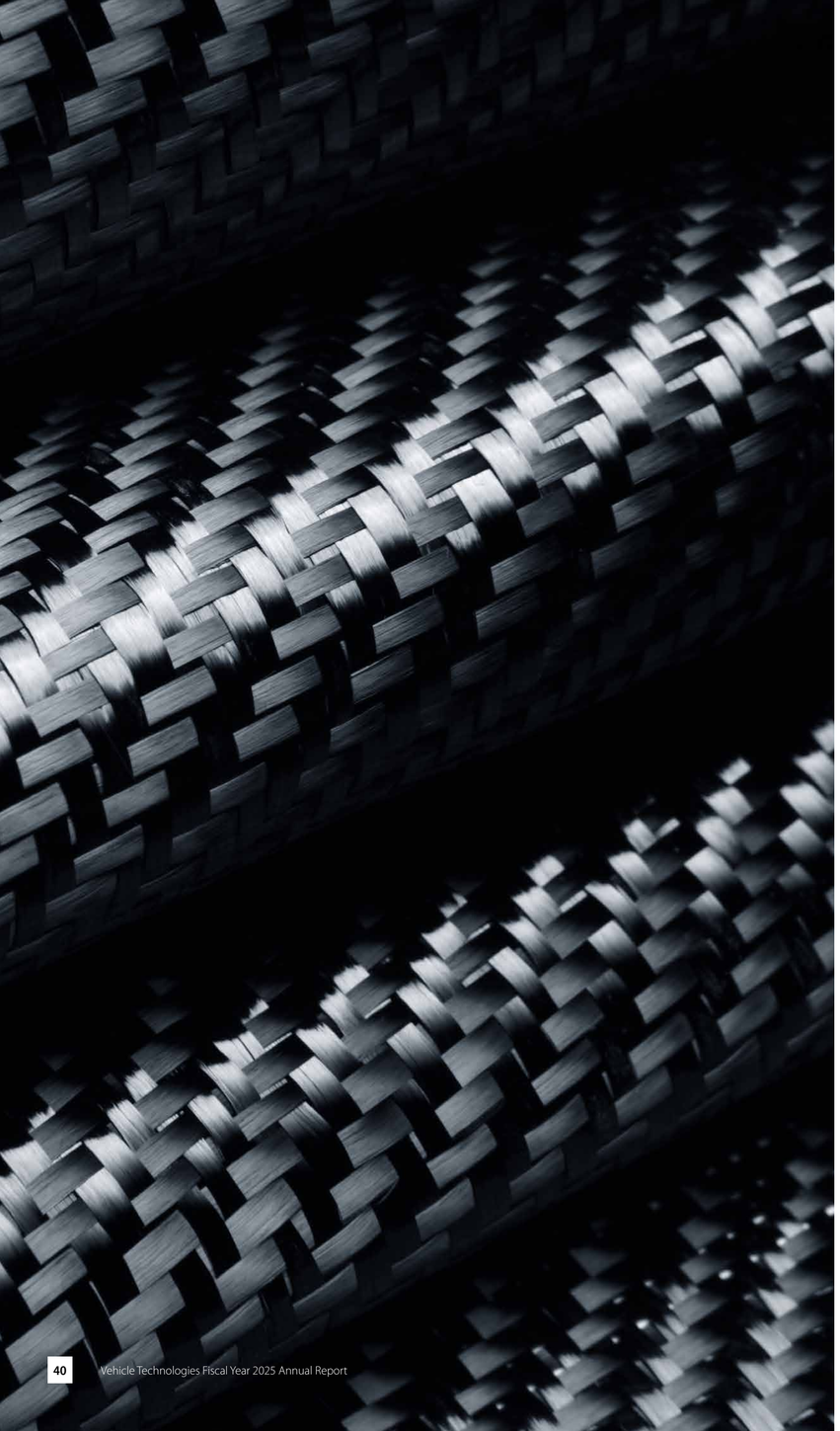
As part of the ARPA-E ASCEND program, NLR researchers teamed up with Marquette University to design a powerful motor that uses a 3D-printed cooling system that could lay the foundation for next-generation aerospace powertrains capable of power density greater than 12 kW/kg and greater than 93% efficiency. The motor's 3D-printed components include hollow conductors and heat sinks that efficiently maintain optimal temperatures by bringing coolant as close as possible to its heat sources. The motor and its power electronics share the tightly integrated cooling system, further reducing its cost, weight, and volume. These innovations are critical to advanced aircraft and aerospace vehicles, as they help tackle the twin challenges of ever-increasing heat generation from high-power density motors and ever-shrinking size and weight requirements. The next step for the research team is to fabricate and evaluate a prototype of the electric motor on NLR's thermal analysis platform and then optimize the design.

Off-Road, Rail, Marine, & Aviation Technologies

Integration of Fuel Property Estimation and Simulation Tools Progresses Measurement of Jet Fuel Performance

Impact & Significance: *NLR researchers integrated a C++ version of the FuelLib jet fuel property prediction model with the Pele tools multiphysics reacting flow simulation platform. These tools will allow NLR to rapidly simulate the combustion of jet fuels, dramatically lowering product development and certification costs and timelines.*

Currently, the high cost and risk of new fuel qualification limits the approval of new jet fuels for commercial use; new fuels must fit within the property range of petroleum-derived fuels. This research reveals how fuel properties will impact jet engine performance, reducing these risks. Researchers demonstrated that FuelLib can accurately calculate individual molecular compound and fuel mixture properties, which Pele uses to simulate complex multiphysics reacting flow in aircraft engines. Simulating fuel property impacts on the performance of aircraft engine combustors can expand knowledge of fuel effects on performance, leading to easier approval of new fuels and expanded allowable property range for all jet fuels. The Pele simulations will also reveal fuel property impacts on airplane outputs that impact air quality around U.S. airports. Next, researchers will apply the integrated tools to examine performance and emissions of a range of conventional and renewable jet fuels.



Materials Technology

Incorporating Second-Life Plastics Can Reduce Cost of Hybrid Composites for Vehicle Materials

Impact & Significance: *NLR researchers found that incorporating recovered plastics into hybrid composites for vehicle materials could reduce the composites' cost by more than 20% while preserving tensile properties.*

Lightweight materials can reduce vehicle weight, improve efficiency, and reduce fuel costs for drivers, but can also be costly. Recent work at NLR explored the use of hybrid composites to reduce the cost associated with lightweighting vehicles. NLR researchers investigated implementing various "second-life materials" that can be obtained at a lower cost. Their analysis showed that glass fibers, polypropylene, and recovered polyethylene could all be implemented into hybrid composites to reduce their cost in excess of 20% with minimal impact to tensile properties. Not only can implementing these alternative fibers reduce the cost of composites, but it can also expand the supply chain for vehicle materials. These two effects compounded could lead to greater lightweighting of vehicles and greater overall efficiency. Researchers will next translate these foundation findings into alpha protype materials for further testing.

Technology Integration

Upgrades to the AFDC Enhance Security and Improve User Experience for Millions

Impact & Significance: *Upgrading the AFDC web application template and redesigning the site homepage resulted in better alignment with DOE branding and priorities, improved site security, and reorganized homepage navigation. These changes enable site visitors to quickly identify resources available and easily access what they need, leading to a better experience for the site's millions of users.*

NLR upgraded the AFDC to the latest web application template from the Office of Critical Minerals and Energy Innovation (CMEI)—formerly known as EERE— to incorporate essential security updates and give the site a more modern look and feel. As part of this effort, the AFDC team also redesigned the site homepage, helping users quickly identify the resources available and easily access what they need. This undertaking began in February 2024 and involved updates to hundreds of pages across the site to fit into the new template. The AFDC now reflects the latest Energy.gov header and footer throughout the site, as well as the current DOE logo and CMEI branding styles and colors. The homepage redesign involved analyzing how users interacted with the homepage via heat maps, traffic data, and direct user feedback to identify how the user experience could be improved. The AFDC received around 16 million page views in FY 2024, making it one of the most visited CMEI sites. The updates align with DOE's branding and priorities while modernizing the site. As a next step, NLR is revamping the AFDC tools page to turn the static list of highlighted tools into a comprehensive directory of tools with expanded descriptions and features to search by keyword and filter by topic.

NLR Assesses Real-World Impacts as Automated Vehicles Move From Theory to Practice

Impact & Significance: *Automated vehicle technology is rapidly advancing into real-world mobility operations, particularly through the introduction of "robotaxis" in an increasing number of cities. This project evaluates the potential impacts of automated mobility on the transportation landscape in terms of energy, economics, and access.*

Automated vehicle systems and human-driven on-demand mobility services are being introduced in various locations across the country. Companies are rapidly expanding operations in pursuit of future market share, but objective evaluation is lacking. Such evaluation of robotaxis and other automated mobility systems is essential to determine whether they can efficiently and reliably meet mobility needs. The research team, with established connections to companies such as Waymo, Zoox, Via, and others, has developed a database to identify, characterize, and track the

growth of on-demand and automated mobility services. Initial case studies are underway, analyzing these systems in terms of energy use, cost, and accessibility, and estimating their broader impacts at local, regional, and national scales. As automated mobility continues to grow—sometimes accompanied by exaggerated performance claims—objective analysis is critical to support informed decision-making by transportation managers and the public. Next steps include quantifying anticipated outcomes, expanding the database, and making it publicly accessible.

Automated Wheelchair-Like Vehicle Network Enhances Airport Passenger Mobility

Impact & Significance: *An estimated 37% of U.S. travelers are over age 60, and this share is expected to remain high and possibly grow as more people continue to travel later in life. As airports expand, they face mounting challenges in efficiently moving passengers through their facilities.*

Air travel continues to increase in the post-pandemic era, prompting airports to expand to accommodate rising demand. At the same time, a growing share of travelers are over age 60, many of whom require wheelchair assistance to ease the strain of walking while navigating large airport facilities. In response, LUCI, in partnership with NLR, has developed an automated network of small, wheelchair-like vehicles designed to move passengers through airports more efficiently. The team has built prototype vehicles and evaluated them in airport facilities, demonstrating their ability to navigate safely through crowds. The team also developed fleet management software to coordinate these vehicles and support on-demand, app-based ride requests. The integrated system—vehicles, management software, and an app—provides a convenient service that is scalable, flexible, and reconfigurable, unlike traditional people movers. This is important because airports struggle to staff human-assisted wheelchair services, which can result in late arrivals, flight delays, wasted energy, and increased costs. The LUCI automated vehicle system supports airport growth by improving passenger mobility and convenience while reducing energy use and operational costs. Next steps include pilot demonstrations in airports to further refine the system.

Mobile App With 3D Graphics Could Help Emergency Responders Safely Manage EV Incidents

Impact & Significance: *A mobile app with 3D graphics could help emergency responders safely manage incidents involving EVs by providing model-specific graphics that highlight critical vehicle components, such as the locations of high-voltage systems and high-strength materials.*

NLR completed an exploratory study to assess the feasibility and value of a mobile app to help emergency responders safely manage incidents involving EVs. Responders currently rely on PDF guides with 2D graphics to find model-specific information they need, such as the locations of high-voltage systems and high-strength materials. An app with 3D graphics would provide information in a more usable interface and allow users to zoom and rotate the images. NLR conducted listening sessions with original equipment manufacturers and first responders to gather feedback, including whether manufacturers could provide the necessary graphics to support the app and whether responders would use it. Both groups supported the concept and shared insights about how to navigate potential hurdles and key features to make the app valuable. Based on these insights, NLR created an app wireframe with a minimalistic interface that would allow a user to easily search for a vehicle and access 3D images that highlight critical vehicle components. NLR reported the listening session findings and app wireframe with DOE in Q4, along with recommendations, and will work with DOE to determine next steps.

Online Guide Provides User-Friendly Resources To Help School Bus Fleets Achieve Their Goals

Impact & Significance: *The online School Bus Electrification Center provides a centralized location of resources for school bus fleets to strategically plan for and adopt electric school buses.*

NLR published an online School Bus Electrification Center to help school bus fleets strategically plan for and adopt electric school buses. Information on school bus electrification is often scattered across multiple sources and too complex for a nontechnical audience. NLR's

guide provides a centralized location for all the resources a fleet manager needs and is designed to build their technical capacity without being overwhelming. The modular, step-by-step format allows users to follow the full process or quickly jump to the spot where they need additional support. Topics covered include fleet assessment, route analysis, bus procurement, charging infrastructure, and battery recycling. The guide is available on the AFDC, leveraging that site's reputation as the go-to resource for advanced transportation fuels and technologies.

Athena Launches Three Models for Airports To Map Out Advanced Transportation Energy Planning

Impact & Significance: *The new models on the Athena Aeroportal introduce users to the project's unique capability to provide an interface between a user-friendly web platform and the robust backend computational resources of NLR's powerful supercomputer. Athena enables access to high-resolution insight for any airport's specific transportation and airport equipment needs.*

As air travel increases dramatically, airports need to identify how to meet growing demands on key energy infrastructure while maintaining operating costs at manageable levels. Tailored solutions are necessary to meet a specific airport's needs while reducing waste and unnecessary cost. Through the Aeroportal web platform, researchers with DOE's Athena project—led by NLR—are providing airports with customizable advanced modeling tools. The team developed three computational models for specific airport applications of advanced vehicles: rental cars, transportation network companies like Lyft and Uber, and electric ground support equipment. Airport representatives can sign up for an account on the Aeroportal to access general model results that they can compare to their own use cases to approximate the energy use and electric load of any of these applications. Authenticated stakeholders will even have the ability to execute tailored scenarios, using their own specific airport operations data, on NLR's high-performance supercomputer via the Aeroportal. The research team is actively working with the full group of the project's stakeholders, including a network of 16 U.S. airports of all sizes, to improve and adapt these models so they are user-friendly and relevant.

Engagement With Compressed Natural Gas (CNG) Stakeholders Provides Potential Research Opportunities

Impact & Significance: *NLR identified key trends impacting the CNG market and summarized nearly 30 industry research project ideas through discussions with industry stakeholders.*

Key learnings from the discussions included that heavy-duty CNG vehicles offer the lowest-cost option for alternative fuel powertrains, and the improved range and performance of Cummins' new 15-liter engine enable a wider range of fleets to use CNG. NLR summarized several research ideas provided by industry, including an industry-led development of a CNG hybrid engine, a highway corridor analysis to meet the new 15-liter engine needs, and analysis of the secondary CNG vehicle market. The CNG industry stakeholders that participated in the discussions represented large fleets, original equipment manufacturers, station owners, and renewable natural gas producers. NLR summarized industry input and research ideas in a white paper for DOE and will work with DOE to prioritize research projects.

Sharing Real-World Success Elevates Impact of National Partnership for DOE and CC&C

Impact & Significance: *NLR produced 25 success stories showcasing the impact of the CC&C partnership with DOE. Sharing deployment project stories provides confidence in alternative fuels and advanced vehicle technologies, demonstrates solutions to common challenges, and enhances project replicability.*

NLR produced 10 project videos, 10 single-slide success stories, and five case studies featuring CC&C coalitions bringing VTO fuels and technologies to American fleets and consumers. The quick-snapshot slides allowed VTO leadership to share concrete examples of alternative fuel and community microgrid projects with incoming staff and at the VTO Annual Merit Review. These stories highlighted the partnership's ability to bring VTO's work to market for an audience of peers who could benefit from CC&C connections. For external audiences, the stories illustrate how the right partners and processes set projects up for success. NLR featured more than 75 coalition partners joining CC&C

and VTO to advance transportation energy choices for decision makers nationwide. Providing information in formats that resonate with different audiences allows more stakeholders to connect with CC&C to achieve their goals and impact change. NLR is expanding CC&C storytelling efforts with a story intake form, communications office hours, and reviews of coalitions reporting.

Coalition-Building Efforts Extend Reach of CC&C Through Nine New Coalitions and Statewide Expansions

Impact & Significance: *NLR's coalition-building efforts extended reach of CC&C to 93% of the U.S. population, with rural areas accounting for a substantial portion of the growth. Businesses in these areas can now leverage coalition technical expertise to evaluate transportation energy choices for potential cost savings and efficiency improvements.*

NLR efforts to expand CC&C contributed to more than 93% of the U.S. population now living within the boundaries of a coalition, up from 83% 3 years ago. Adding rural areas to the network accounted for a substantial portion of the growth, with geographic coverage increasing from 50% to 70%. Businesses in these areas can now leverage coalition technical expertise to evaluate transportation energy choices for potential cost savings and efficiency improvements. The increase in coverage comes from nine coalitions joining the partnership (southern Nevada, Nebraska, southwest Missouri, North Carolina, Alaska, south Texas, Mississippi, Nevada, and Kansas), as well as several existing coalitions expanding their territories (Oklahoma, eastern Missouri, and Kansas City). NLR helped expand the network by working with DOE to establish an "apprentice" coalition designation category that provides high-touch support for aspiring coalitions, as well as providing coalition-building support to existing coalitions. NLR is continuing to work with aspiring coalitions to achieve full DOE designation and creating the foundations for new coalitions.

Fleet Database Upgrades Enable More Robust Analysis and Enhanced User Experience

Impact & Significance: *Upgrades to fleet database will reduce costs, facilitate stronger analysis capabilities, and enhance user experience.*

NLR upgraded the State and Alternative Fuel Provider Fleet Program reporting database to facilitate stronger analysis capabilities and enhanced user experience. Fleets submit reports to this database as part of requirements under the Energy Policy Act. Without disrupting use of the system, NLR moved the database from expensive commercial software to a free, open-source, cloud-based platform. This switch will reduce costs and facilitate more efficient application improvements. The new platform uses a more universal coding language and allows the team to easily test new features, making the database easier to maintain and improve. In FY 2026, NLR will develop new data analysis features for streamlined reporting and address remaining software bugs impacting the user experience.

Tool That Streamlines EV Charging Permitting Processes Can Increase Efficiency and Reduce Costs

Impact & Significance: *NLR developed a tool to help streamline permitting processes for EV chargers, facilitating increased efficiency, reduced delays and costs, and consistent code enforcement.*

Permitting processes and requirements to install charging stations vary significantly from one jurisdiction to another, which can cause project delays and increased installation costs. NLR's tool provides questions to help entities instantly validate code compliance based on the user's input, calculations or logic for each question, and national code references. The tool's logic will help assess whether a project meets code requirements, reducing staff time required to review and verify or interpret compliance, particularly for high-frequency and low-complexity projects. The project team leveraged data from existing permitting processes and insights from jurisdictions, installers, automated permitting companies, and other experts. NLR will discuss next steps with DOE, which might include developing automation software and allowing jurisdictions to tailor the tool to their local codes and regulations while maintaining a basis in national model codes.

Analysis

Newly Identified "Fleet Chromosomes" Will Boost Economies of Scale for Commercial Vehicle Manufacturing

Impact & Significance: *Rather than identifying powertrain characteristics by the vehicle weight class, NLR's Fleet Chromosomes project classifies them by their real-world performance. These distinct commercial vehicle driving patterns can help manufacturers align vehicle component designs with real-world operations, create manufacturing economies of scale across their vehicle platforms, and boost overall fleet efficiency.*

For the first time, NLR researchers have designed a state-of-the-art clustering methodology and automated naming system to define "Fleet Chromosomes": innate patterns in commercial vehicle drive cycles, from vehicle stopping and starting to acceleration and average speeds. Just like mapping human DNA, the newly defined fleet "chromosomes" illustrate how commercial vehicles as diverse as long-haul trucks, parcel delivery vans, airport shuttles, and yard tractors are driven in the real world. Manufacturers will be able to apply the methodology to align vehicle component designs with real-world operations, create manufacturing economies of scale across vehicle platforms, and boost overall fleet efficiency. The Fleet Chromosomes team will soon publish their results to expand stakeholder awareness, demonstrate the value of NLR's Fleet Research, Energy Data, and Insights (FleetREDI) data and analysis platform, increase opportunities to apply the advanced pattern recognition tool to additional research questions, and potentially attract new partners.

FleetREDI Supports 20 Commercial Vehicle Projects With 400,000 Miles of Newly Analyzed Data

***Impact & Significance:** NLR's standardized methodology enables the rapid and streamlined addition of new commercial vehicle operating data to its FleetREDI platform, in turn increasing the efficiency of high-impact commercial vehicle research through operational data collection, streamlined analysis, and rapid insight generation.*

In FY 2025, NLR's FleetREDI platform leveraged 400,000 miles of newly collected and analyzed vehicle data and supported more than 20 commercial vehicle projects. The high-resolution (1-Hz) data spanned vocations from school and transit buses to Class 8 tractors and fishing vessels, and were added to the database through the standardized data collection, ingestion, cleansing, and analysis pipeline that populates Fleet DNA, the country's largest public repository of rich, multi-channel, 1-Hz operational data. The process allows FleetREDI to increase the efficiency of high-impact commercial vehicle research through data collection, streamlined analysis, and rapid insight generation that reduce barriers for R&D of advanced vehicle technologies. Next, anonymized, aggregated statistics and insights will be made available on the FleetREDI web dashboard for public use, and individual datasets will be made available to researchers through VTO's Livewire Data Platform.

Understanding Regional Vehicle Survival Rates Enables Improved Modeling of Vehicle Sales and Ownership

***Impact & Significance:** By leveraging historical vehicle registration data, this project derived regional net survival rates by age for vehicles in every U.S. state. This provides insight into vehicle preferences, ownership behavior, and vehicle migration patterns, enabling detailed modeling of vehicle sales and ownership across the nation.*

In transportation energy transition analysis, vehicle survival rates are used to model the retirement of existing vehicles and the adoption of new technologies. Previously, only national-level statistics were available, often leading to over- or underprediction of local vehicle sales and stocks. In collaboration with the University of Tennessee, Knoxville and ORNL, NLR produced new data on regional net survival rates by age for light-duty vehicles in every U.S. state. The analysis found that up to about 30% of light-duty vehicles aged 2–10 years entered or left the state where they were first sold, compared to about 10% of similarly aged vehicles retiring from the national fleet each year. These rates vary by vehicle class, type, and age, as well as by state-level factors such as population, economics, and vehicle lifespan. The pace of new technology adoption varies not only by economics and technology preferences, but also by vehicle retirement and migration. This research highlights differences in vehicle ownership behavior and vehicle migration patterns across the nation, showing that some states have much older vehicle stocks, import more used vehicles, retire vehicles later, and may adopt new technologies at a different rate than others. These insights enable detailed modeling of vehicle sales, ownership, and technology adoption in NLR's TEMPO model and Automotive Deployment Options Projection Tool (ADOPT). Next steps include model integration and validation to ensure consistency between national- and county-level models.

TEMPO Model Enhancements Improve Scenario Analysis of Technology Adoption, Energy Use, and Transportation Affordability

***Impact & Significance:** Improvements to the TEMPO model—specifically in technology adoption decisions, county-level functionality, and policy representation—enable more robust estimates of technology adoption, energy use, and transportation affordability across a range of scenario assumptions. Additionally, code base improvements boost efficiency and support large-scale scenario analysis.*

Robust estimates of the transportation sector are critical for infrastructure planning, grid modernization, and guiding research toward high-impact technologies. Developing these estimates requires a modeling approach that accurately reflects current trends, potential technological and infrastructure advancements, and evolving policies to support informed decision-making. The TEMPO model was improved in several key areas: vehicle cost, infrastructure, and related assumptions were updated based on the latest data and policies; flexibility was added to better capture variations in technology adoption assumptions; the representation of medium- and heavy-duty vehicle adoption was refined to account for diverse ownership behaviors; income group variations were explored to improve representation of transportation affordability; and the code base was upgraded to enhance compatibility and computational efficiency on high-performance computing systems. Accurate inputs and realistic model dynamics are essential for effective scenario analysis. Given the uncertainty of future scenarios, exploring assumption variations and their impacts requires efficient models capable of large-scale analyses. Expanding the model to include additional impacts such as affordability further supports comprehensive analysis. Next steps include finalizing the initial technology adoption scenarios, incorporating feedback from the TEMPO Technical Review Committee, and continuing to improve model efficiency to streamline workflows and accelerate results.

Smart Mobility Systems

Enhanced EVI-X Spatial Resolution Enables Modeling of Localized EV Charging Impacts on the Distribution Grid Enabling Planning for Grid Reliability and Affordability

***Impact & Significance:** An NLR research team has enhanced the spatial resolution of the EVI-X modeling framework to support electricity distribution planning and analysis with detailed, spatially resolved data. Such granularity is critical for evaluating localized grid impacts, optimizing charging station siting, and ensuring grid reliability amid growing EV adoption.*

This enhancement bridges the gap between national-scale EV charging station adoption simulations and the detailed, spatially resolved data required for electricity distribution planning. The research team developed a methodology to convert national-scale EV charging station adoption simulations into parcel-level infrastructure estimates. Applicable to the full range of on-road EVs, this granular approach can also generate highly resolved data on EV load and flexibility potential, enabling integration into power flow analyses, hosting capacity studies, and other distribution grid assessments. Transportation electrification can pose challenges to the electricity grid—particularly at the distribution level—without adequate planning. Parcel-level data enable NLR to model localized grid impacts and explore mitigation strategies such as managed charging. This enhancement will support the update of NLR's Electric Vehicle Infrastructure – Projection Lite (EVI-Pro Lite) tool, a publicly available decision support resource for proactive EV and grid planning.

Quantifying the Potential for EVs To Enhance Grid Stability, Lower Costs, and Increase Utilization Demand Flexibility in the United States

Impact & Significance: *Researchers at NLR are quantifying the potential of EV demand flexibility, assessing its implications for grid integration, and analyzing its evolution in order to identify opportunities to bolster reliability and affordability of the electric power system in the United States.*

The extent of EV demand flexibility—particularly across vehicle types, locations, and times of day—remains highly uncertain. A lack of detailed modeling prevents grid planners and operators from fully leveraging this resource. To address this gap, NLR conducted a robust analysis of EV demand flexibility and its grid integration implications, quantifying flexibility across vehicle types, geographic regions, and EVSE types. The study also assessed how different EVSE build-out strategies may influence flexibility. Findings provide actionable data and recommendations to help grid planners and researchers develop optimized managed charging strategies. This research supports infrastructure planning aimed at maximizing the grid benefits of EV integration.

Integrating Thermal Effects Improves Energy and Range Predictions in RouteE Powertrain

Impact & Significance: *Improved RouteE Powertrain models reduce prediction errors by nearly 50%, with even greater accuracy at extreme hot and cold temperatures, enabling reliable predictions of how ambient temperatures affect vehicle energy consumption and driving range.*

Predicting the energy use and range of EVs under varying ambient temperatures is challenging because temperature significantly affects energy consumption. Accurate modeling of these thermal impacts is essential for estimating real-world vehicle energy efficiency and operational range. The NLR research team has enhanced the RouteE Powertrain battery-electric vehicle models by integrating temperature sensitivity using large-scale thermal simulations from FASTSim. These improved models reduce prediction errors by nearly 50%, with even greater accuracy at extreme hot and cold temperatures. This enhancement improves estimates of energy consumption and driving range, supporting more reliable fleet planning, route optimization, and vehicle performance assessments. Improving model accuracy across temperature ranges is crucial for addressing range anxiety and informing infrastructure planning. Next steps include expanding temperature-sensitive modeling to additional RouteE Powertrain vehicle models and integrating these enhanced models into downstream analyses, fleet optimization, and broader transportation research.

New Publication To Demonstrate NLR's Thought Leadership in Commercial Vehicle Opportunity Costs

Impact & Significance: *NLR's T3CO tool is uniquely capable of quantifying the opportunity costs of driving and maintaining advanced commercial vehicles, and its new methodologies for soft costs help reduce the cost of developing and implementing commercial vehicle transportation services.*

NLR researchers are documenting the methodologies that power the first-of-its-kind T3CO tool. T3CO is uniquely capable of quantifying the opportunity costs that impact operations and deployment decisions

for advanced trucks. Unlike existing models, which rely on average daily mileage to generate a rough cost of ownership, T3CO integrates with NLR's FASTSim tool to simulate vehicle operation over actual drive cycles—and its batch mode can enable rapid analysis of hundreds of duty cycles representing the full variation of a vehicle's operations, resulting in more realistic cost-of-ownership estimates. Forthcoming documentation will detail T3CO's cost methodologies, including those that enable estimates of lost revenue opportunities due to fueling, charging, maintenance, and repair. Next, researchers will implement a new methodology to assess opportunity costs if operators opt to purchase higher-weight-class vehicles to offset the reduced payload capacity of medium-duty vehicles.

National Operating Speed Prediction Model Enhances MEP Accuracy and Capabilities

Impact & Significance: *By calibrating the operating speed prediction model and integrating realistic traffic speeds into MEP analysis, this project improved MEP score accuracy and enabled time- and day-specific calculations, enhancing the tool's precision for transportation planning.*

This project addressed a key limitation of OpenStreetMap (OSM) network data, which includes only speed limits. Since MEP calculations rely on this data, they cannot reflect actual traffic speeds, which vary due to congestion and time-of-day effects. As a result, MEP scores solely based on OSM speed limits can be inflated or unrealistic, highlighting the need for accurate, time-sensitive traffic speed inputs. To address this, the project integrated multiple data sources, including speed limits, link and traffic characteristics, and points-of-interest data from OSM; historical probe speeds from a commercial vendor; and population and employment data from the U.S. Census. Several machine-learning models were trained on data from 10 diverse U.S. cities to predict operating speeds on network links, and the best-performing model was selected. The final national model can predict traffic speeds for any time period at any location across the nation. This enhancement allows the MEP tool to produce more accurate score calculations and perform time- and day-specific assessments. Using predicted operating speeds instead of OSM speed limits also enables the tool to identify urban areas where congestion significantly impacts accessibility, supporting more targeted congestion mitigation strategies. Next steps include integrating the national speed prediction model into the MEP codebase for seamless calculations at both city and national scales, and further calibrating it with additional datasets, such as Overture, to enable accurate MEP calculations using other network datasets.

Achieving Nationwide Access Modeling Through Rust-Based High-Performance Computing

Impact & Significance: *By implementing the MEP data analysis pipeline as a high-performance Rust library, this project computed MEP scores for 10.2 million hexagonal grid cells covering the continental United States in just 6 hours on the Kestrel high-performance computing system—enabling a scale of analysis that was previously intractable.*

A system was designed to massively parallelize the central processing unit (CPU)-intensive route planning and geospatial analysis algorithms that underpin access modeling. Supporting tools were developed to aggregate results to various census-designated geographical boundaries. The project met its objective of generating a nationwide MEP dataset for 10.2 million data rows. Porting the code to Rust enabled completion of a previously infeasible task in just 6 hours. This effort also resulted in a software library for scalable access modeling across diverse data inputs and access metrics. The project was supported by a team of year-round and summer software engineering research interns, all of whom contributed code and will be credited in the open-source release of the software. Previous MEP modeling efforts have shown that inefficiencies in dataset generation increase labor costs and limit opportunities for deeper analysis. By reducing run times and enabling larger-scale analysis, researchers can shift focus from execution to analysis. Next steps include enhancing the software's behavioral capabilities to support transit-mode traversal modeling, enhanced walk/bike/drive realism, and open-source input datasets. With these added capabilities, both the library and datasets were issued for open-source release in September 2025.

New Framework Leverages Parallel Computing and AI To Co-Simulate CDA Vehicles and C-V2X Wireless Communications

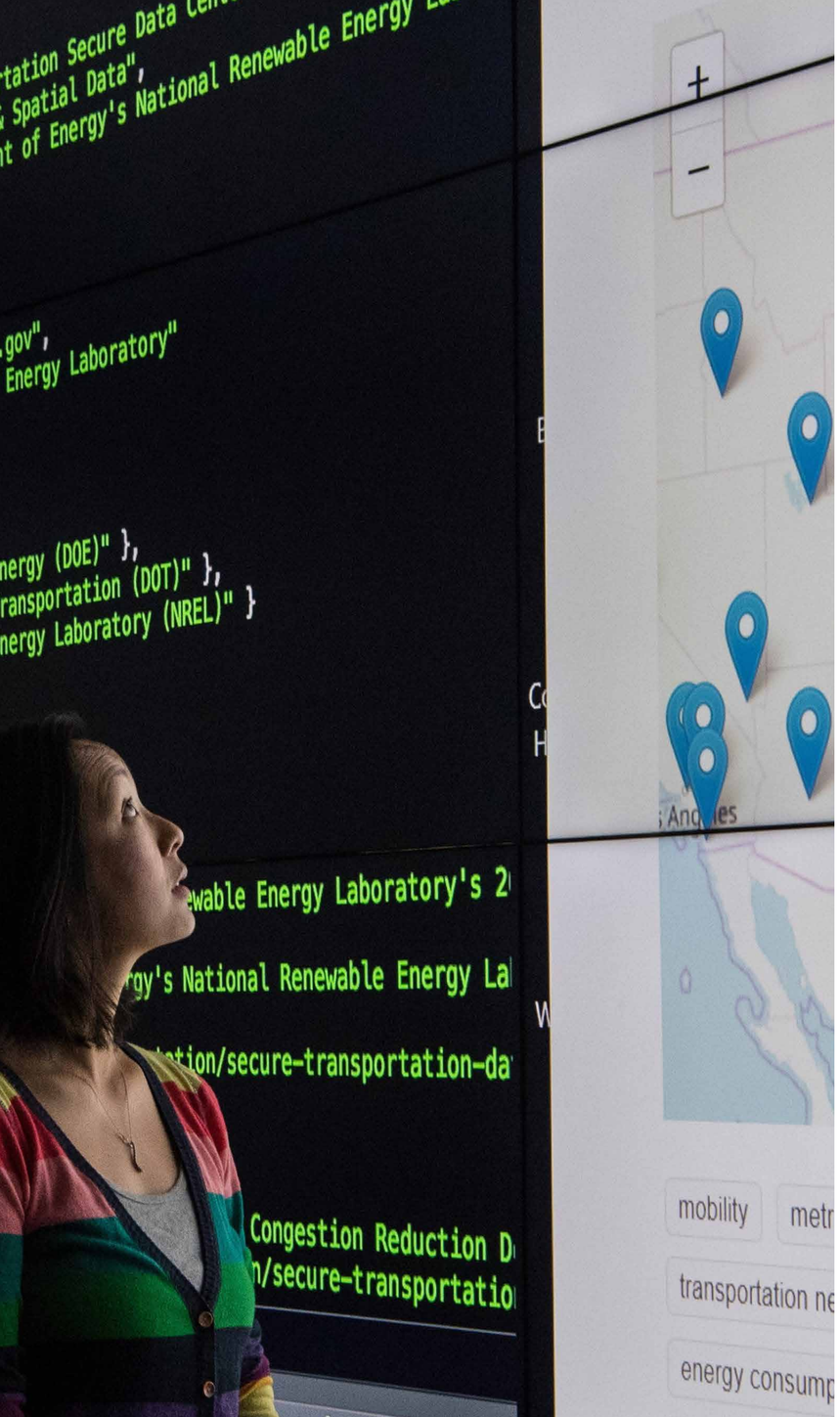
Impact & Significance: *This project addresses the need to better understand the large-scale impacts of the new C-V2X communications standard.*

Until now, CDA vehicles and C-V2X wireless communications had not been modeled together in a co-simulation environment at scale. One major challenge was the long computational time required to simulate C-V2X wireless communications. To address this, NLR developed a high-performance co-simulation framework that integrates a CDA vehicle model from LBNL with NLR's C-V2X wireless communications model. By leveraging parallel computing, AI, and high-performance computing resources, the framework radically improved the computational efficiency of the simulations. This co-simulation framework is the first of its kind to support large-scale experimental studies, enabling researchers to assess the impacts of increased C-V2X adoption before conducting field trials. Next, NLR will further enhance the realism of C-V2X communications modeling.

Literature Review Informs Development of New Book on Cooperative Driving Automation

Impact & Significance: *A deep understanding of the current state of the art in CDA is critical for advancing the technology and realizing its full potential to significantly reduce energy consumption and improve traffic efficiency and safety.*

A systematic review of the current state of the art in CDA—the use of connected and automated vehicle technologies to enable coordination among vehicles and infrastructure—is needed. To address this need, researchers from NLR, in collaboration with LBNL, ANL, and ORNL, are coauthoring a book based on a comprehensive literature review of the latest developments in the field. The book, to be published by Springer Nature, will help guide future research. The next step is the formal publication of the book.



Augmented Reality Application Developed and Demonstrated for Track Testing Connected and Automated Vehicles

Impact & Significance: *The V2X industry has expressed great interest in leveraging the new augmented reality application to visualize V2X messages*.

Track testing of connected and automated vehicles has typically relied on vehicle-in-the-loop simulations. However, the simulation scenarios were not based on real-world drive cycles, and test track observers could not see the virtual vehicles, limiting their ability to anticipate behavior or identify issues. To address these challenges, NLR researchers collaborated with Leidos, the American Center for Mobility, and the Michigan Tech Research Institute to develop simulated scenarios informed by real-world drive cycles. They also created an augmented reality application that provides observers with an immersive visualization of virtual vehicles alongside real vehicles on the test track. Funded by ARPA-E, this work established a framework for developers to track test connected and automated vehicles in a simulated environment. The research team is currently exploring commercial applications of this technology to support industry needs.

Livewire Stakeholders Drive Future Platform Priorities

Impact & Significance: *The Livewire project team sent a questionnaire to all Livewire account holders to gather insights that will help shape the future of the platform. Through the results, the team gained valuable insight into how Livewire users interact with the site, what platform features they would like to see, and their data wants and needs. Understanding data and feature priorities is essential to the platform's success.*

Livewire responds to the needs of the transportation and mobility research community to support research and analysis, foster a sense of collaboration, and grow the platform's catalog of data so that it may be useful to future researchers. As part of this effort, the Livewire team keeps Livewire updated with modern technologies and uses best practices to improve the experience for both data providers and users. After analyzing the results, the Livewire team learned that users' top data priorities include EV charging station activity; light-, medium-, and heavy-duty vehicle operating data (electrified and conventional); vehicle trajectories, trip distributions, and origin-destination data; and automated and connected light-duty vehicle data. Findings also indicated that 78% of questionnaire respondents would find useful the ability to filter, query, and visualize the data on Livewire before downloading it. More respondents obtain data from the platform than archive it, but many indicated that they plan to archive future project work on the site, augmenting the catalog of available data sources. In FY 2026, the Livewire team plans to cross-reference questionnaire findings with actual usage and highlight top datasets in the upcoming site redesign based on dataset statistics and questionnaire feedback.

SUCCESS METRICS

Patents & Records of Invention

Records of Invention

- Energy-Efficient Vehicle and/or Traffic Light Control
- Eco-Pilot-Energy-Efficient Vehicle Speed Advisory Through Vehicle-to-Infrastructure Communications
- A Mobile App for Energy-Efficient Vehicle Speed Advisory Through Real-Time Vehicle-to-Infrastructure (V2I) Communication
- Systems and Methods for Training and/or Using Machine Learning Models To Detect Traffic Accidents on Roads
- Dry-Process Lamination of Electrode Material To Pre-Coated Electrode Substrates
- Black Mass Purification for Battery Direct Recycling
- Digital Twin-Based System and Method for Reducing Peak Power and Energy Consumption in a Physical System
- Nitrogen Assisted Polyester Covalent Adaptable Network – NAPCAN
- Active Aluminum Based Heat Exchangers for Interpolar and End Winding Cooling for Wound Rotor Synchronous Motor (WRSM) Rotor
- Hybrid of Direct and Active Aluminum Heat Exchanger-Based Cooling for Wound Rotor Synchronous Motor (WRSM) Rotor
- Nonflammable Electrolyte Formulation for Lithium Titanate/Lithium Nickel (0.9) Manganese (0.1) Oxide Batteries
- Solid State Circuit Breaker for Battery Safety Discharge
- Microgrid Controller With Smart Charging Management

Patent Provisional Applications

- Ultra-Thin Current Collectors for Lithium-Ion Batteries
- Methods for Increasing Porosity in Carbon-Silicon Electrodes
- Lithium Carbonate and Methods of Making
- Methods for Increasing Solid-State Lithium-Ion Conductivity in Silicon Electrodes
- Black Mass Purification for Battery Direct Recycling
- Solid State Circuit Breaker for Battery Safety Discharge

Patent Applications

- Eco-Pilot-Energy-Efficient Vehicle Speed Advisory Through Vehicle-to-Infrastructure Communications
- Energy-Efficient Vehicle and/or Traffic Light Control
- Systems and Methods for Training and/or Using Machine Learning Models To Detect Traffic Accidents on Roads
- Nitrogen Assisted Polyester Covalent Adaptable Networks

Patent Awards

- Methods and Devices for Electrochemical Relithiation of Lithium-Ion Batteries
- Electrolyte Components for Charging of Lithium-Ion Batteries

Journal Articles and Publications

Vehicle Technologies Publication Metrics

Publication Type	Q1	Q2	Q3	Q4	Total
Books/Chapters	0	0	1	0	1
Conference Papers	9	10	6	1	26
Fact Sheets	10	2	0	2	14
Journal Articles	23	14	21	17	75
Posters	7	8	5	0	20
Presentations	19	8	18	7	52
Technical, Management, and Subcontractor Reports	17	9	8	21	55
Total YTD Publications	85	51	59	48	243

Publications

Chapters

1. Furat, Orkun; Fuchs, Lukas; Finegan, Donal P.; Smith, Kandler; Schmidt, Volker. 2025. "Methods of Machine Learning and Spatial Stochastics for Characterizing the 3D Morphology of Battery Materials at Various Length Scales." In *Multiscale and Multiphysics Modelling for Advanced and Sustainable Materials*, 113–125. doi.org/10.1007/978-3-031-84379-2_9.

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NLR'S VTO TEAM

Technical Team and Facility Leaders

Advanced Biofuels and Combustion ..... **Robert McCormick**

Commercial Vehicle Technologies ..... **Alicia Birky**

Data Sciences ..... **Monte Lunacek**

Electric Vehicle Grid Integration ..... **Jesse Bennet and John Kisacikoglu**

Energy Storage – Systems Data Science and Modeling ..... **Kandler Smith**

Energy Storage – Advanced Cathode Material Development ..... **Rob Tenent**

Energy Storage – Materials Development and Modeling ..... **Andrew Colclasure**

Legislative/Regulatory Support ..... **Erin Andrews-Sharer**

Lightweight Composite Materials ..... **Nicholas Rorrer**

Mobility Systems ..... **Andrew Duvall**

Power Electronics & Electric Machines ..... **Gilbert Moreno**

Technology Integration/ Data & Tools ..... **Emmy Feldman**

Technology Integration/Technical Assistance ..... **Abby Brown**

Vehicle Modeling and Analysis ..... **Brennan Borlaug and Eric Wood**

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Laboratory Program Manager, Vehicle Technologies Office

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Laboratory Program Manager (Acting), Joint Office of Energy and Transportation

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Chris Gearhart
Director, Integrated Mobility Sciences

Ray Grout
Director, Computational Science

Matt Thornton
Director, Energy Conversion & Storage Systems

Jao Van de Lagemaat
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Tony Burrell
Chief Technologist, Energy Storage

Sarah Cardinali
Group Manager, Transportation Technical Assistance

Mark Chung
Group Manager, Mobility Infrastructure and Impacts Analysis

Marc Day
Group Manager, High-Performance Algorithms & Complex Fluids

Gina Fioroni
Group Manager, Fuels & Combustion Science

Venu Garikapati
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Jeff Gonder
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Katie Harrison
Group Manager, Battery Materials

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Principal Researcher, Power Electronics

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Nate Neale
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Group Manager, Hybrid Energy Systems

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Group Manager, Transportation Applications & Data Analysis

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Liz Weber
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Stan Young
Advanced Mobility Technical Lead

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John Farrell
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Juan Torres
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Bill Tumas
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