NREL
Transforming ENERGY

VEHICLE AND MOBILITY TECHNOLOGIES
2023 ANNUAL IMPACT REPORT

October 2023

Table of Contents

EXECUTIVE SUMMARY

Federal Investments Catalyze RD&D, Actions To Decarbonize Transportation

Federal investments from the bipartisan Infrastructure Investment and Jobs Act and the Inflation Reduction Act have provided unprecedented backing to the nation's clean energy future—supercharging efforts to slash transportation-related carbon emissions through deep decarbonization across the country and reinvigorating research, development, and deployment in the areas of clean energy, transportation, and the environment. At the National Renewable Energy Laboratory (NREL), these funds have catalyzed our efforts to deliver transformational technologies that will remake the U.S. transportation system as we know it. Prioritizing projects that allow us to advance both an efficient—and equitable—transportation system that is inclusive and accessible to all remains central to NREL's mission and strategy. There's no denying we're in the midst of a clean transportation revolution like we haven't seen in decades. Armed with these concrete investments in clean energy solutions, I'm heartened by the prospects of the road ahead: This is our chance as a nation to make a lasting impact, and NREL is leading the charge.

Onwards,

John Farrell, Ph.D.
Laboratory Program Manager
Vehicle Technologies
National Renewable Energy Laboratory
303-275-4434 | *john.farrell@nrel.gov*

NREL Continues To Drive Deep Transportation Decarbonization Priorities

Historic federal clean energy goals have put a renewed focus on the transportation sector at a moment when NREL's pioneering transportation decarbonization research has reached new heights.

NREL's cross-cutting approach to transportation decarbonization looks beyond on-road, light-duty cars. The laboratory's world-class researchers are also working to overcome the most challenging technical barriers to clean mobility for off-road and non-road vehicles. This includes efforts to dial down carbon emissions in sectors dubbed "difficult to decarbonize," such as the aviation, rail, marine, construction, and agricultural sectors.

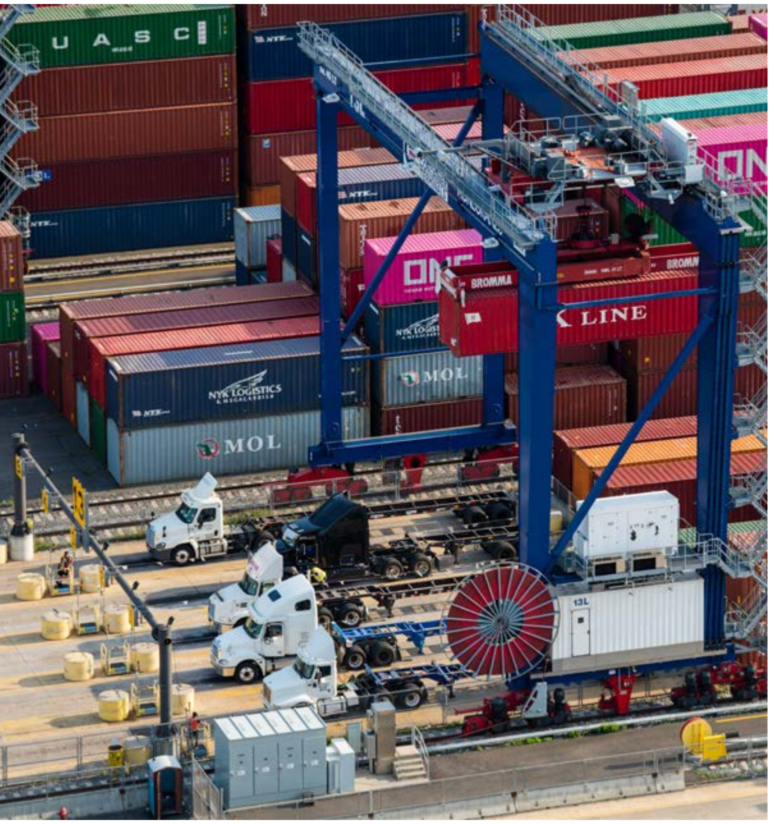
Recent research advances—including the release of the world's first fully integrated, open-source software to explore deep rail decarbonization, and the hybridization of Alaska's first small commercial fishing vessel—highlight NREL's trailblazing impact on non-road vehicles. Other efforts, including a nationwide electric vehicle (EV) charging needs assessment, showcase the laboratory's leading contributions to federal clean energy strategies.

White House Commissioned Study Identifies Nationwide EV Charging Needs

- **The Story Behind the Study:** By 2023, an anticipated 30–42 million EVs may drive American roads. These vehicles will require an affordable, reliable, and convenient nationwide EV charging network. Now, a groundbreaking NREL study has estimated what that charging network will look like.
- **What NREL Determined:** The nation may need 28 million charging ports to support a mid-adoption scenario of 33 million EVs. The majority of chargers will likely need to be Level 1 and Level 2 charging ports at homes and workplaces, complemented by public Level 2 chargers and direct-current (DC) fast chargers along corridors.
- **What Makes It "Groundbreaking":** NREL's analysis considered all of the ways Americans travel, from commuting and running errands to hailing ride-share vehicles and taking road trips. The result is a nationwide needs assessment with a never-before-seen level of detail.

National Blueprint for Transportation Decarbonization Charts Path to Net-Zero

- **The Background:** Developed by DOE, the U.S. Department of Transportation, the Department of Housing and Urban Development, and the Environmental Protection Agency (EPA), *The U.S. National Blueprint for Transportation Decarbonization* is the federal government's first coordinated strategy to eliminate nearly all greenhouse gas (GHG) emissions from the domestic transportation sector.
- **An NREL Connection:** NREL's Matteo Muratori spent more than 2 years on detail assignment as the chief analyst for sustainable transportation at DOE and ultimately served as DOE's lead author for the blueprint.
- **Why It Matters:** The blueprint is a roadmap for transformation of the transportation sector, which is now the largest source of GHG emissions in the United States. It outlines how every level of government will work together to provide clean, safe, secure, accessible, affordable, and equitable transportation for all Americans.

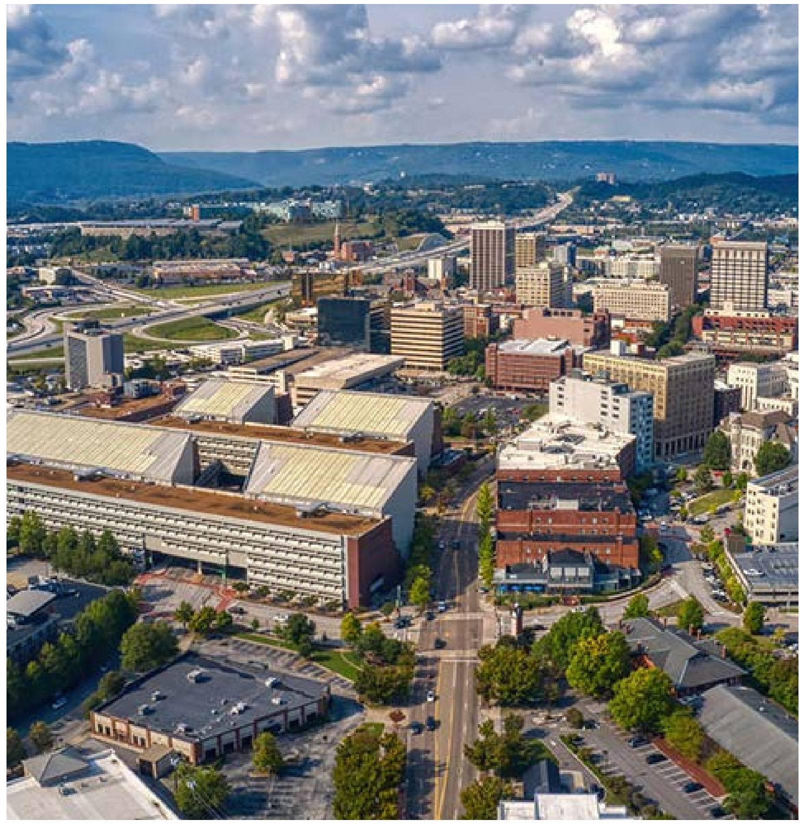


Real-World Operational Data Fuel Plans for Port Drayage Truck Electrification

- **What To Know:** NREL researchers have partnered with the Port Authority of New York and New Jersey to determine how the Port Authority can transition to net-zero carbon emissions by 2050.
- **The Opportunity:** Detailed real-world operational data collected from three drayage truck fleets show that a major opportunity to reduce the port's emissions lies in electrifying drayage trucks, which haul shipping containers from the port to warehouses and railyards.
- **Bigger Picture:** NREL researchers showed that the majority of studied drayage truck operations could be accomplished with electric trucks already on the market. By doing so, fleet operators could eliminate up to 76 tons of carbon emissions per truck each year and slash vehicle tailpipe and carbon emissions by 75%.

Chattanooga Digital Twin Project Signals Potential To Ease Traffic Nationwide

- **About the Project:** For 4 years, NREL and Oak Ridge National Laboratory (ORNL) transportation researchers have partnered with the city of Chattanooga, Tennessee, to reduce congestion using a "digital twin" of the city's traffic conditions.
- **What It Means Locally:** By optimizing traffic signals and applying high-performance computing (HPC) strategies, researchers successfully eased congestion by 32% in a real-world deployment.
- **The (Potential) National Impact:** The project has resulted in a transferrable traffic mitigation framework capable of powering efforts to reduce traffic congestion nationwide.



Researchers Release World's First Fully Integrated, Open-Source Freight Rail Decarbonization Software

- **Why?** Because rail can move freight up to four times more efficiently than trucks, railroads will be a critical aspect of transportation decarbonization. But until now, there has never been a unified model capable of demonstrating how rail operators can transition to clean locomotive technologies in a cost-effective way.
- **What To Know:** ALTRIOS, the Advanced Locomotive Technology and Rail Infrastructure Optimization System, is the world's first fully integrated, open-source software designed for exploring deep rail decarbonization. It was built in partnership with BNSF Railway, Southwest Research Institute, the University of Illinois Urbana-Champaign, and the University of Texas at Austin.
- **Future Projects:** Follow-on work will apply ALTRIOS to a Parallel Systems freight decarbonization project that aims to develop autonomous, battery-electric, platooned rail vehicles with flexible routes with the goal of potentially shifting freight from trucks to rail.

Sitka, Alaska, To Deploy First Small Hybridized Commercial Fishing Vessel

- **The Partnership:** A collaboration between NREL and Sandia National Laboratories researchers, the Sitka-based Alaska Longline Fishermen's Association (ALFA), and DOE's Energy Transitions Initiative Partnership Project (ETIPP) will result in the deployment of one of Alaska's first-ever hybridized commercial fishing vessels.
- **What Happened?** Using years of real-world operational data, NREL researchers developed a unique parallel hybrid battery-diesel system, which will allow a small commercial salmon fishing boat to travel at full speed using its diesel engine, then switch to a battery-electric motor when fishing.
- **Why It Matters:** ALFA has leveraged the results of the study into renewed funding to evaluate three novel low- and zero-emissions propulsion systems. The organization also plans to train local boat builders to install the new systems and inspire decarbonization efforts across the fleet.

Consortia and Technical Leadership Accelerate Zero-Emission Transportation Future

Silicon Consortium Project

Promising next-generation lithium-ion battery (LIB) designs are using silicon (Si) as an alternative to graphitic carbon anode material to increase the energy density and driving range of EVs. The NREL-led Silicon Consortium Project addresses critical barriers to the development of smaller, cheaper, and better-performing Si-based batteries, using cycling and electrochemical modeling to better understand the formation and evolution of the solid–electrolyte interphase. Recent advances in modeling techniques incorporate atomistic and physical reaction network insights with machine-learning algorithms to investigate how electrolyte decomposition impacts the calendar lifetime of Si anodes.

Guided by new insights from HPC and calendar aging models, NREL researchers are developing new electrode and cell designs to unlock the full potential of Si. A new rapid screening method uses potentiostatic holds to evaluate potential electrolyte materials much faster than traditional open-circuit voltage tests. Furthermore, researchers are using voltage hold deconvolution analysis and screening experiments to evaluate how cell architecture affects the projected calendar lifetime of Si-based cells. Findings have also prompted researchers to develop a surface-engineered Si electrolyte interface to prevent direct contact between active materials and increase the lifetime stability of Si designs.

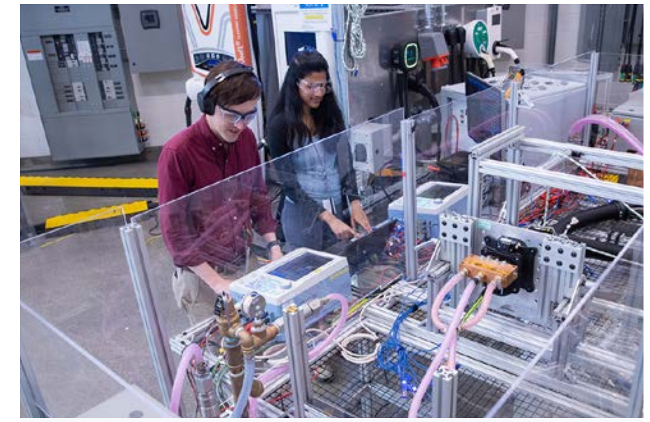
Behind-the-Meter Storage

Behind-the-meter storage (BTMS) systems are combining the benefits of energy storage, EV fast charging, photovoltaic generation, and building demands to minimize costs and grid impacts of nationwide electrification initiatives. As leaders of DOE's BTMS Consortium, NREL researchers are considering all aspects of BTMS systems, including materials, full system design, and controls. BTMS analysis projects help visualize energy flows, compare potential trade-offs between upgrades, and optimize components and system designs for different climates, building types, and utility rate structures.

The unique specifications of stationary energy storage allow NREL researchers to explore promising critical-material-free designs—such as lithium-titanate anode and lithium-manganese-oxide cathode batteries—alongside solid-state batteries (SSBs) and other emerging technologies. A new BTMS battery rack design developed at NREL will combine the benefits of new and aged systems, while combining nickel manganese cobalt and lithium-ion phosphate chemistries. The innovative design has so far demonstrated promising state of-charge balancing to accommodate the shifting loads of BTMS systems.

The NREL-led Silicon Consortium Project works to eliminate barriers to implementing silicon-based anodes in lithium-ion cells.

NREL's BTMS research evaluates how next-generation battery designs can meet the unique demands of stationary storage.



NREL researchers Isaac Tolbert and Namrata Kogalur work at the adaptable Megawatt Charging System (MCS) Thermal Evaluation Bench in NREL's Energy Systems Integration Facility to test prototype MCS charging connectors and inlets for medium- and heavy-duty EVs from a wide variety of manufacturers at currents of up to 3,000 A.

Electric Vehicles at Scale (EVs@Scale) Lab Consortium

The NREL-led EVs@Scale Lab Consortium, funded by DOE's Vehicle Technologies Office (VTO) in 2021 for 5 years, brings together six national laboratories—Argonne National Laboratory (ANL), Idaho National Laboratory (INL), NREL, ORNL, Pacific Northwest National Laboratory, and Sandia National Laboratories—and key stakeholders to conduct EV charging and grid integration R&D that will support the creation of a secure and scalable U.S. charging network for light-, medium-, and heavy-duty EVs. NREL will lead numerous outreach efforts in 2024, including hosting the consortium's fourth semiannual stakeholder meeting to identify R&D opportunities alongside thought leaders from government, academia, industry, and more. The consortium's first year of R&D is documented through several publications and presentations, including a study on breakeven costs to charge Class 8 tractors.

In the consortium's second year, the NREL consortium team developed a kilowatt-scale DC charging hub platform that can integrate various DC-DC converters connected to a common DC distribution system. This type of charging equipment is vital for designing and validating efficient, low-cost, and interoperable hardware for the next generation of heavy-duty EVs to operate via high-power DC-hub charging, communication, and control architectures. To investigate the transportation needs of drivers in Virginia, the NREL consortium team also acquired and processed millions of trip data sets using EVI-Pro, NREL's Electric Vehicle Infrastructure – Projection tool, to develop 30 million daily travel itineraries. By outlining daily distances traveled, driving times, and dwell periods, these itineraries identify future EV energy needs and charging opportunities. The NREL consortium team also collected a total of 24 EV high-power charge profiles from a Hyundai Ioniq 5, Ford F150 Lightning Pro, and Ford eTransit and completed 16 nominal temperature (23°C) characterization assessments to improve control performance of high-power charging systems and vehicles due to variations in performance from abnormal conditions (grid voltage, frequency, and temperature).

21st Century Truck Partnership

As efforts to electrify medium-and heavy-duty vehicles pick up speed, fleet owners and operators will require a critical piece of information to inform their future plans: the total cost of ownership for battery-electric commercial vehicles. Total cost of ownership includes operational implications such as energy requirements and charging power needs, as well as anticipated financial impacts such as initial capital investments and maintenance costs. It is also sensitive to fluctuations in the price of electricity.

In support of the 21st Century Truck Partnership—a collaboration between DOE, the U.S. Department of Transportation, the EPA, industry partners, and 12 national laboratories—NREL transportation researchers leveraged the laboratory's proprietary EVI-X modeling framework to determine the breakeven cost to charge Class 8 electric tractors.

Twenty different scenarios informed the report, which identified a cost-to-charge range of \$0.17–\$0.38/kWh and created a streamlined process to determine site- and fleet-specific breakeven costs. Now, stakeholders can use the framework developed by the report to consider site- and use-case-specific parameters and develop a business case for viable fleet electrification.

VTO High-Performance Computing System "Swift"

In late 2020, VTO's HPC needs were forecasted to exceed the availability of Eagle—the HPC resource within the Office of Energy Efficiency and Renewable Energy—starting in FY 2022. In response, the advanced computing and computational science experts at NREL designed an HPC system—appropriately named "Swift"—which became operational in NREL's Energy Systems Integration Facility (ESIF) in summer 2021.

Swift is a 440-node cluster with 28,160 compute cores and 2-PB storage that provides approximately 20 million additional "allocation units" (AUs) annually for VTO (in addition to its share of the 55 million AUs NREL's supercomputer already provides). As predicted, demand for the HPC resource has continued to grow, with the system now regularly seeing more than 95% utilization. Swift targets computational jobs at the 1–20-node scale, reducing unmet demand for computing capacity.

Swift's placement inside NREL's ESIF alongside the flagship machines Eagle and Kestrel enables rapid data movement and economies of shared support infrastructure and will continue to provide robust computational resources for VTO research. In addition, continual optimization of the software environment by users and the application engagement team enables performance optimization, even greater flexibility, and harmonization of resources supporting and accelerating the impact of VTO research.

In combination with Eagle and Kestrel, Swift provides robust support for the VTO portfolio.

Battery Recycling Prize

NREL prize administrators continue to lead efforts to develop and demonstrate processes that, when scaled, have the potential to capture 90% of all discarded or spent LIBs in the United States for eventual recovery of key materials for reintroduction into the supply chain. Over the past year, this team designed a novel two-phase continuation of the Lithium-Ion Battery Recycling Prize, leveraging funds from the Bipartisan Infrastructure Law to build on success from previous phases of the prize. DOE launched this continuation on July 12, 2023, with a public Breakthrough contest to incentivize submissions from battery industry entrepreneurs, including new or former prize participants, that enable or meet the prize goal. Breakthrough winners will advance to Phase IV of the competition, where they will work alongside battery recyclers and second-life testing organizations to demonstrate the impact of their solutions.

AMERICAN MADE
BATTERY RECYCLING
PRIZE
U.S. DEPARTMENT OF ENERGY

NREL Propels Transportation & Mobility Priorities

Researchers Advance Joint Office of Energy and Transportation Charging Reliability and Technical Assistance Priorities

As the buildout of a national charging network ramps up, NREL continues to play an integral role in supporting the Joint Office of Energy and Transportation's (Joint Office's) mission to accelerate an electrified transportation system that is convenient, reliable, affordable, accessible, and equitable. The Joint Office offers free technical assistance services that help transit and school bus fleets pursuing or receiving funding from the Federal Transit Administration's Low-No and EPA's Clean School Bus programs. Technical assistance has directly helped more than 150 fleets since June 2022 with resources and hands-on assistance through the Joint Office Technical Assistance Concierge Service. The technical assistance team has also supported many other school and transit stakeholders through webinars, presentations, and web-based tools and resources. Moving ahead, the NREL technical assistance team will continue to collaborate closely with the EPA and Federal Transit Administration to support fleets while expanding educational opportunities.

In 2023, the Joint Office also zeroed in on the complex challenges impacting the public charging experience and formed the National Charging Experience (ChargeX) Consortium. NREL has joined ChargeX Consortium lead lab INL, ANL, and multiple industry stakeholders to work on rapidly transforming the public charging experience for drivers and innovatively tackle many widely recognized charging challenges in the next 2 years. NREL is also leading a new multiyear effort for the Joint Office to enhance understanding about the indirect "soft" costs associated with installing electric vehicle supply equipment (EVSE), such as permitting costs and other aspects that are not directly tied to station construction. Building on novel insights generated through the solar soft cost reduction project that NREL began leading in 2010, the laboratory's project team will identify the types of data needed to perform EVSE soft cost analysis, collect the identified data and inputs from industry stakeholders, and track specific metrics and soft costs over time.

NREL Expertise Supports Data-Driven Decisions To Transition Federal Fleet to Zero-Emission Vehicles

NREL transportation deployment experts continue to provide guidance for transitioning federal fleet vehicles to zero-emission alternatives through the White House Council on Environmental Quality. The team, including Ted Sears, an NREL senior project leader on assignment to the Council on Environmental Quality, is providing hands-on support to federal agencies to help them achieve their zero-emission vehicle (ZEV) adoption goals. NREL's involvement gives fleets access to tools and resources for making data-driven decisions around vehicle procurement and charging infrastructure buildout.

The council is also coordinating with the EVSE Accelerator project (led by DOE's Federal Energy Management Program with support from NREL) to develop a guidebook for federal agencies to help expedite EV charging infrastructure deployment. The guidebook is based on examples and lessons learned from federal agencies that are on the leading edge of infrastructure buildout. NREL's direct involvement in these efforts brings the lab's expertise front and center among federal policymakers and provides them with the data and tools necessary to make evidence-based decisions and generate stronger outcomes.

Sustainable Mobility Systems and Behavior Research Sculpts Novel, Promising Strategies

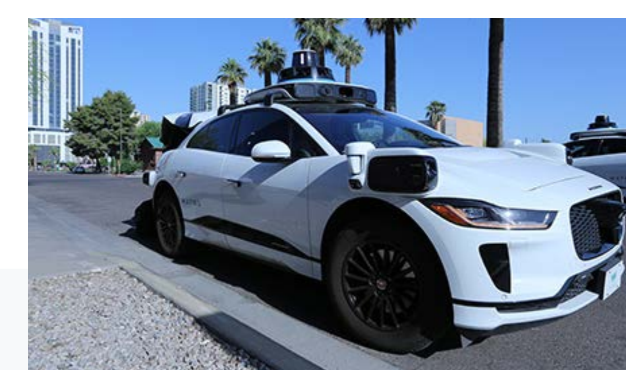
Backed by world-class technological capabilities and expertise, NREL research in the sustainable mobility systems and behavior realm informs the development and deployment of efficient, accessible, and affordable mobility systems of the future. Cultivating viable, real-world solutions for the movement of people and goods is at the heart of this work.

Workshop Identifies Priorities for Creating Tomorrow's Sustainable Mobility Systems

- **The Background:** With a historic federal goal to eliminate nearly all GHG emissions from the transportation sector by 2050, the nation is asking, "Which energy-efficient mobility strategies will get us to the finish line in time?"
- **What Happened:** Insights from a 2-day workshop involving thought leaders from industry, government, and academia have resulted in new strategic thinking about the key challenges and opportunities to prioritize in creating sustainable transportation systems of the future.
- **The Outcome:** Research priorities arising from the discussions include emerging travel modes, freight, connections between research and deployment, ground mobility at airports, transit solutions for underserved communities, and operations concepts for intelligent infrastructure.

Technology Tour Sheds Light on the Future of Transportation in Action

- **What To Know:** NREL researchers joined DOE technology managers and leaders in the transportation technology space for a 3-day tour of innovative mobility systems across the Southwest.
- **How They Compare:** Tour stops ranged from Arlington, Texas—with its low-cost, on-demand ride-share fleet, two-thirds of which is hybrid electric—to Phoenix, Arizona, which sports the world's first fully autonomous EV ride-hailing service.
- **The Bigger Picture:** Electric, driverless, on-demand travel can sound like science fiction, but such examples foreshadow the future of sustainable transportation—one that aims to be more energy efficient, less expensive, and more equitable than transportation today.



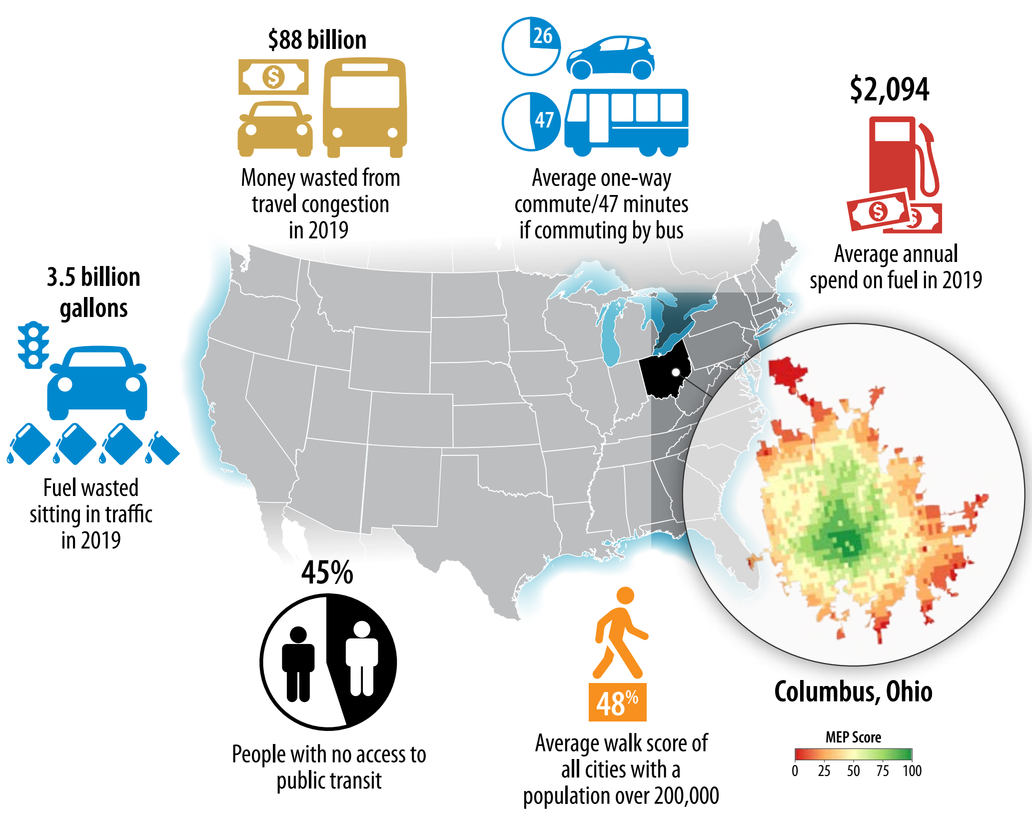
Waymo rolled out the world's first fully autonomous EV ride-hailing service in metro Phoenix.

Google Partnership Aims To Expand Eco-Routing Across the Globe

- **The Backstory:** A 2021 partnership with Google Maps resulted in the integration of FASTSim, the Future Automotive Systems Technology Simulator, and RouteE, the Route Energy Prediction Model, into the popular navigation software to inform eco-routing across the United States.
- **The Latest:** NREL's continued partnership with Google Maps has included adding more vehicle types—beyond conventional vehicles—and expanding Google Maps' eco-routing capability to Europe and elsewhere. Ongoing collaboration involves further refining vehicle coverage, accuracy, and robustness, as well as further expansion across the globe—including in markets that heavily use motorcycles and other two- and three-wheeled vehicles.
- **Why It Matters:** Google Maps' eco-routing is estimated to prevent more than 1 million metric tons of carbon emissions per year in the United States, and with its plan to expand this feature worldwide for its 1 billion users, emissions savings could grow exponentially.

Mobility Energy Productivity Tool Helps Decision Makers Find Equitable and Efficient Transportation Solutions

- **Better Together:** Collaborations with state departments of transportation in Colorado, Florida, and Delaware involve integrating MEP, the Mobility Energy Productivity methodology, into their transportation planning processes and evaluating the impact of transit, bicycle, and freeway infrastructure investments on improved access in specific cities.
- **What's New:** Researchers are also using the MEP tool to quantify disparities in mobility and access and show possible improvements in mobility equity based on specific scenarios, such as high levels of automated and electrified ride-sharing.
- **Zooming Out:** MEP distills three major components of mobility—time, cost, and energy—into a simple score, which can quantify the efficiency of connectivity provided by one or more travel modes in a given area or for specific groups, such as those based on income, age, or vehicle ownership. Its flexibility makes MEP a powerful tool for government agencies, companies, and other organizations interested in assessing and improving transportation options and access.



Many areas of the United States lack affordable, accessible, and efficient travel options. The MEP tool offers a way for decision makers to assess a region's quality of mobility.

The results of the pilot project show that e-bikes can serve unmet transportation needs while providing a cost-effective and energy-efficient alternative to other modes of transportation.

	Cargo e-Bike	Crossover SUV
Typical Fuel Fill-Up Cost	$0.20 @ $0.20/kWh	$50.75 @ $3.50/gal
CO_2e Emissions/Mile	0 to 3 grams	350 Grams
Annual Ownership Cost	$500	$10,728*
Can Carry What You Need?	Usually	Usually
Good Choice for Short Trips?	Yes	Not always

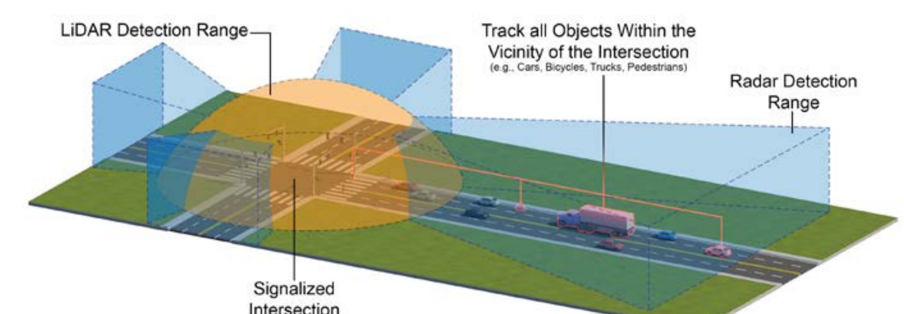
*AAA 2022 estimate

Nation's Largest E-Bike Pilot Program Identifies Energy, Emissions, and Mobility Behavior Impacts

- **What Happened:** The Colorado Energy Office partnered with NREL in the largest e-bike pilot project in the nation, which included data collection via NREL OpenPATH, NREL's Open Platform for Agile Trip Heuristics tool.
- **The Takeaway:** The results of the pilot project show that e-bikes can serve unmet transportation needs while providing a cost-effective and energy-efficient alternative to other modes of transportation. The NREL OpenPATH tool continues to provide data collection for e-bike programs and investments in California, Massachusetts, and other locations.
- **More Findings:** Participants in the pilot project generally preferred to walk distances up to 1 mile and use e-bikes for distances between 1 and 4 miles. About half of all trips in the United States are less than 3 miles, making e-bikes a viable mode of travel for most daily trips.

New Lab Merges Transportation and Computational Science To Improve Mobility Efficiency

- **What Happened:** NREL has established a new lab dedicated to researching the application of the Internet of Things on the roadside and in the built environment.
- **More About the Lab:** The Infrastructure Perception and Control (IPC) Lab builds on the evolving role that advanced sensing and computational future capabilities play in connected and automated movement and applies it to the coordinated movement of vehicles on the road, as well as how people move and navigate in large facilities such as airports.
- **Why It Matters:** The IPC Lab enables NREL to apply its world-class advanced computing capabilities and IPC domain expertise in ways that conserve energy, increase safety, bolster equity, and reduce travel time for mobility across various realms.



NREL has built an IPC computational engine to collect and combine real-time data from infrastructure-based sensors to create accurate digital representations of intersection traffic, speeding the rollout of next-generation traffic controls that save time and energy while increasing safety.

Study Spotlights Opportunities To Combine Energy Justice and Innovation

- **The Backstory:** Almost 2,500 miles and numerous differences in size, culture, and climate separate Los Angeles, California, from Tehuantepec, Mexico. At the same time, these places share admirable objectives for advancing clean energy, although their approaches to engaging underserved communities provide a stark study in contrasts in terms of process and ultimate outcomes.

- **A Closer Look:** An NREL-led study examined how these areas in California and Mexico have chosen to address inequities in their clean energy transition plans and the very different outcomes of their approaches. Drawing on their successes and failures, the social and behavioral science research team has identified best practices and developed an innovative methodology for cultivating win-win scenarios for clean energy and diverse communities.

- **Restoring Balance:** As described in *Nature Energy*, the new methodology can help government agencies, developers, and others establish dialogue with community members to pinpoint and effectively address energy inequities. It serves to familiarize decision makers with social science techniques to help them understand and address past and current energy inequities, empower community leadership in the process, and formulate equitable distribution of both benefits and risks related to an energy transition.

NREL Technical Expertise Sought for Clean Transportation Deployment at Local, National, and International Levels

NREL's clean transportation deployment experts remain at the forefront of providing critical technical assistance to solve some of the most complex transportation decarbonization challenges. Notably, researchers provide unbiased, cutting-edge expertise and customized solutions to stakeholders at the local, regional, and national levels to facilitate the deployment of alternative fuels, fuel economy improvements, and emerging transportation technologies. In FY 2023, NREL continued its work deploying clean transportation at the local and regional levels through the Clean Cities Coalition Network and Clean Energy to Communities (C2C) program. NREL transportation data analysts were also tapped to work internationally, including building out a binational ZEV corridor.

Collaboration Between Clean Cities and C2C Strengthens Both Efforts

- **Leveraging Long-Standing Expertise:** NREL is facilitating collaborations between Clean Cities coalitions and municipalities participating in the C2C program to leverage coalition expertise around transportation technology deployment.

- **New DOE Investment:** This effort is supported through a $10-million investment from VTO, with approximately half of the funding going directly to Clean Cities coalitions.

- **Benefits to All:** Involving Clean Cities coalitions will facilitate long-term partnerships with local, regional, and tribal governments, and coalitions will enhance their institutional capacity around working with municipalities to develop local clean transportation strategies and plans.

Clean Cities Thrives for 30 Years as Model for Collaborative Technology Deployment

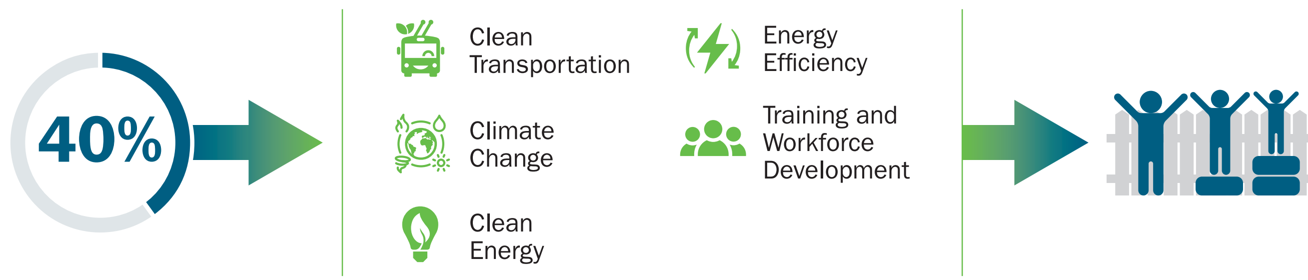
- **Local Action To Achieve National Goals:** The Clean Cities Coalition Network is celebrating 30 years of advancing affordable, efficient, and clean transportation fuels and technologies in urban, suburban, and rural communities across the United States.

- **Model for Federal Deployment Efforts:** The innovative model built over the past 30 years by the network—including proactive and meticulous development by NREL and other national laboratories—demonstrates how federal programs can successfully deploy new technologies through long-term, multidirectional stakeholder engagement.

- **Centering Community Knowledge:** Clean Cities centers the knowledge, expertise, and vision of local communities, making it a model for how to design community-centered solutions that align national objectives with local goals and visions.

NREL provides unbiased expertise and customized technical assistance to facilitate the deployment of alternative fuels, fuel economy improvements, and emerging transportation technologies.

40% of overall benefits of certain **Federal Investments** must flow to **Disadvantaged Communities**.



Energy and Environmental Justice Advanced Through Clean Cities Activities

- **Building Clean Cities Capacity:** NREL is collaborating with DOE and ANL to build the capacity of Clean Cities coalitions to advance energy and environmental justice goals by providing them with knowledge and skills to co-create transportation projects alongside community-based partners.
- **Bridging National and Local Levels:** Clean Cities coalitions can put federal equity priorities into practice by leveraging their community connections, enabling national priorities to manifest at a local level.
- **Enacting Federal Commitment:** This work aligns with the Biden administration's Justice40 Initiative, which established a goal that 40% of the overall benefits of certain federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution.

NREL Tapped To Develop First-Ever Binational ZEV Corridor

- **Alternative Fuel Corridors Go International:** NREL researchers were tapped to help develop the first-ever binational ZEV corridor, which will facilitate the movement of passengers and goods via ZEVs through a key entry point into Canada. The new international corridor will have DC fast chargers approximately every 50 miles and runs from Kalamazoo, Michigan, to Quebec City, Quebec.
- **Providing Key Analysis Capabilities:** NREL transportation data analysts leveraged their years of experience developing more than 75,000 miles of Alternative Fuel Corridors in the United States to develop corridor maps under various scenarios and criteria. Once the criteria were finalized, NREL validated the corridor and calculated final corridor distances.
- **International Announcement:** Transportation Secretary Pete Buttigieg, Canadian Minister of Transport Omar Alghabra, Michigan Governor Gretchen Whitmer, Detroit Mayor Mike Duggan, and IBEW Member Bill Baisden announced the corridor during the Asia-Pacific Economic Cooperation conference.

A new modeling framework may help DFW—and others in the future—design electric bus deployment strategies.

Insights, Innovation, and Impact—NREL Publications Chart a Path Toward Clean Energy, One Discovery at a Time

Whether at the bench or in the field, NREL researchers are always at the forefront of the clean energy transition. With more than 75 peer-reviewed articles in high-impact journals like *Nature Energy*, *Joule*, and *Advanced Energy Materials*, as well as 38 NREL-authored reports with more than 21,000 lifetime downloads, NREL's scientific publications continue to reflect the cutting-edge advances being made every day across the lab. Explore some of this year's groundbreaking results:

"Conjugated Imine Polymer Synthesized via Step-Growth Metathesis for Highly Stable Silicon Nanoparticle Anodes in Lithium-Ion Batteries"
(doi.org/10.1002/aenm.202203921)
Advanced Energy Materials | NREL authors: **Trevor Martin, Mackenzie Kuller, and Nathan Neale**

Conjugated polymers are driving innovations across energy storage and conversion, but producing these macromolecules is costly and difficult to scale. NREL's chemistry and nanoscience research team is tackling this problem head-on by developing a new method to synthesize polyphenylmethanimine (polyPMI) as a linear or hyperbranched conjugated polymer using an aldehyde-imine metathesis reaction. This new approach demonstrates that polyPMI can be grown directly on silicon nanoparticles to create silicon anodes that are highly efficient, stable, and corrosion-resistant, ultimately extending the lifetime and performance of LIBs. But that's not all—the new approach indicates the potential for recyclability, providing a new avenue toward a circular economy for energy materials.

"Machine-Learning-Driven Advanced Characterization of Battery Electrodes"
(doi.org/10.1021/acsenergylett.2c01996)
ACS Energy Letters | NREL authors: **Donal Finegan and Katherine Jungjohann**

Materials characterization is fundamental to understanding the performance—and limitations—of LIB electrodes. Advances in lab-based characterization techniques have yielded powerful insights into the structure–function relationship of electrodes, but there is still much to learn. Further improvements rely, in part, on gaining a deeper understanding of complex physical heterogeneities in these materials, but practical limitations remain. For example, some techniques are destructive, preventing multiple analyses on the same region. Fortunately, artificial intelligence has great potential to achieve representative, 3D, multimodal data sets by leveraging data collected from a range of techniques. This article surveys recent advances in lab-based characterization techniques for lithium-ion electrodes and discusses how artificial intelligence methods can combine and enhance their insights, substantially accelerating our understanding of these electrodes.

"Charging Needs for Electric Semi-Trailer Trucks"
(doi.org/10.1016/j.rset.2022.100038)
Renewable and Sustainable Energy Transition | NREL authors: **Brennan Borlaug, Matthew Moniot, Alicia Birky, and Matteo Muratori**

With the market for battery-electric semi-trailers still in its infancy, how can we plan for the charging requirements of an all-electric trucking industry? Leveraging hundreds of millions of miles of trucking telematics data, NREL researchers estimated the charging behaviors and infrastructure requirements for local, regional, and long-haul trucking; what might be supported by the infrastructure we already have in place; and how these demands might shift as technologies improve. Among their key insights, NREL researchers determined that slow charging could satisfy a majority of charging demand, particularly for local trucks in urban areas. Long-haul trucking requires faster charging and more demand along rural interstates, but future increases in vehicle range and the availability of charging equipment could enable off-shift charging for this crucial transportation sector.

"Data-Driven Simulation-Based Planning for Electric Airport Shuttle Systems: A Real-World Case Study"
(doi.org/10.1016/j.apenergy.2022.120483)
Applied Energy | NREL authors: **Zhaocai Liu, Qichao Wang, Devon Sigler, Andrew Kotz, Kenneth Kelly, Monte Lunacek, Caleb Phillips, and Venu Garikapati**

New simulation and modeling tools are helping Dallas/Fort Worth International Airport (DFW)—and likely other airports in the future—make informed decisions about electrifying their bus fleet. This study evaluated one such planned system at DFW, leveraging empirical data collected from existing systems to drive their simulations. By optimizing predefined objectives like minimizing costs or emissions, the model can determine real-world specifics like battery capacity, charging power, number of chargers, and costs. These NREL-developed tools, stemming from the DOE-funded Athena project, help stakeholders plan for and optimize their shuttle systems with much higher fidelity than ever before.

Strategic Research Partnerships Drive Transportation Decarbonization Impacts

Due to a combination of NREL's unparalleled research capabilities and technical expertise, the lab is widely recognized as a lynchpin across many strategic partnerships aiming to solve some of the nation's most complex transportation and mobility challenges. In FY 2023, NREL continued or initiated 90 strategic partnerships with leading industry, government agency, and research players, contributing to a groundswell of sustainable transportation initiatives through efforts such as eco-routing, EV adoption, and power storage.

Google Maps and Transportation Services Provider Implement NREL-Developed Emissions-Saving Routing Tools for Middle-Mile and Public Use

- **What Happened?** NREL is supporting the global expansion of Google Map's eco-friendly routes product, modeled after the RouteE-Powertrain methodology, using the FASTSim tool to model representative passenger vehicles around the world. Google estimates the eco-friendly routing option has reduced on-road CO_2 emissions in the United States by an estimated 1 million metric tons so far.

- **Powering the Research:** NREL considered the best-selling vehicles globally and relevant fuel economy regulations to more accurately model vehicles in FASTSim. This has resulted in the addition of more than 20 new FASTSim powertrain models to the open-source repository.

National Highway Traffic Safety Administration Partnership Aims To Set EV-Inclusive Fuel Economy Requirements, Develop Extreme Weather Battery Safety Guidance

- **What's Happening:** NREL is modeling the impact of EV charging infrastructure development and characteristics on EV adoption rates to assist the National Highway Traffic Safety Administration (NHTSA) in setting their Corporate Average Fuel Economy (CAFE) requirements.

- **Other Research Efforts:** NREL is also supporting NHTSA research to help better understand and address prevention of fires involving lithium-ion high-voltage batteries and vehicles, especially those related to submersion and flooding. This research includes how first responders can best respond to and extinguish EV fires, as well as how to safely transport submerged or flooded EV batteries and vehicles to reduce the risk of reignition. This partnership is expected to include management of an industry working group to address these concerns.

- **Looking Ahead:** The first research effort will help NHTSA set CAFE requirements that are achievable and maximize fuel economy. The second effort will reduce the risk of fires and thermal events due to vehicle flooding or submersion, as well as improve the education for first and second responders to better handle these types of incidents when they occur.

Collaboration With Eaton Corporation Brings Increased Efficiency to DC Charging

- **What?** NREL researchers will evaluate charging equipment developed by Eaton Corporation aimed at reducing costs for DC charging connected to the medium-voltage utility distribution system.
- **The Details:** NREL will run a demonstration using ARIES, the lab's world-class Advanced Research on Integrated Energy Systems platform, which provides the ability to simulate simultaneous charging of multiple vehicles at a combined power above 1 MW of DC power at both 400 V and 800 V to characterize the project's ability to meet efficiency targets and demonstrate functionality under different grid conditions.
- **Why It Matters:** The new system shows promise of dramatic cost savings through volume and weight reduction for smaller site space and fewer components that will lead to less time to install and commission. If effective, this new charging approach would increase affordability and efficiency of meeting the demand for convenient, reliable, and affordable DC charging across the nation.

Electric Power Research Institute Partnership Advances Heavy-Duty Battery-Electric Trucks

- **What's Happening?** NREL will provide technical support and guidance to the Electric Power Research Institute (EPRI) and CALSTART teams to advance research, development, and demonstration activities that extend the delivery range of heavy-duty battery-electric trucks, with an initial focus on drayage operations at seaports.
- **How?** NREL will leverage previous lab work for other DOE projects to guide design and development of research charging and demonstration sites and support the development of California's Electric Truck Utilization Center (eTRUC) lab.
- **The Impact:** This work will support NREL, EPRI, and CALSTART's shared vision to advance electrification into the heavy-duty vehicle space to improve air quality and efficiency for freight and transport operations across the nation.

Shell Energy and NREL's Novel Aging Experiments Support Electrification of Heavy-Duty Vehicles and More Quickly Map Degradation Physics

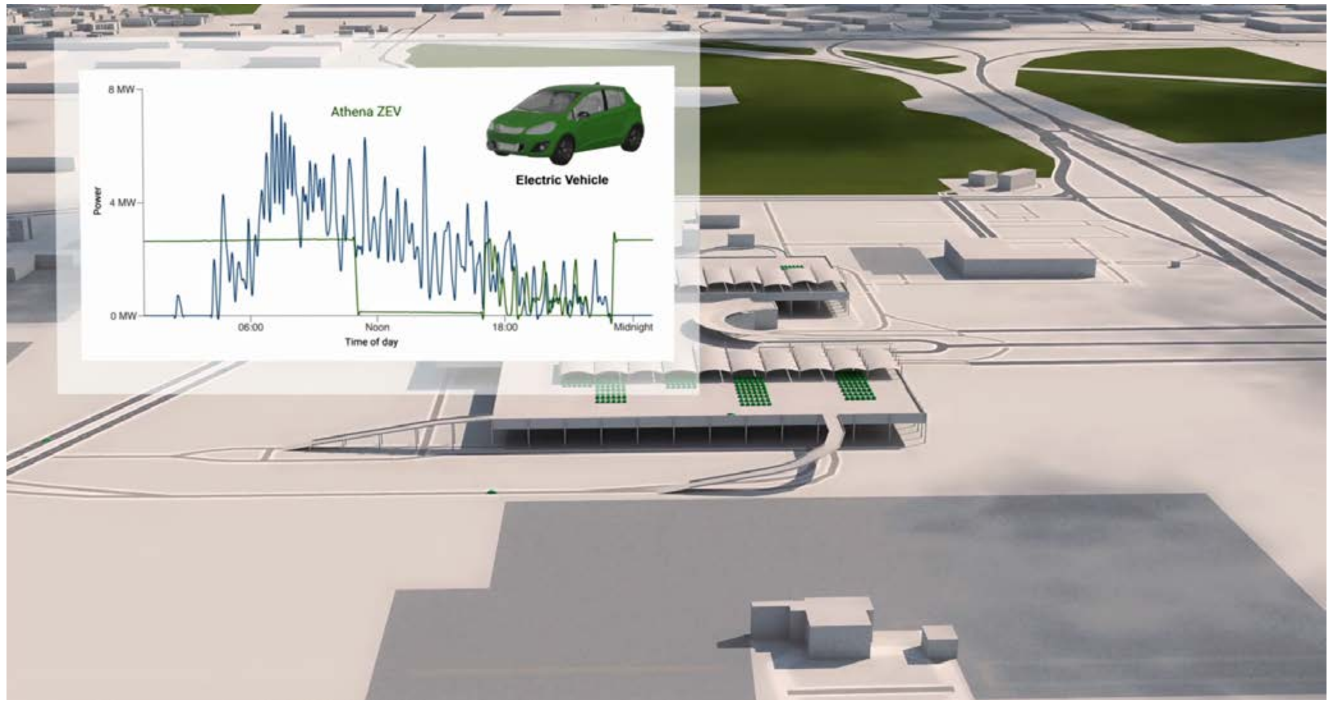
- **The Details:** Novel aging experiments on commercial 75-Ah graphite/NMC cells have outlined a path to compress time-consuming life prediction experiments to 3 months, a threefold reduction in time for today's accelerated aging tests, while also identifying chemomechanical degradation physics.
- **What They Found:** A nanoamp-resolution potentiostat provided a high-quality rapid measurement of total capacity fade during calendar aging tests, enabling faster quantification of irreversible lithium loss and calendar life prediction. Cycling experiments on harvested electrode materials provided rapid measurement of irreversible cathode loss, a less expensive method than full cell testing.
- **Why It Matters:** These rapid life/reliability test methods more directly measure degradation processes linked to cell design and degradation physics, enabling transference of learnings to new technologies.
- **Coming Up:** NREL is investigating the life of lithium-titanate cells at charge rates as fast as 5 minutes when submersed in a novel immersion cooling fluid, accelerating the electrification of heavy-duty vehicles and other challenging applications.

NREL Equips California in Leading the Charge for Zero-Emission Transit Buses

- **What's Happening:** In 2023, NREL kicked off phase two of its comprehensive review of the state of California's transit industry under California's Innovative Clean Transit (ICT) rule. In phase one, NREL evaluated the transit industry's readiness to meet the ICT requirement that, beginning in 2023, 25% of all new standard bus purchases be zero-emission buses (ZEBs). The second phase will evaluate transit industry readiness to meet the next level of ICT requirements that up to 50% of new bus purchases be ZEBs beginning in 2026. In phase two, NREL will also evaluate smaller transit agencies and nonstandard buses with the California Air Resources Board, University of California, Berkley, and California Transit Association.
- **The Background:** NREL's phase one report covers ZEB performance, transit agency rollout plans, economics, maintenance, infrastructure, workforce development, and the impacts of the global COVID-19 pandemic for large transit agencies.
- **Key Takeaways So Far:** Phase one concluded that the California transit industry is well positioned to proceed with the next phase of ICT requirements for 25% of new transit bus purchases to be ZEBs. To achieve a successful transition to 100% ZEB transit fleets in the coming years, the report found the need to further drive down costs, improve ZEB reliability and performance, expand charging and fueling infrastructure, develop a highly skilled workforce, and increase financial support.
- **Why It Matters:** The ICT regulation requires 100% of all new bus purchases to be ZEBs by 2029. NREL's comprehensive review is critical to understanding the state of the ZEB industry, as well as identifying and addressing remaining challenges and barriers as California and other states implement similar goals.

Other Notable Strategic Partnership Projects

- ExxonMobil Technology and Engineering Company (EMTEC) – Predicting Fuel Properties and Emissions
- Dallas/Fort Worth International Airport – DFW MSA Ceiling Increase – MTES Bookings Adjustment
- Centers for Disease Control (CDC) – Joint Design of Advanced Computing Solutions for Epidemiological Modeling
- CAE Inc. – CAE Electric Vehicle Charging Equipment Infrastructure Requirement Study
- U.S. Department of Defense, Environmental Security Technology Certification Program (ESTCP) – Electric Vehicles As Mobile Power (EV-AMP) for Texas Readiness Centers
- Coordinating Research Council – Carbon Return on Investment for Electrified Vehicles
- Eastman Chemical Company – Impact of Window Film on Electric Vehicle Range
- U.S. General Services Administration – NREL Support and Development of api.data.gov – Mod 2023
- Port of Los Angeles – ZANZEFF Project Extension – Electric Crane Data
- Port of Corpus Christi Authority – Regional Clean Hydrogen Analysis
- Ford Motor Company – EV Charging Infrastructure Planning Modeling
- Engine Manufacturers Association (EMA) – Non-Road Decarbonization Study
- Faith Technologies Inc. – FTI Data and Market Analysis Projects
- NASA Langley Research Center – NASA RAM Follow-On
- NAATBatt International – Develop Online Version of NAATBatt Lithium-Ion Battery Supply Chain Database.



The next phase of DOE's Athena project—referred to as Athena Zero-Emissions Vehicles (Athena ZEV)—will seek to electrify transportation and de-risk airport investments, with an initial focus on rental cars. The project was officially launched at DFW in August 2023.

Capability Investments in Support of Clean Transportation

NREL's ARIES Platform Aims To De-Risk DFW's Transition to Electrified Transportation and Buildings

Building on the Athena project funded by DOE, NREL is working with DFW on the Athena ZEV project aimed at developing sophisticated strategies that will accelerate the decarbonization of thousands of vehicles operating at the airport, with an initial focus on rental car operations. Athena ZEV leverages a combination of the lab's ARIES platform, HPC, data science, digital twins representing transportation and building demand, and analysis of on-site energy storage. As EVs become a larger part of rental fleets, taxis, and airport ground transportation, the operational and infrastructure challenges to decarbonize DFW's airport operations will become increasingly complex. By leveraging the lab's deep expertise in modern computing techniques, commercial buildings, vehicle-grid integration, and BTMS, ARIES will evaluate sophisticated technology solutions to meet DFW's ambitious electrification goals while maintaining a reliable energy supply for other critical infrastructure that supports their operations before the airport invests in real-world deployment.

What's Happening

Large airports and other entities are beginning to prepare for widespread electrification of vehicles and buildings.

- **The Need:** Mass adoption of EVs requires a network of high-power charging stations that is interoperable and can reliably deliver more than 200 kW per car.
- **The Challenge:** Large entities like airports are powered by complex energy infrastructures with diverse, variable loads that are projected to scale significantly over time and are not yet prepared to support charging for possibly hundreds of thousands of rental cars, which are aiming to electrify first in coming years.
- **The Potential Impact:** Clean energy solutions that lower costs, optimize performance, improve operations, and enhance resilience are critical to overcome operational and infrastructure challenges and meet increasing energy demands and ambitious decarbonization goals.

How NREL Will Support

EV characterization work and state-of-the-art, at-scale emulation capabilities address challenges associated with vehicle electrification.

- **What To Know:** NREL researchers will create large-scale, data-driven simulations and conduct megawatt-scale experiments of various controllable building loads and managed charging scenarios strategies that use transformational technologies.
- **Why We're Different**: NREL's ARIES platform will allow researchers to perform crucial at-scale experiments, including necessary hardware, software, and controls validation, to de-risk and optimize the airport's investments in vehicle charging infrastructure buildouts. Researchers will leverage NREL's state-of-the-art charging infrastructure analysis tools to configure cost-optimal, behind-the-meter energy storage and solar photovoltaic systems based on the climate, building type, and utility rate structure of potential EV charging sites.
- **The NREL Advantage:** By leveraging the lab's existing smart charge management and EV characterization research, ARIES will identify how to lower the levelized costs of charging, improve resilience to weather disruptions and other events, reduce peak demand charging, and accurately size thermal and electrical storage system—all while maintaining reliable energy supply for other critical infrastructure that supports DFW's operations.

Other Details

The airport is tapping the expertise f both vehicle and buildings technology research at NREL.

- **Supporting the Research:** The EVs@Scale Lab Consortium's Next Generation Profiles project identifies high-power charging system limitations, the characteristics of high-power charging sessions, and issues that the power grid will likely encounter with at-scale high-power charging. The data from this consortium's project directly feed into ARIES emulation capabilities.
- **The Vehicles Research:** Implementing intelligent controls and optimal integration with energy storage, renewable power generation, and flexible building loads will prove crucial to mitigating grid impacts caused by multimegawatt peak loads. This effort leverages NREL's suite of state-of-the-art charging infrastructure analysis tools, known as the EVI-X Modeling Suite, to help understand what electrical system upgrades may be needed to accommodate high-power charging needs. EVI-X employs charging strategies to minimize costs associated with variable electricity rates and discerns how charging times could affect rental turnarounds and available lot space.
- **Don't Forget About Buildings:** Integration with building loads will be key to maximizing the benefits from increased electrification of the airport's energy systems. This effort leverages a DOE-funded buildings optimization tool developed for use at DFW to shift building loads in concert with vehicle charging loads to proactively respond to grid needs and increase resiliency.

Zooming Out

NREL's world-class ARIES platform can de-risk, optimize, and validate next-generation infrastructure solutions that are replicable, transferrable, and scalable to real-world scenarios.

- **The Scalability:** Grounded in advanced computation and optimization of systems to meet the emerging challenges of domestic airports, seaports, and beyond, NREL's computational environment and models are made fully accessible to stakeholders to run their own scenarios.
- **The Cost Savings:** ARIES is the nation's most advanced research platform for energy system integration research and validation, supporting major enterprises like DFW with their transition to a decarbonized grid with unique controls and design custom strategies to integrate everything before any money is spent on real-world deployment.
- **The Bigger Picture:** From creating modern and customized approaches to deploy cost-effective, at-scale clean energy solutions that can manage elaborate networks of devices, NREL's world-class research capabilities deliver next-generation infrastructure solutions.

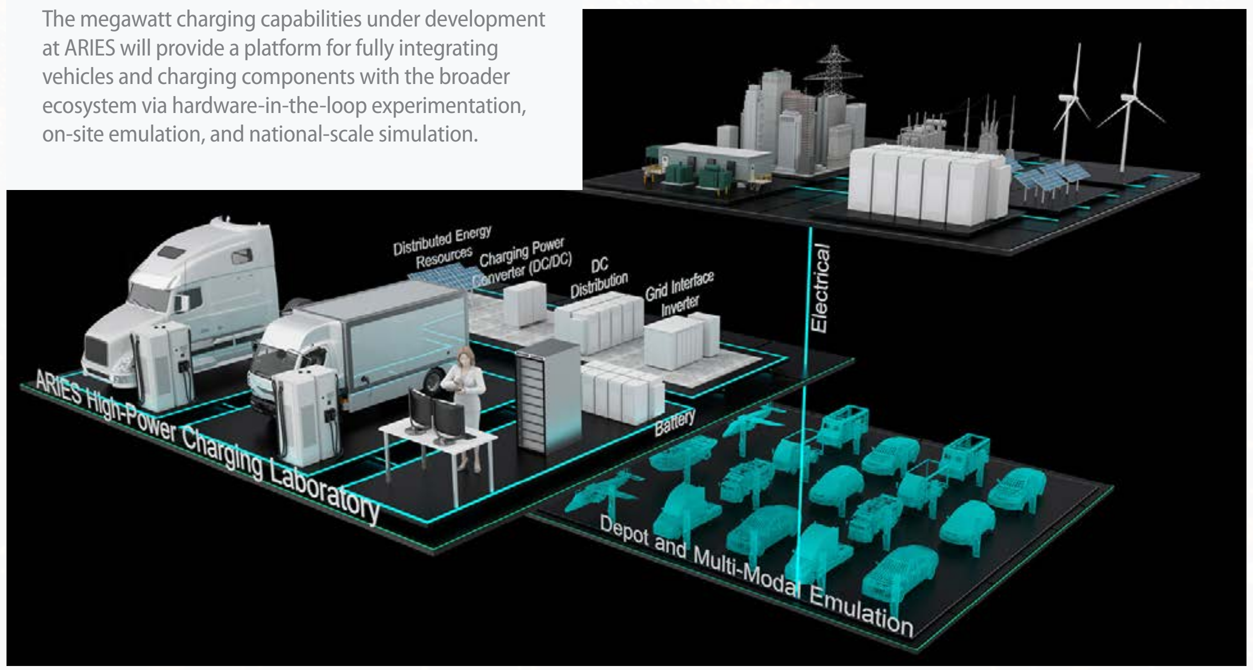
ADVANCED RESEARCH ON INTEGRATED ENERGY SYSTEMS (ARIES)

The ARIES research platform unifies research capabilities at multiple scales and across sectors to help understand the impacts of energy systems integration at scale.

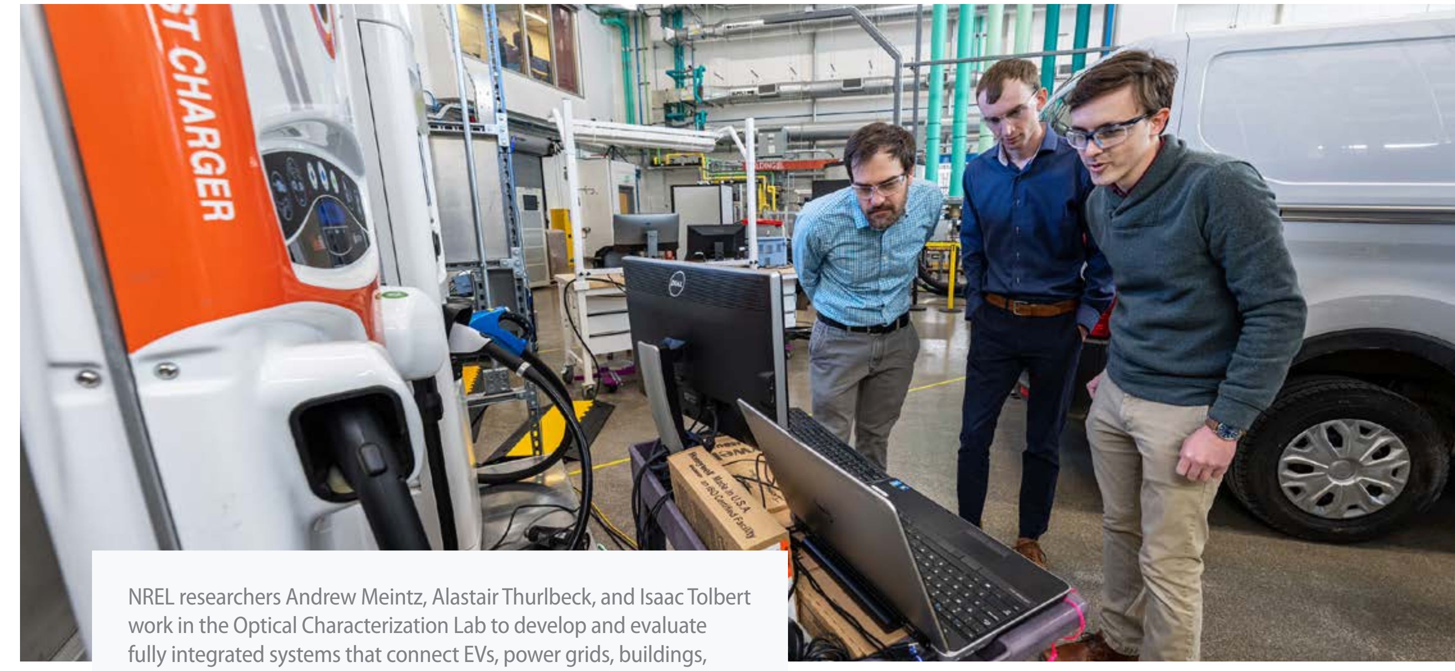
Situated on NREL's Flatirons Campus in Arvada, Colorado, the Integrated Energy Systems at Scale (IESS) is one of several field research sites and facilities that work together to demonstrate the potential for renewable energy to power a large fraction of the country's transportation needs in concert with buildings and a healthy, resilient grid.

The site design for the new IESS expansion includes novel capabilities that will expand to multimegawatt electric vehicle charging and grid integration capabilities from the hundreds of kilowatts currently available at the ESIF. This campus expansion is slated for completion in calendar year 2024.

The megawatt charging capabilities under development at ARIES will provide a platform for fully integrating vehicles and charging components with the broader ecosystem via hardware-in-the-loop experimentation, on-site emulation, and national-scale simulation.



An aerial view of NREL's Flatirons Campus and grid integration research pads. The campus is the site of the ARIES research platform's IESS expansion.



NREL researchers Andrew Meintz, Alastair Thurlbeck, and Isaac Tolbert work in the Optical Characterization Lab to develop and evaluate fully integrated systems that connect EVs, power grids, buildings, renewable energy sources, and BTMS options.

EVRI Evaluation Platform Evolves To Address Critical Needs

NREL continues to enhance its world-class facilities through a combination of internal and VTO investments from the bench scale to the utility scale, providing a continuum of critical capabilities to enable EVs at scale. The laboratory's leading Electric Vehicle Research Infrastructure (EVRI) evaluation platform within ESIF enables researchers and industry stakeholders to study and develop a new generation of electrified transportation technologies within the context of the larger energy ecosystem.

The Need

Demand for faster, higher-power charging integrated with the power grid will scale significantly with widespread adoption of EVs.

- **The National Target:** The White House made plans for EVs to comprise 50% of all new vehicle sales by 2030 with the EV Charging Action Plan.
- **Bigger Picture:** Tens of millions of EVs are expected to hit American roads in the next 7 years. A comprehensive U.S. network of EV charging infrastructure, capable of supporting an anticipated 30–42 million EVs, will be needed.
- **What It Means**: Demand for faster, higher-power charging continues to rise at a rapid pace to support the transition to an electric fleet.

World-Class Facilities

Advanced equipment enables innovative, systems-integrated research.

- **The Vehicles:** New EVs in the EVRI this year are the Ford F150 Lightning Pro and Ford eTransit, which interface with the chargers installed at the ESIF and represent medium- and heavy-duty vehicles currently used in EV fleets.
- **The Software**: NREL continues to refine its in-house emulation system at the EVRI platform, which enables enhanced power-hardware-in-the-loop studies as well as the emulation of EV batteries and battery management systems. The innovative emulation system allows researchers to perform dynamic battery voltage evaluations of charging systems for any battery chemistry and charging protocol.
- **The Hardware:** NREL's megawatt-scale DC charging hub platform integrates various DC-DC converters connected to a common DC distribution system, employing a DC-fed high-power charging unit in EVRI that enables broader system performance and control studies for DC-integrated charging systems. This type of charging equipment is vital for designing and validating efficient, low-cost, and interoperable hardware for the next generation of heavy-duty EVs to operate and will accelerate the adoption of EVs and their infrastructure. NREL also recently approved an expansion into the medium-voltage outdoor test area through additional capabilities investments.

Empowering Partners

Various partnerships and stakeholder events leverage NREL's capabilities to help accelerate the transition to electric fleets.

- **Cybersecurity Event:** NREL co-hosted a fourth high-power EV charging connector evaluation event at EVRI in collaboration with the Charging Interface Initiative (CharIN). NREL facilities and insights assist industry partners to assess the cybersecurity of public key infrastructure under real operating conditions.
- **Interoperability Research**: Manufacturers can evaluate interoperable designs for vehicle inlets and charger connectors with the EVRI's thermal evaluation benches for characterizing air- and liquid-cooled charging connectors for 350–3,000 A. NREL's evaluation events provide a platform for researchers and industry participants to discuss and improve the technical merits of different equipment parameters and standards.
- **Multi-Vehicle-Class Research:** NREL validates safety and durability within the MCS standard for medium- and heavy-duty EVs. These activities enable researchers and industry stakeholders to study and develop a new generation of electrified transportation technologies within the context of the larger energy ecosystem.

Why It Matters

NREL's expanded research efforts enable high-power charging research at scale and in real-world conditions.

- **The Platform:** The lab's best-in-class ARIES research platform continues to expand its world-class megawatt charging and grid integration capabilities for enabling the electrification of over-the-road commercial vehicles and beyond.
- **The Progress:** This year, NREL completed the site design of and is proceeding with contracting for DC emulation of multimegawatt battery systems at up to 7.5 MW at the lab's Flatirons Campus in Arvada, Colorado, leveraging ARIES investments in the 20-MW controllable grid interface.
- **What Makes It Unique:** New features include a sophisticated megawatt-scale BTMS system, a megawatt-scale battery emulator, a DC-as-a-service microgrid and fast chargers, and megawatt-level charging evaluation and vehicle emulation capabilities. These features help evaluate systems at the megawatt scale.

Game-Changing Batteries Research Unlocks Potential for Sustainable Electrified Transportation

With the shift to renewable energy, a new era of electrification is on the horizon, largely supported by NREL's breakthrough battery research and capabilities. NREL experts are meeting complex challenges in energy storage that span technology readiness levels—from atom-scale materials science to full-scale systems—including insights that are helping to shape a sustainable future for battery recycling and clean energy supply chains.

Modeling Experts Guide Battery Innovations

NREL's advanced multiscale modeling, physics-based machine learning, and analysis guide battery innovations by offering key insights into the physical, chemical, mechanical, and structural properties of energy materials and storage systems. Backed by state-of-the-art X-ray diagnostic capabilities, these findings accelerate the development of next-generation battery designs to meet fast-charge, high-energy, low-cost, and long-lifetime performance goals.

In other research, NREL helped develop more efficient techniques to quantify lithium plating—a phenomenon known to damage batteries—using electrochemical measurements and advanced computer modeling. Future battery designs can use the NREL model to simulate the onset and behavior of lithium plating to avoid irreversible lithium consumption and make extremely fast battery charging a reality.

At the Forefront of Emerging Technologies

The clean energy transition will demand more from electrochemical energy storage systems than ever before. Although LIBs are already widely used in transportation energy storage, consumer electronics, and stationary storage, NREL researchers continue to evaluate and synthesize novel battery materials and next-generation battery technologies, such as redox flow and solid-state batteries. Much of this research tackles significant manufacturing and commercialization challenges, leading to recent advancements in cell fabrication and system designs.

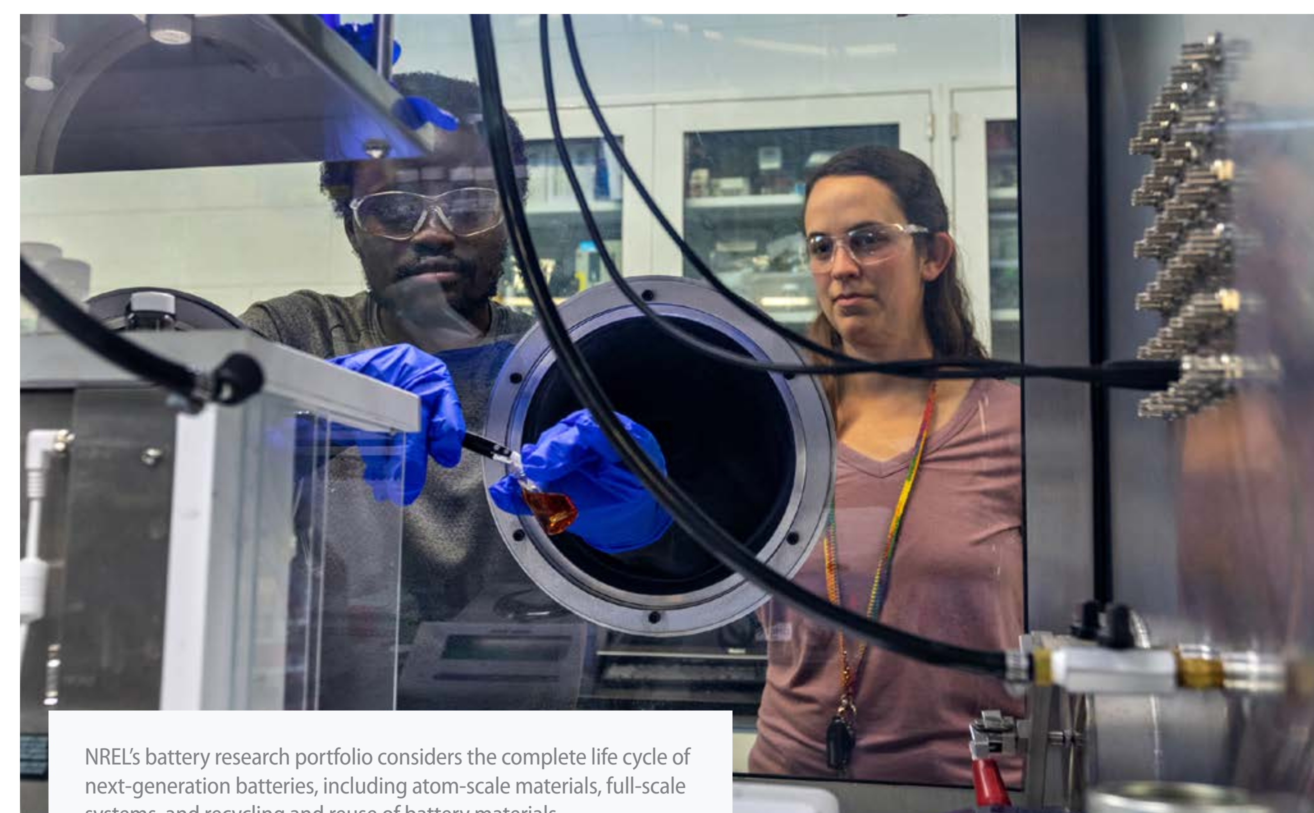
This year, NREL was awarded $3.4 million from DOE's ARPA-E program to de-risk up-and-coming battery technologies to support vehicle electrification across the United States. The project, part of the Electric Vehicles for American Low-carbon Living (EVs4ALL) initiative, will evaluate the safety of new battery cell designs from novel materials including sodium, potassium-ion, and solid-state lithium metal, as well as cobalt- and nickel-free cathodes. NREL researchers will characterize the resulting technologies to develop a thorough understanding of the failure conditions that could cause safety risks for the batteries.

The Future of Battery Recycling

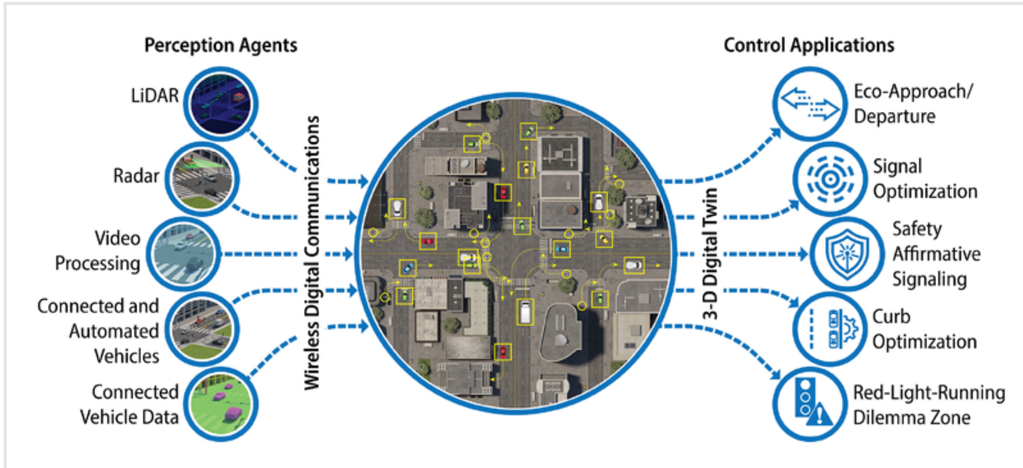
NREL's vision for the future of energy storage also considers the complete life cycle of energy materials and the LIB recycling supply chain. The lab is spearheading the lithium-ion recycling revolution with holistic and forward-thinking research, both as part of the leadership team for DOE's ReCell Center and through ongoing collaborations with industry experts to support analysis, mapping, and technological advancements. One such collaboration between the United States and the United Kingdom aims to support the development of high-capacity batteries and new methods for battery materials recycling through black mass valorization, electrolyte salt recovery, recycling of low-value materials, and techno-economic analysis of battery recycling. In addition, NREL administers the Lithium-Ion Battery Recycling Prize, which recently announced two additional phases and $7.4 million in new funding.

As the guiding force behind recent nationwide investments, LIBRA, the NREL-developed Lithium-Ion Battery Resource Assessment model, uses powerful system dynamics modeling to analyze the supply chain and evaluate the economic viability of LIB manufacturing, reuse, and recycling. Recent LIBRA analysis evaluated the impact and importance of battery chemistry and sorting in the recycling supply chain to demonstrate how automated sorting can maximize cobalt recovery and make recycling more profitable.

In summary, our researchers are addressing challenges to increase nationwide adoption of electric vehicles, evaluating emerging technologies, and collaborating on nationwide initiatives to guide a new era of electrification. NREL's work is a driving force toward a decarbonized future where energy storage plays a central role in powering our world sustainably.



NREL's battery research portfolio considers the complete life cycle of next-generation batteries, including atom-scale materials, full-scale systems, and recycling and reuse of battery materials.



The IPC pipeline integrates sensed data from a variety of sources to develop advanced computational controls designed to improve the energy and time efficiency of mobility while increasing safety.

Equipment Investments Expand Transportation and Mobility Research Capabilities

NREL is enhancing its world-class facilities from the bench scale to the utility scale.

Two New Labs Boost Resources and Capabilities

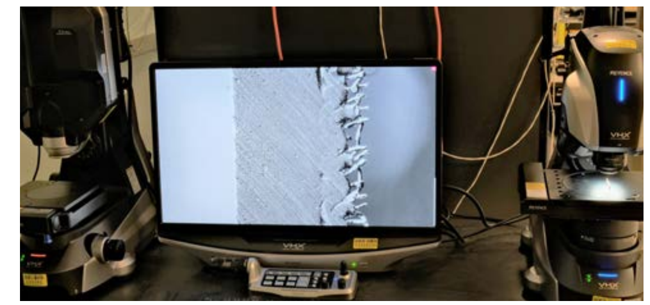
IPC Lab – NREL has outfitted its new IPC Lab with modern equipment, some of which can be configured to take on the road in a customized mobile trailer as researchers work with partners across the country. New equipment includes traffic control cabinets and components; traffic controller hardware and software; connected vehicle onboard transceiver units, which can be mounted on a vehicle to collect and relay real-time data to other connected vehicles or roadside units; radar and lidar sensors; telescoping mast assemblies for sensor and traffic light deployment; edge-computing devices; video imaging and visualization equipment; virtual reality and driving simulation equipment; and global positioning system devices. Researchers use this equipment to build on the evolving role that advanced sensing and computational controls play in connected and automated movement and apply it to the coordinated movement of vehicles on the road, as well as how people move and navigate in large facilities such as airports.

Charging Power Electronics (CharPE) Lab – NREL's new CharPE Lab enables the development and evaluation of power electronics systems and enhanced idea development, research, and prototyping for EV charging infrastructure, energy systems integration, and energy storage systems. It features a Speedgoat real-time target machine/simulation platform enabling rapid control prototyping, hardware-in-the-loop testing, and real-time simulations. Researchers have already employed the machine in a BTMS project demonstrating a mixed-chemistry battery pack with active state-of-charge balancing. Other new equipment and capabilities for the CharPE lab include oscilloscopes; power supplies; a digital power meter; an inductance, capacitance, and resistance meter; a benchtop digital multimeter; three-phase 480 V and 208 V AC house power systems; 24 kW of programmable DC loads and 20 kW of programmable DC supplies; and a 100-kW power feed capacity.

New Equipment Enhances Capabilities Across Research Areas

Advanced Power Electronics and Electric Machines – A Keyence VHX-7000 optical microscope—coupled with an EA-300 elemental analyzer featuring laser-induced breakdown spectroscopy—provides scanning-electron-microscope-quality images. This is also useful for NREL's energy storage research. On the fabrication front, a new stereolithography 3D printer from FormLabs enables researchers to create advanced cooling manifolds for use in power electronics, while a more powerful computer numerical control mill enables the rapid creation of power electronics prototypes, increasing the pace of model validation. An Elektro-Automatik bidirectional power supply allows researchers to test custom-built power modules at full capacity. Its bidirectional functionality allows 95% of the converted energy to be fed back into the power grid instead of dumping it as waste heat. And finally, a Keysight B1505A power device analyzer, which characterizes high-power devices from sub-pico amps up to 10 kV/1,500 A, improves understanding of power device electrical characteristics and how parameters change over time due to aging, supporting state-of-health estimations for power electronics systems.

Fuels and Combustion Science – NREL worked with an equipment manufacturer to design and build a custom surface tension instrument to gather key data supporting the development of exascale-ready combustion simulation capabilities. The instrument will cover nearly the entire range of high-temperature and high-pressure conditions experienced by aviation turbine engines to enable the measurement of surface tension, which plays a critical role in combustion and emissions formation processes.



Optical microscope and elemental analyzer.

Energy Storage – New thermal conductivity meters and environmental chambers enable researchers to evaluate the thermal properties of new battery technologies. Additionally, new equipment to support battery recycling research includes numerous battery cyclers, temperature-controlled ovens, and a Nutsche filter-dryer batch reactor to evaluate black mass purification.

A researcher uses a 1-L reactor in NREL's energy storage laboratory to evaluate black mass from recycled battery electrodes.

Commercial Vehicle Technologies – NREL has acquired about 60 vector loggers and 120 CSS Electronics CAN Edge 2 loggers, bringing the lab's total number of loggers to 240. Researchers use the loggers to capture in-use data from medium- and heavy-duty vehicles to grow the Fleet DNA database of commercial fleet vehicle operating data and to expand NREL's data-gathering capabilities for the Fleet Research, Energy Data, and Insights (FleetREDI) program and EV school bus evaluations.

NREL Adds Lab Space with New Building, Preps for Other Large-Scale Projects

NREL's newest building—the Research and Innovation Laboratory—houses multipurpose and "wet" lab space for research in next-generation batteries, advanced energy materials, and other technologies. The 15,000-square-foot building also provides much-needed space for cross-disciplinary collaboration.

Meanwhile, two other major developments are underway just south of NREL's South Table Mountain campus. DOE is transforming the former Camp George West, a 6.6-acre site, into the South Table Mountain Energy Park to serve as an incubator for clean energy companies. And the state of Colorado is building the Global Energy Park as a hub for the cleantech industry.

Looking to the future, early planning is underway for a new NREL building—the Energy Materials and Processing at Scale Facility—to help researchers minimize barriers to technology scale-up for new energy materials, processes, and devices for market.

The planned Glo Park will be immediately south of the NREL campus, while STEP is further south.

New Researcher Leads Initiative To Transform Material Supply Chains

Robust and resilient material supply chains are critical to the success of sustainability initiatives. Increased demand for renewable energy systems, such as EVs and photovoltaics, requires reliable access to materials that enable these technologies. As supply chains evolve and expand, researchers must evaluate nontraditional material sources, including recycled materials, to develop a shared understanding of their cost, performance, and impurity tolerances across applications.

NREL researcher Katie Harrison brings extensive expertise in materials science and electrochemistry, particularly for battery applications, to meet this challenge. As part of a new transformational LDRD project, Harrison is leading the development of a flexible suite of tools and capabilities to evaluate how impurities in nontraditional material sources impact refining, manufacturing, and performance of renewable energy technologies. Harrison's background in electrochemical characterization will support NREL's research to evaluate cathode materials with major impurities to evaluate their impact on battery performance.

"Exploring nontraditional materials sources is critical to support the growth of resilient material supply chains," Harrison said. "This initiative will evaluate cathode materials across applications to simplify impurity assessments with new modeling tools."

The team will also screen photovoltaic glass cutlets to identify problematic impurities. In addition to providing an integrated and accelerated approach to impurity evaluations, these tools will offer insights to inform manufacturing decisions, lifetime predictions, and economic viability across sources.

Katie Harrison.

Award Recognition

Wendy Dafoe Honored With VTO Lifetime Distinguished Achievement Award

Wendy Dafoe, an NREL senior project leader for DOE's Clean Cities Coalition Network, was recognized with a prestigious Lifetime Distinguished Achievement Award at VTO's 2023 Annual Merit Review. Dafoe, who joined NREL in 1994, was honored for her loyal dedication to the Technology Integration program and commitment to the Clean Cities mission, which aims to support the nation's energy and economic security by building partnerships to advance affordable domestic transportation fuels.

Wendy Dafoe.

Doug DeVoto Recognized With VTO Distinguished Achievement Award

Doug DeVoto, an NREL power electronics and electric machines researcher, received a Distinguished Achievement Award at VTO's 2023 Annual Merit Review in recognition of his outstanding contributions to VTO Electric Drive Technologies advanced power electronics packaging and reliability research and development. In his research, DeVoto leads reliability evaluation and prognostics research for automotive power electronics with a focus on bonded interfaces, electrical interconnects, and high-temperature packaging. This year, he was also honored with the American Society of Mechanical Engineers (ASME) Excellence in Mechanics Award for the Electronic and Photonic Packaging Division.

Doug DeVoto.

Matt Keyser Named NREL Distinguished Researcher

For more than 30 years, NREL's Matthew Keyser has played a crucial role in the development of the electrochemical energy storage group, putting NREL on the map as a leader in battery characterization, synthesis, safety, and system design. Keyser has developed award-winning devices to improve the performance of LIBs, facilitated new partnerships while strengthening existing ones, and spearheaded the growth of NREL's battery energy storage research equipment and facilities. Now, Keyser has been named an NREL Distinguished Member of Research Staff—an honor that recognizes outstanding contributions to the laboratory and internationally recognized leadership and achievements in his field.

Matt Keyser.

Sreekant Narumanchi Earns ASME Avram Bar-Cohen Memorial Medal

NREL's Sreekant Narumanchi, group manager and senior power electronics and electric machines researcher, has been honored with the coveted ASME Avram Bar-Cohen Memorial Medal. Granted to a single individual each year, the medal recognizes Narumanchi's remarkable contributions to the fields of thermal management, power electronics, and electric machines. Narumanchi will formally accept the Avram Bar-Cohen Memorial Medal in October at the 2023 ASME InterPACK Conference and Exhibition in San Diego, California.

Sreekant Narumanchi.

Bidzina Kekelia Elevated to IEEE Senior Member

In recognition of his significant contributions to vehicle thermal management, power electronics, and electric machines, NREL's Bidzina Kekelia has been elevated to a senior member of the Institute of Electrical and Electronics Engineers (IEEE). Kekelia was specifically recognized for his contributions to novel thermal management methods for power electronics, electric motors, and electric traction drive systems for ground vehicles and electrified aviation applications.

Bidzina Kekelia.

Faisal Khan Named Associate Editor of *IEEE Transactions on Power Electronics*

Faisal Khan serves as NREL's chief researcher in the field of power electronics and electric machines, power semiconductor device packaging, transportation electronics, and reliability and degradation analysis of power converters and batteries. This year, he was named associate editor of *IEEE Transactions on Power Electronics*, a peer-reviewed journal that covers issues of widespread interest to engineers who work in the field of power electronics. As associate editor, Khan will serve as a subject matter expert and play a key role in the journal's peer-reviewed publishing process.

Faisal Khan.

Venu Garikapati Recognized as Outstanding Reviewer Two Years in a Row

For the second year running, NREL's Venu Garikapati, a senior transportation data researcher, has been honored by the National Academies of Sciences, Engineering, and Medicine's Committee on Effects of Information and Communication Technologies on Travel Choices. Garikapati was recognized as an outstanding paper reviewer who provides constructive, insightful, and timely peer review. This year, Garikapati was also honored with NREL's Outstanding Postdoctoral Mentor Award, with nominations from three members of his research group.

Venu Garikapati.

Jeff Gonder Earns VTO Team Award for SMART Mobility Steering Committee

NREL's Jeff Gonder, a group manager and senior mobility, behavior, and advanced powertrains researcher, was honored with a Team Award at VTO's 2023 Annual Merit Review for his work on the SMART Mobility Lab Consortium steering committee, which provides consortium insights for a high-impact webinar series. The consortium connects seven of DOE's national laboratories with a goal of delivering new data, analysis, and modeling tools, and creating new knowledge to support smarter mobility systems.

Jeff Gonder.

Matteo Muratori Honored With Secretary of Energy Achievement Award

For his work in helping the nation to transition away from fossil fuels, Matteo Muratori, group manager and senior transportation energy analysis researcher, was presented with a Secretary of Energy Achievement Award, the highest form of recognition for federal employees within DOE. Muratori was recognized for his contributions to the Sustainable Aviation Fuel (SAF) Grand Challenge, a collaborative, cross-agency effort to develop a comprehensive strategy for scaling up new technologies to produce SAF on a commercial scale.

Matteo Muratori.

Patricia Romero-Lankao Appointed to Deep Decarbonization Committee

The National Academies Board on Energy and Environmental Systems' Deep Decarbonization Committee is conducting a Deep Decarbonization Consensus Study to assess the technological, policy, and societal impacts of putting the United States on the path to reach net-zero carbon emissions by 2050. NREL's Patricia (Paty) Romero-Lankao, a senior behavioral science researcher, has been appointed to the committee, where she will co-lead the chapter focused on achieving an equitable and just energy transition. The chapter will emphasize principles, policies, and inclusive stakeholder engagement.

Paty Romero-Lankao.

K. Shankari Named CO-LABS' Outstanding Early Career Scientist

In recognition of her pioneering work to bring free, open-source mobility insights to communities around the world, K. Shankari has been named the second-ever Outstanding Early Career Scientist through the CO-LABS Governor's Award for High-Impact Research. Shankari has been recognized for her groundbreaking work using the novel open-source platform she developed, NREL OpenPATH. Shankari leverages NREL OpenPATH to collect rich, end-to-end, multimodal data and create community-specific mobility insights with a goal of empowering underserved communities to achieve their sustainability goals. She is the second-ever individual to earn this award.

K. Shankari.

Moreno Awarded Two Patents for Innovative Thermal Management Technologies

Gilbert Moreno, a senior research engineer with NREL's power electronics and electric machines group, has been awarded two patents this year for cutting-edge developments in thermal management technologies. One patent, an evaporator stack developed with John Deere, represents a step forward for cooling heavy-duty, off- and non-road vehicle systems. The other, developed by NREL's advanced power electronics and electric machines group, uses jet impingement manifolds to cool power electronics modules within vehicles. This year, Moreno was also honored with the NREL Chairperson's Award. As the highest award granted by the laboratory, it recognizes outstanding and sustained contributions to the laboratory's mission.

Gilbert Moreno.

R&D HIGHLIGHTS

Battery Technologies

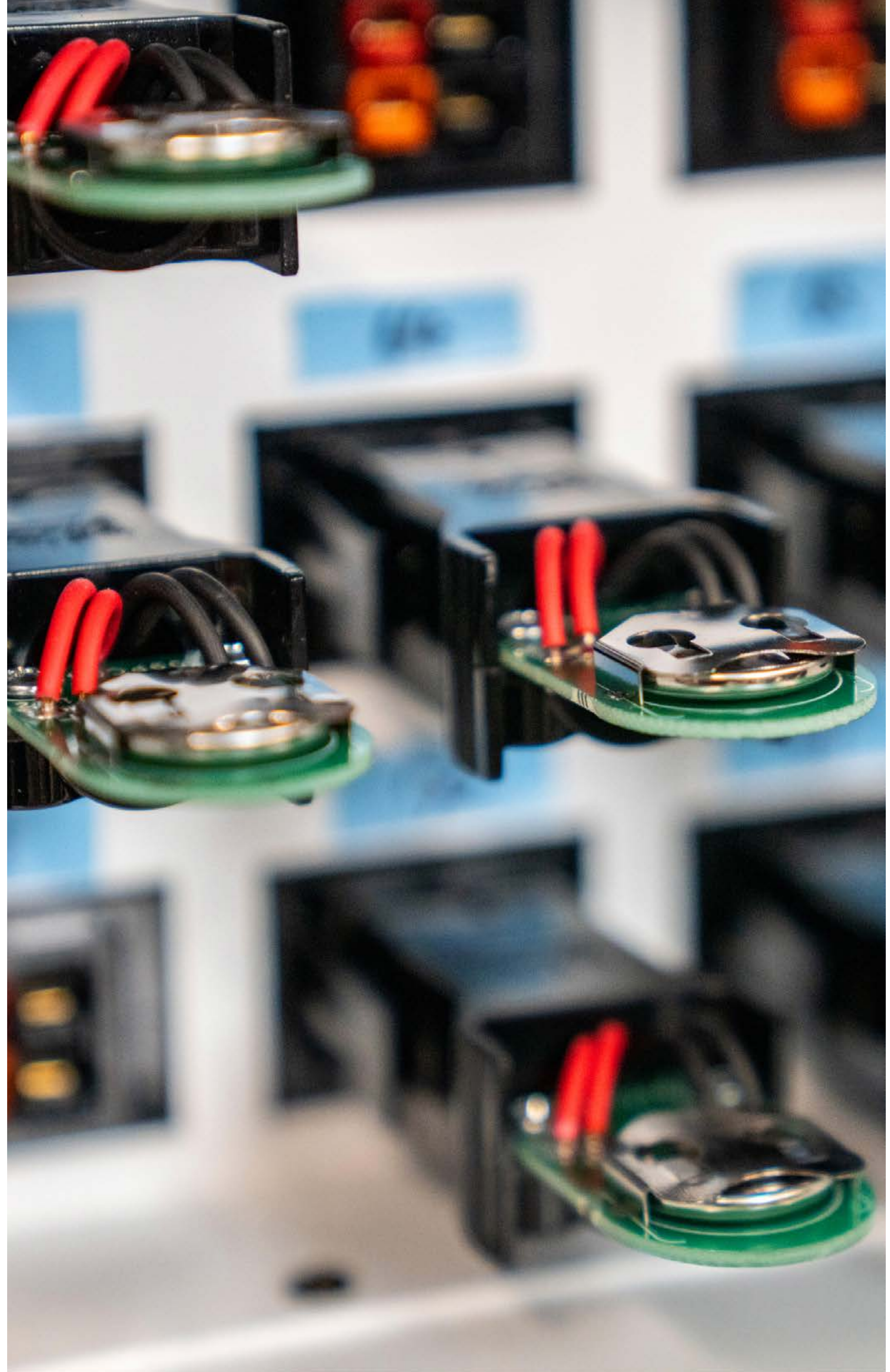
BATTERY R&D

NREL Characterization of Thermal and Safety Features for Stationary Battery Designs

Stationary batteries can help building owners minimize energy costs and grid impacts as part of integrated BTMS designs. Unique NMC/LTO configurations developed as part of DOE's ReCell Center aim to improve the performance and energy density of stationary batteries. However, these designs must undergo rigorous characterization at NREL to ensure thermal runaway within battery cells does not lead to propagation and system failure. To optimize operational conditions and troubleshoot potential issues, NREL engineers will evaluate the thermal and safety features of a new 1-kWh battery pack design. Future BTMS work will scale up to larger pack designs, as well as explore opportunities using mixed chemistry systems.

Advanced Characterization Guides and Validates Long-Life, Earth-Abundant Cathode Material, Lithium-Ion Cell Designs

NREL researchers are using multiscale X-ray diagnostics to better understand the performance of next-generation materials in LIB designs. These advanced characterization techniques allow researchers to evaluate how nickel- and magnesium-rich cathode particles degrade during battery cycling, tracking the morphological, crystallographic, and chemical changes. First, researchers conducted synchrotron X-ray diffraction computed tomography to identify spatial variations in crystallographic activation of the cathodes during formation. This method allowed researchers to clarify the heterogeneity of crystal phases present in the fresh cathodes, which is expected to significantly influence the cell's lifetime. Next, researchers used Fourier-transform infrared spectroscopy to elucidate changes to the cathode surface and electrolyte composition during formation and the first few charge and discharge cycles. These data help identify a direct link between cathode performance and the material properties, or morphology, as well as the interaction with electrolyte at the beginning of the cell's life. These findings allow researchers to identify target material properties and adjust cell designs during synthesis, leading to higher-performing materials in LIB designs. Continued research will establish a 4D scanning transmission electron microscopy technique at NREL to focus on the evolving interfacial chemistry and crystallographic structure.



Full-Cell Configuration Demonstrates >90% Capacity Utilization for High-Nickel Solid-State Batteries

Ongoing research into solid-state battery configurations has encountered challenges to achieving effective utilization of cathodes, limiting cell performance. Additionally, NREL researchers found that early reported success using lithium-indium alloys suffers from low energy capacities that render the batteries impractical for transportation applications. To address these challenges, the NREL team is working with a practical full-cell configuration and promising active materials to identify techniques that maintain contact between the active cathode and solid-state electrolyte. In addition, researchers adjusted fabrication and cycling pressures and electrochemical cycling protocols to maximize cathode capacity. So far, this team has demonstrated >90% capacity utilization using a nickel–manganese–aluminum cathode and silicon anode. These two active materials can support energy densities of 400–500 Wh/kg with further cell optimization. Future research will attempt to maintain this high capacity over extended cycling, using improved coatings and softer electrolyte materials to maintain particle-to-particle contact and allow the conduction of lithium ions during charging and discharging.

Chemomechanical Model Optimized To Consider Fade Mechanisms for LIBs

Electrochemical/aging-coupled models are needed to optimize electrode designs and develop fast-charge control policies that adapt over a battery's lifetime. Literature models, at present, are based on incomplete assumptions due to limited characterization and understanding of the parameters needed to track aging. Under DOE's eXtreme Fast Charge and Cell Evaluation of Lithium-Ion Batteries (XCEL) program, NREL has worked diligently with ANL and INL to characterize and understand how aging mechanisms arise and change with material and electrolyte selection, electrode design, and fast-charge condition. To incorporate aging considerations into their state-of-the-art electrochemical model, NREL researchers identified the primary fade mechanisms, namely solid-electrolyte interface growth, lithium plating, and cathode cracking. Appropriate equations were derived to represent fade mechanisms while balancing computational efficiency. The mechanisms were coupled to electrode properties that evolve with aging. Next, the team implemented these equations for testing in NREL's electrochemical model and streamlined the model to reduce computing time. The resulting model will help researchers co-optimize battery design and fast charge to minimize fade and cost. NREL researchers will continue to improve upon this model, validate, and publish results in FY 2024.

Silicon Models Highlight Strategies To Stabilize Calendar Lifetimes

Silicon is a promising next-generation anode material with the potential to increase the driving range of EVs, but it is hindered by a limited calendar lifetime. NREL researchers used Si-electrolyte interface models to identify and summarize multiple strategies to address this challenge. One method, using an updated 1.5-M $LiPF_6$ in fluoroethylene carbonate/ethyl methyl carbonate (FEC/EMC) electrolyte composition, offers an accessible path to potentially improve Si calendar lifetime by 4 times. In addition, models and experiments show that calendar lifetime significantly improves when the Si state of charge is low. The team is also investigating whether mechanical effects, such as applying compressive stress, have a significant impact on calendar lifetime. By using models to down-select promising methods and opportunities, the NREL-led Silicon Consortium Project can focus on demonstrating strategies that will significantly improve Si calendar lifetime.

Control of Nanoparticle Dispersion, Solid-Electrolyte Interphase Composition, and Electrode Morphology Enables Long Cycle Life in High-Silicon-Content Nanoparticle-Based Composite Anodes

High-silicon-content LIB composite anodes must accommodate extreme volume changes during charging/discharging and reactive interfacial chemistries to achieve suitable calendar and cycle life. Tethering organic molecules onto Si nanoparticle surfaces enables a highly dispersed and homogeneous slurry that can easily be integrated into a standard electrode fabrication process to fabricate a predominantly (~75 wt %) Si composite electrode. Thermal curing removes the organic surface functional groups, and when the initial 1,000-mAh/g specific capacity, 2.55-mAh/cm areal capacity Si-based anode is paired with a capacity-matched lithium-NMC cathode, the cell retains 72% of its capacity after 1,000 charge/discharge cycles. This breakthrough shows that high-cycle-life Si anodes are achievable using a conventional slurry coating process and validates a key hypothesis of the Silicon Consortium Project to minimize direct Si-electrolyte contact. Next steps are to evaluate the effects of this unique electrode enabled by molecularly coated Si nanoparticles on the calendar life, as well as pursue higher-areal-capacity electrodes and electrolytes tailored for Si-NMC cells.

Solventless Processing for Precise, Reliable, and Scalable Solid-State Battery Manufacturing

A vast collaborative partnership between NREL, ORNL, SLAC National Accelerator Laboratory, Solid Power, SkyNano Technologies, Epic Advanced Materials, and Mott Corporation aims to advance next-generation SSB technologies with dry process electrode manufacturing. This effort will combine state-of-the-art modeling, advanced characterization, new material formulation, novel high-throughput processing, and unique three-dimensional cell architecture to demonstrate high-energy (>400 Wh/kg), large-area (>100 cm^2) all-SSBs with commercially relevant, low-failure-rate (<20%) manufacturing processes. This approach will enable the team to make the further improvements needed to make SSBs commercially viable in demanding applications.

Selectively Retaining Surface Products on End-of-Life Anodes Can Enhance Remanufacturability and Improve Recycling Prospects

Traditionally, recycling graphite from end-of-life batteries has offered low material value. However, aged graphite contains a native surface layer, or solid–electrolyte interface (SEI), which contributes beneficial passivating properties. A high-performing upcycled anode with a preformed, optimized SEI will drastically reduce requirements for cell formation, which is among the most time-intensive and costly processes in battery manufacturing. This added market value also offers a unique pathway to increase graphite recycling prospects. As part of DOE's ReCell Center, NREL is developing a novel approach to capitalize on the beneficial components within the SEI while countering its highly resistive properties that reduce battery performance. Researchers have designed tailored solvent systems to selectively purify the surface of the graphite, resulting in a more optimal surface composition. In addition, researchers have developed a series of chemical, structural, and electrochemical metrics to evaluate the performance and quality of the upcycled graphite material. In the first year of this effort, NREL has identified a set of promising solvent systems that enable selective SEI component removal and reduce anode resistance close to that of pristine material. In FY 2024, NREL will continue to fine-tune this approach and explore applying these methods to a broader set of industrial samples.

Morphological Upcycling Offers Promising Pathway To Improve Performance of Recycled End-of-Life Graphite

The graphite material used in early EV batteries is unable to match the performance and fast-charge requirements of today's batteries. As a result, recycling these batteries requires morphological upgrades before it becomes a viable alternative to modern virgin graphite. In a joint effort supported by DOE's Advanced Materials & Manufacturing Technologies Office, NREL researchers will work with industry partner Koura to identify optimal room-temperature processing conditions to upgrade the morphology of spent graphite. Through this study, the NREL/Koura team will evaluate the ability of mechanical and mechanochemical treatments to selectively tune and "upcycle" flake-like first-generation graphite to the spherical morphology currently preferred for high-rate cycling. Researchers will evaluate the success of this process through advanced structural, chemical, and electrochemical analysis. This project—which begins in early FY 2024—will enable recycled graphite to meet the demanding requirements of modern battery applications and compete with the cost and performance of today's virgin graphite.

Lithium-Ion Battery Recycling Prize Engages New Participants, Supporting Organizations

As prize administrator for the Lithium-Ion Battery Recycling Prize, NREL leads ongoing outreach and coordination for the competition. Shortly after the prize continuation and Breakthrough contest announcement, administrators hosted two kickoff webinars to engage with potential participants. The NREL team also joined NAATBatt International at their annual Lithium Battery Recycling Workshop in Indianapolis to engage with prize participants, industry stakeholders, voucher service providers, and potential evaluation entities. In addition, prize administrators launched an Evaluation Entity application to identify qualified battery recyclers and second-life testing organizations for support in the validation and evaluation of winning concept solutions that advance to Phase IV of the competition.

Swift Enables Computing To Advance Battery Technologies Research Faster

Computational science informs advancement research in battery technologies, especially in replacing traditional combustion engines with sustainable EVs, which is challenging. Only LIBs achieve the practical energy density required for EVs, while all-solid-state batteries offer high energy density and better safety options for energy storage but provide significant challenges. Advanced computing research facilitates the discovery of new materials—like disordered lithium-excess rock salt (DRX) materials, which have high energy density and can be synthesized without cobalt or nickel—and understanding of electrochemical performance, including modeling of improved DRX cathode performance, to enable progress toward all-solid-state batteries. Researchers can improve the methodologies and exploration of solid-electrolyte interface systems, including the shift from graphite to silicon—a promising avenue that suffers from degradation at the solid-electrolyte interface. Modeling probes the effects of material microstructure on cell performance of solid-state electrolytes—alternatives to liquid electrolytes found in LIBs. The work will accelerate the design of DRX materials with optimal electrochemical performance, allowing for optimal electrolyte and additive compositions and leading to stable solid-electrolyte interface in all-solid-state rechargeable cells. It will also demonstrate how the chemical and microstructural evolutions of the interface affect the mechanical robustness of the electrochemical cell and dictate battery performance.

Atmospheric Plasma Enables Cathode Relithiation and Upcycling

Aged cathode materials from EVs hold tremendous value if recycled economically, but numerous challenges limit their recycling opportunities. Aged cathode particles typically have less lithium than their pristine counterparts, are covered in electrolyte degradation products, and suffer from severe mechanical cracking. As a result, no technology currently exists to enable the reuse of these materials. NREL and Storagenergy are working together to utilize a one-step atmospheric microplasma reaction to address some of these issues by eliminating the electrolyte degradation products and relithiating end-of-life cathode materials. This process allows researchers to streamline the direct recycling of battery components by reducing the required steps and time. In addition, the atmospheric plasma array could drastically increase the reuse of the most valuable material in LIBs. Next, NREL researchers will send healed cathode particles to ANL for further evaluation.

Project Agreements Finalized for Safety Evaluation of Next-Generation Energy Storage Cells

Due to uncertainties about their safety, emerging energy storage materials face significant barriers to adoption in EVs. A new project from DOE's ARPA-E program will incentivize partnerships between NREL and vehicle manufacturers to de-risk next-generation materials. NREL researchers will provide thorough characterization of the failure mechanisms and risks associated with thermal runaway of energy storage materials provided by vehicle manufacturers, enabling manufacturers to make more informed decisions on which technologies offer the most potential for success. NREL has finalized agreements with industry partners to support this project, which is anticipated to start in October 2023.

High-Throughput Laser Processing and Acoustic Diagnostics Enhance Battery Performance and Manufacturing

A novel laser ablation technique developed at NREL improves the rate of electrode wetting during cell manufacturing, unlocking performance improvements for fast charging and operational lifetimes of batteries. NREL researcher worked alongside industry partners Clarios and Amplitude Laser Group to successfully demonstrate the efficacy of this technique with roll-to-roll processing for 700 m of electrode material, proving that laser ablation is a scalable and economically feasible technique for roll-to-roll production of LIBs. Next, researchers will work alongside Liminal to evaluate the performance of commercial cells manufactured with the laser-ablated electrode with *in situ* acoustic monitoring of the wetting process. The success of this research will de-risk adoption of this manufacturing technique for industry partners.

Electrification Technologies

ELECTRIC DRIVE TECHNOLOGIES

New Power Module Cooling Method Unlocks Efficiencies for Automotive Industry

Increasing the power density of power electronics devices is critical to improving the range of EVs and enabling their widespread adoption—but requires innovation in the thermal management system. As part of VTO's Electric Drive Technologies Consortium, NREL researchers have demonstrated a new, experimental dielectric fluid cooling concept using a SiC power module, developed in house. This single-phase cooling method provides superior performance compared to conventional cooling systems. It not only enables the use of new driveline fluids as coolants but may allow for integration of the power electronics with the electric machine. These efficiencies can unlock new benefits for the automotive industry. Next, NREL researchers will evaluate the reliability of the new design.

Analysis Reveals Thermoplastic More Reliable for Power Electronics Packaging

As part of VTO's Electric Drive Technologies Consortium, NREL researchers are thoroughly evaluating the reliability of advanced power electronics packaging—a critical aspect of the overall performance, longevity, and resilience of power electronics modules. Despite the widespread assumption that thermoset polymers are better suited for high-temperature operation than thermoplastic polymers, NREL acoustic microscope analysis showed a complete disintegration of the bond in thermoset samples. Under severe thermal cycling profiles of -40°C to 175°C, thermoplastic samples are more reliable. Because most advanced power electronics packaging will require some form of bonded interfaces, it is critical to evaluate the reliability of these materials under harsh thermal cycling. NREL will next evaluate additional polymer samples under a wider range of thermal cycling profiles to determine their reliability.

New Smart Driver Predicts Power Converter Failure Before it Occurs

In the race to achieve widespread vehicle electrification, power modules play a critical role: smaller, lighter, and more resilient components can help EVs to travel greater distances, reduce range anxiety, and contribute to vehicles' longevity. Yet there is still no commercially available solution for measuring a power module's aging process and predicting its remaining life. Now, as part of VTO's Electric Drive Technologies Consortium, NREL researchers have developed and validated a new aging detection and measurement algorithm that could be integrated into a conventional gate driver circuit, making it capable of measuring the power module's aging in real time. This new approach can predict power converter and system failures before they happen, and even save human lives in cases where uninterrupted operation of the converter is critical. Next, researchers will optimize the developed hardware for compactness and accuracy so that full integration becomes a reality.

NREL Develops Superior Electrically Insulating Material for Power Electronics Packaging

Power electronics packaging determines the electrical, thermal, and mechanical performance that can be extracted from a semiconductor switching device. Now, NREL researchers have replaced the traditional ceramic substrate used to construct power electronics packaging with a polyimide electrical insulating layer that demonstrates superior thermal performance and greater reliability under thermal cycling, thermal aging, vibration, power cycling, and electrical high-potential conditions. Eliminating the ceramic substrates increases power electronics across the board: it reduces device-to-coolant thermal resistance, simplifies package design, offers more design flexibility, and could increase packaging reliability at lower cost. Next, researchers will develop an optimization workflow that balances electrical, thermal, and mechanical constraints.

NREL Designs Alternative to Rare-Earth Material-Dependent Motors

The automotive market is dominated by permanent magnet motors, which often require rare-earth materials to function and are therefore subject to supply chain risk. In contrast, wound-rotor motors completely eliminate the need for expensive, scarce rare-earth magnets—but they require novel cooling solutions to address their performance and reliability and to make them competitive alternatives to the industry standard. In collaboration with BorgWarner and as part of VTO's Electric Drive Technologies Consortium, NREL researchers are not only designing thermal management strategies for this cutting-edge technology, but also building in recyclability and reclamation strategies for several elements within wound-rotor motors. Having successfully built thermal-finite-element and multiphase-thermo-fluid models to understand cooling challenges associated with wound-rotor synchronous motors, NREL will deliver a final thermal solution to BorgWarner and assist in bringing the novel motor to life.

Double-Sided-Cooling Strategies for Power Modules Outstrip the Competition

Conventional, single-sided cooling for power modules has long been the automotive industry standard—and even industry-leading double-side-cooled power modules are limited in performance due to current thermal management practices. Now, in collaboration with Eaton, and as part of VTO's Electric Drive Technologies Consortium efforts, NREL researchers have designed several power-dense, double-side-cooled power modules that integrate advanced thermal management technologies. The designs surpass even best-in-class modules by providing far higher electrical and thermal performance. Next, the team will investigate innovative cooling technologies, including vapor chamber and solid-to-liquid phase-change-material technologies, which may enable further thermal and reliability improvements.

Highly Integrated Traction Drive Unit Sets New Standard for Future Designs

As part of VTO's Electric Drive Technologies Consortium, NREL researchers are collaborating with ORNL to design innovative thermal management system components for a novel outer-rotor motor with integrated power electronics in its central cavity. By integrating power electronics into an electric motor, researchers can eliminate the need for inverter-to-motor cabling, reduce the number of needed components, and create volume and weight savings for the electric traction drive. This highly integrated traction drive unit, complete with an NREL-designed combined cooling system, will simplify vehicle assembly and provide potential cost savings to EV manufacturers—setting a new standard for future automotive traction drive designs. The design also eliminates the need for heavy-rare-earth magnets, reducing supply chain dependence on critical materials.

Substation in a Cable Project Enables Adaptable, Low-Cost Electrical Distribution

The requirements for grid distribution networks are becoming more demanding—yet conventional distribution substations are unable to meet the growing demands of new and evolving electricity sources and loads due to their limited functionality, low flexibility, and large size. As part of ARPA-E's Substation in a Cable for Adaptable, Low-cost Electrical Distribution (SCALED) program, NREL researchers are combining the power density benefits of medium- and high-voltage cables with the functionality and flexibility benefits of power electronics. In collaboration with Virginia Tech, researchers are creating compact coaxial power conversion cells that seamlessly interface with cable lines to step down the voltage, control power flow, and connect lines with different voltages and frequencies, all in a highly modular manner. NREL's thermal management solution will passively dissipate heat generated by the system into the surrounding environment. This work could eliminate the need for large and expensive power substations and enable simple integration of renewable energy sources, an EV fast-charging infrastructure, energy storage, and efficient DC distribution lines.

Designing Reliable Packaging for Ultra-Wide-Bandgap Semiconductors Above 600°C

Gallium oxide-based semiconductors are ultra-wide-bandgap devices that can achieve superior performance compared to SiC devices at a lower fabrication cost. However, reliable packaging must be designed to enable their use in real-world applications. NREL researchers, in collaboration with Colorado School of Mines and Luxium Technologies, and with funding from DOE's Advanced Materials and Manufacturing Technologies Office (AMMTO), are investigating bonding profiles that lead to reliable interfaces. Having studied sintering profiles to bond gallium oxide diodes with copper bus bars, researchers will next characterize the reliability of the package at 600°C to determine if the interface can operate effectively at high temperatures.

Three-Dimensional Packaging To Transform Power Module Design Process for Aircraft and EVs

In partnership with Synteris and Packet Digital, NREL researchers are transforming the design, manufacturability, and function of a power electronic module through additive manufacturing. Through the Breaking the Board: Bringing 3-Dimensional Packaging and Thermal Management to Power Electronics project, funded through ARPA-E's OPEN 2021 program, researchers will print novel 3D ceramic packaging for power electronic modules. This unique packaging will act as both an electrical insulator and heat exchanger for better thermal management compared to traditional power electronics module components. The new module will substantially improve the design, manufacturability, and function of power modules used in EVs, aircraft, renewable energy generation, electrical grid regulation, and other applications, and represents a complete transformation of the power module design process.

Power Electronics Roadmap Charts Path to 50% Emissions Reduction by 2030

Advancements in power electronics performance, efficiency, and reliability promise to transform U.S. energy infrastructure and achieve aggressive economy-wide decarbonization goals. To chart the path forward, NREL, in collaboration with Sandia National Laboratories and Lawrence Livermore National Laboratory, is creating a technology roadmap for the power electronics industry for the next 10 years, ending in 2034. With funding from AMMTO, the laboratories will first collect input from industry stakeholders and relevant literature on existing trends, emerging technologies, goals, and requirements regarding performance and cost of future power electronics systems, as well as technical and market challenges to achieving those goals. The inputs will then be analyzed to determine an ambitious yet achievable vision for a future that meets the U.S. administration's decarbonization goals of a 50% reduction in emissions nationwide by 2030. The first draft of the roadmap is targeted for completion in February 2024.

Thermal Analysis Helps Move SiC Inverters Into the Mainstream

SiC power modules have the potential to improve efficiency and enable higher power density compared to silicon technologies. However, there are limited examples of SiC inverters developed for automotive applications. In collaboration with BorgWarner, NREL researchers are developing a power dense SiC inverter with high thermal performance and experimentally evaluating its durability and reliability. NREL is leveraging its best-in-class thermal management capabilities to conduct power and thermal cycling of the inverter and its components. In the process, the laboratory has developed novel capabilities to power cycle SiC modules while dissipating large amounts of heat—a critical step in demonstrating the durability, reliability, and efficacy of highly efficient SiC inverter technologies, so they can be adopted by the automobile industry.

Industry Partnership Fuels Unprecedented High-Power Inverter for Commercial Vehicles

NREL researchers are partnering with Cummins, ORNL, and Virginia Tech on a significant milestone in the electrification of medium- and heavy-duty commercial vehicles: developing an inverter with 300-kW peak power and an unprecedented lifetime of more than 750,000 miles. NREL researchers applied world-class thermal and thermomechanical modeling of the SiC-based power modules, bus bars, capacitors, and other inverter components, in addition to reliability analysis and experimental lifetime prediction. After completing thermal analysis on inverter subcomponents, the team will perform experimental power cycling of the power modules.

Megawatt-Scale Converter Prototype Enables High-Power System Performance at a Fraction of the Size

Through the Grid Application Development, Testbed, and Analysis for MV SiC (GADTAMS) project funded by AMMTO, NREL researchers are developing a new type of grid device enabled by SiC switches and other medium-voltage power electronics that could segment sections of the grid, providing advanced control for flexibility and resilience for our power systems. NREL researchers have designed a megawatt-scale prototype converter that, once integrated into the power system, could enable higher efficiency, lower loss, and enhanced reliability compared to existing technologies—all while operating at 1/5th the size and 1/10th the weight of equivalent systems. Partners at the Ohio State University and Florida State University have fabricated and assembled the converter for experimentation. Once evaluated, NREL researchers will characterize the converter to ensure its air-cooling system meets thermal management needs.

State-of-the-Art Cooling Strategies Transform Data Center Energy Efficiency

Data cooling can be energy intensive—accounting for 40% of a data center's overall energy usage—and can require hundreds of billions of gallons of fresh water annually. Moreover, rising processing power will increase data centers' power density, increasing the need for innovative cooling strategies. As part of the ARPA-E Cooling Operations Optimized for Leaps in Energy, Reliability, and Carbon Hyperefficiency for Information Processing Systems (COOLERCHIPS) program, NREL researchers are working to develop transformational, highly efficient, and reliable cooling technologies for data centers. NREL researchers are collaborating with the University of Florida, University of Missouri, and University of Maryland to develop software tools, advanced thermal management, and packaging strategies for data centers, in addition to evaluating the reliability of these cutting-edge solutions in real data center operating conditions. The project's goal is to dramatically lower the total cost of ownership, energy demand, and greenhouse gas emissions of data centers while achieving uptimes above 99%.

Liquid Cooling Leads to Highly Efficient Plasma Fusion Power Electronics Boards

Plasma fusion is a new technology with the potential to generate significant amounts of energy, without the drawbacks of conventional nuclear power generation. However, the power electronics boards required for plasma fusion are bulky and inefficient. As part of the ARPA-E Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts (GAMOW) program, NREL researchers collaborated with Princeton Fusion Systems, Qorvo, and Princeton University to develop high-thermal-performance liquid cooling solutions for power amplifier board components. Because each board will be capable of delivering more than 10 kW of power—roughly what an average American household uses in a year—and can replace less efficient devices currently in use, this work could lead to safe, carbon-free, abundant energy with numerous applications.

Advanced Cooling Strategies To Enable Electric Aviation Propulsion

Aviation propulsion electrification is still at a nascent stage. Propulsion electrification for even narrow-body, single-aisle aircraft capable of carrying 100–150 passengers has created significant challenges: cost, power density, efficiency, and reliability of electric propulsion systems, among others. Through the ARPA-E Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives (ASCEND) program, NREL researchers are helping to develop advanced thermal management systems that can enable electric aviation. In partnership with General Electric and the University of Wisconsin, NREL researchers designed an efficient, high-performance, supercritical carbon-dioxide-based thermal management system for the electric motor, power electronics, and 2-MW electric drive system of a lightweight electric propulsion plane. With Marquette University, Raytheon, and Florida State University, NREL researchers have helped develop an advanced thermal management system of additively manufactured coils and heat pipes to enable a highly integrated high-power electric motor and drivetrain system, which will be critical to cool aviation power electronics.

GRID AND INFRASTRUCTURE

High-Power Interoperable EV Charging Experimental Platform Developed To Demonstrate Integration Solutions

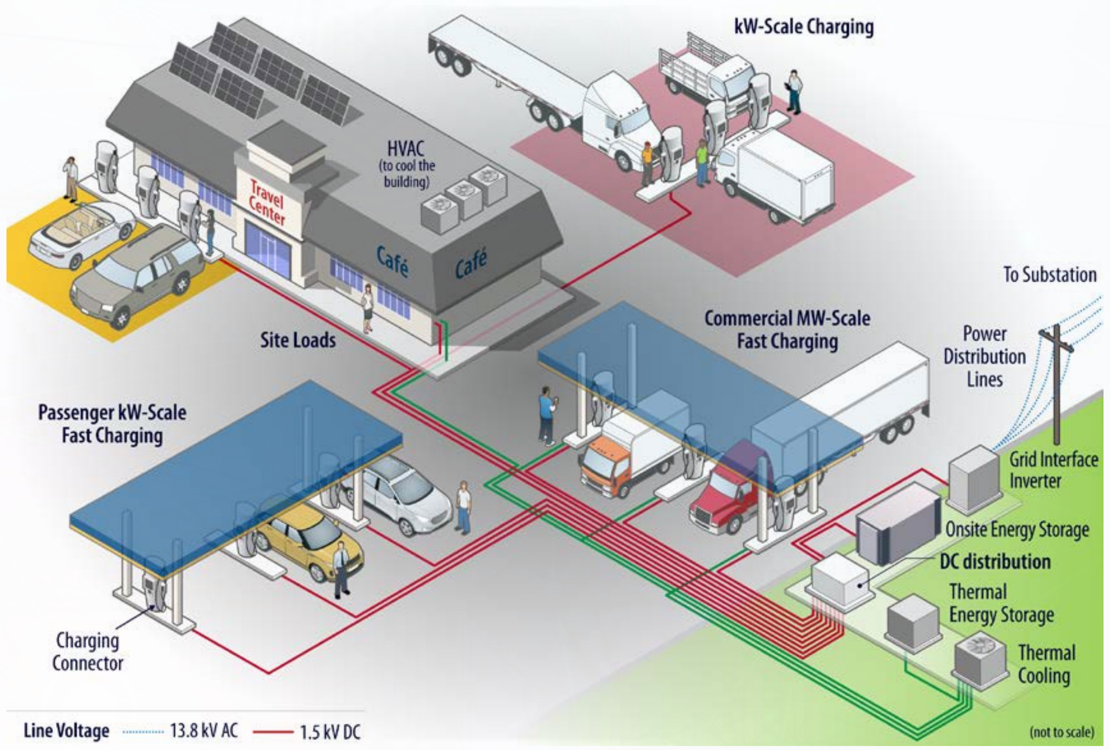
The EVs@Scale Lab Consortium is designing and developing a high-power, interoperable EV charging experimental platform to research, develop, and demonstrate various integration approaches and technology solutions. This project requires developing several key modules that will integrate seamlessly, including (1) the supply equipment communication controller, which will communicate with a vehicle using the ISO 15118 standard; (2) high-power electronics to provide the power needed for bidirectional charging; and (3) a site energy management system to provide real-time monitoring and control for all subsystems. NREL developed a kilowatt-scale DC charging hub platform that can integrate various DC-DC converters connected to a common DC distribution system. Large-scale adoption of EVs will introduce new challenges for high-power charging, load management, and facility equipment operation. Designing and validating efficient, low-cost, and interoperable hardware for high-power DC-hub charging, communication, and control architectures is crucial for the next generation of heavy-duty EVs to operate and to accelerate adoption of EVs and their infrastructure. A DC-hub charging hardware test bed also enables the appropriate development and testing of various controllers and charging stations from different vendors to execute this work. The team will continue developing the DC charging hub and kilowatt-scale test bed with more charging stations and vehicles included. Furthermore, on-site energy storage systems and distributed energy resources will also be integrated in the system in the coming years.

Characterization and Quantification of High-Power Charging System Profiles Advances Intelligent Integration With the Electric Grid

It is critical to characterize and quantify the charging profiles of high-power charging systems to intelligently integrate them within the grid and among collocated loads and sources. Conducting characterization tests can improve control performance of high-power charging systems and vehicles due to variations in performance from abnormal conditions (e.g., grid voltage, frequency, temperature). In partnership with ANL, INL, and ORNL, NREL researchers collected 24 EV high-power charge profiles from a Hyundai Ioniq 5, Ford F150 Lightning Pro, and Ford eTransit and completed 16 nominal temperature (23°C) characterization tests. The recent work performed and data collected will provide critical inputs to several ongoing efforts, including modeling electrified transportation systems, battery designs, standardization best practices, and grid energy management systems, especially for nominal temperature charging performance scenarios. Next, the team will complete

HIGH-POWER CHARGING

The transition to a nationwide fleet of electric vehicles will require smart-charge-control strategies that enable multiple vehicles to charge at the same time without overloading the grid. Initially as part of the 1+ MW project and continuing into the EVs@Scale Laboratory Consortium High-Power Charging Pillar, NREL is exploring crosscutting factors influencing the effective design and optimization of such a system, including site-integrated charging for improved operations and equipment costs, high-power conversion equipment, and the grid impacts of a multiport, publicly accessible charging station. The successful implementation of this system will depend on reliable integration between the renewable energy grid, all-electric vehicle classes, and buildings such as charging stations.



one nominal temperature pre-driven test and 10 hot temperature soak and pre-driven tests once weather conditions are conducive to testing. Additionally, the team anticipates taking delivery of a Hummer EV and commencing EV supply equipment characterization testing at DC current levels up to 500 A.

Analysis of Combined Public Data Sets and Travel Behaviors Informs Potential Future Charging Demands for EVs at Scale

Understanding the energy and power demands of EVs is key to the electrification of the transportation sector. Planning for these EV charging demands will require an understanding of the energy and charging power needed to satisfy varying transportation behaviors and corresponding dwell periods. To investigate the transportation needs of drivers in Virginia, the EVs@Scale Lab Consortium team acquired data from Wejo for more than 25 million origin-destination pair trips from September 2021 through February 2022. In conjunction with public data sets such as vehicle registrations, real estate, land use, and census data, these trips were processed using NREL's EVI-Pro tool to develop 30 million daily travel itineraries. These travel itineraries identify energy needs and charging opportunities by outlining daily distances traveled, driving times, and dwell periods. Combining these real-world itineraries with Transportation Energy & Mobility Pathway Options (TEMPO) adoption models provides insight on the future of EV charging loads. Understanding these energy and power requirements in space and time are critical to determine how charging will coincide with current loads on the grid and the potential impacts. The next steps for this effort are to process grid models that will be shared by partners at Dominion Energy and perform assessments of the grid impacts of EV charging as it may occur in real-word scenarios and if smart charge management controls were to be implemented.

Decarbonization of Off-Road, Rail, Marine, and Aviation Technologies

HEAVY-DUTY R&D

Exascale Computational Fluid Dynamics Simulations Reveal Fuel Property Impacts on Aircraft Engine Combustor Performance

NREL is using the Pele suite of computer codes developed by the Exascale Computing Project in simulations to reveal fuel chemistry and property effects on aviation turbine performance. NREL simulated the effects of 100% SAF on fuel evaporation in two aircraft engine combustors, including NASA's seven-element lean direct injection burner and the Federal Aviation Administration-funded General Electric (GE) Aerospace and Georgia Institute of Technology (Georgia Tech) lean premixed pre-vaporized combustor. NREL is actively collaborating with Georgia Tech's experimental facility, incorporating the NASA lean direct injection burner to validate the modeling results, as well as with GE Aerospace to validate simulations of their proprietary combustor design. Initial simulations targeted the impact of fuel properties on combustor performance characteristics, leading to key takeaways, including how lower liquid fuel viscosity leads to smaller spray droplets and quicker subsequent evaporation within the combustor. Discoveries made in these computational fluid dynamics simulations will accelerate 100% SAF introduction by reducing the inherent risk in the SAF qualification process and may lead to the acceptance of a wider range of properties. Next, NREL will incorporate surrogate chemical kinetics models into the simulations and validations by comparing them with data from highly instrumental combustion experiments.

Measurement of Thermophysical Properties of SAF To Support High-Fidelity Simulations

NREL is using exascale computational fluid dynamics simulations to accelerate 100% SAF introduction by revealing fuel chemistry and property effects on aviation turbine performance. Simulation of fuel property impacts requires accurate data on fuel properties over a wide range of temperatures and pressures. Throughout FY 2023, NREL worked to establish a first-of-its kind capability to take measurements for density, bulk modulus, viscosity, surface tension, and pressure enthalpy diagram at up to 68 atm and –40°C–400°C to support goals for 100% SAF introduction. These experimental measurements are helping to evaluate conventional jet fuels, SAF, surrogate mixtures, and pure compounds, developing new thermophysical property data to inform new fuel property prediction models and serve as inputs to combustion simulations. These high-fidelity combustion simulations will reduce the time and cost risks inherent in the SAF qualification process and potentially lead to the acceptance of a wider range of properties. In the coming year, NREL will acquire extensive data on properties from a range of fuel samples, and researchers will utilize these data as key model inputs.

Open-Source Software Charts a Path to Freight Rail Decarbonization

To meet national decarbonization goals, the United States must address all segments of the transportation system, including the rail industry. However, there has never been a thorough analysis of pathways for freight rail, nor has there existed a comprehensive, open-source software platform with the necessary modeling capabilities for deep exploration of freight rail decarbonatization. Through the ARPA-E ALTRIOS project, NREL researchers developed and deployed this novel software in partnership with BNSF Railway, Southwest Research Institute, the University of Illinois Urbana-Champaign, and the University of Texas at Austin. ALTRIOS will enable gradual, model-guided rollout of freight rail decarbonization technologies. Because existing freight rail technologies produce only a third of the greenhouse gas emissions per ton-mile compared to long-haul trucking, shifting freight movement to battery-electric rail fleets can have an outsized impact on the transportation sector's emissions as a whole. Having released ALTRIOS as an open-source software tool, the team will now apply it in numerous follow-on projects, beginning with an ARPA-E-funded project supporting Parallel Systems in estimating the energy and emissions impacts of their battery-electric, autonomous "bogey" rail cars.

Materials Technology

LIGHTWEIGHT MATERIALS

Multiple End-Of-Life Options for Bio-Derivable Materials Enables Enhanced Circularity

The promise of making today's vehicles lighter and more efficient using carbon-fiber-reinforced composites (CFRCs) is attractive, especially as more vehicles are electrified. Despite the benefits of CFRCs, their production is expensive and produces significant greenhouse gas emissions. These disadvantages are amplified by the inability to reuse CFRCs. Researchers at NREL have redesigned the resins used in CFRCs and demonstrated multiple recycling techniques to enable their reuse, making the material a good alternative to steel. In chemical recycling, the resin is stripped away from the CFRC using methanol and a catalyst to yield pristine carbon fibers. In thermal molding, the entire CFRC is left intact and reshaped into a different part. Both recycling processes are enabled by the polyester covalently adaptable network and do not decrease mechanical performance. NREL analysis demonstrates that the cost and emissions of the material's second life can be reduced by more than 90% compared to its first life. This concludes NREL's first 3 years of work on recyclable-by-design composites. In a future project, NREL will examine implanting these resins and CFRCs in actual parts while also improving their ductility and cycle time for manufacture, ideally priming these materials for a transition to market.

Technology Integration

OUTREACH, TRAINING, PARTNERSHIPS, AND COORDINATOR SUPPORT

Clean Cities Outreach Materials Depict Tangible Examples of Real-World Impacts

In celebration of the Clean Cities 30th anniversary, NREL created new engaging outreach materials to provide visual, tangible examples of how coalitions act locally to generate national impact and the real-world benefits to people's lives. One of these products is a new infographic that visually illustrates the work of Clean Cities coalitions and features a diverse representation of people, including race, gender, age, size, and abilities. This infographic can be used in its entirety, or the individual scenes can be used separately to maximize usability. NREL also developed an online, interactive story map to elevate stories of coalition-led, community-based transportation deployment projects from across the country that are helping move transportation systems into the clean energy future. To disseminate these materials, NREL executed coordinated promotional campaigns that leveraged the local networks of coalitions to reach a broader audience than NREL or DOE could achieve alone. NREL provided coalitions with newsletter and social media content to share with their audiences of more than 20,000 stakeholders across the country. Materials developed for the 30th anniversary will continue to be used in Clean Cities education and outreach materials, and the story map will be updated annually with new projects from coalitions.

DATA AND SYSTEMS RESEARCH

Alternative Fuels Data Center Remains Cutting Edge with Resources on New Commercial Fuels

Through long-standing partnerships with transportation industry stakeholders, NREL ensures the Alternative Fuels Data Center (AFDC) maintains its reputation as a leading source of unbiased information to advance affordable, domestic transportation fuels, energy-efficient mobility systems, and other fuel-saving technologies and practices. Remaining at the forefront involves strategizing the right time to publish expanded information, data, and tools about emerging fuels that are transitioning to more widespread commercial use. In FY 2023, NREL built out resources for three fuels on the AFDC—renewable diesel, SAF, and renewable propane—so fleet managers and transportation stakeholders can make more informed decisions about switching to renewable fuels and reducing greenhouse gas emissions. For renewable diesel, NREL integrated the fuel into tools throughout the site, including the Station Locator, laws and incentives search, fuel prices, maps and data, case studies, and publications. These changes reflect NREL's strong government-industry partnerships in the transportation sector that help ensure the AFDC generates ongoing value as the market evolves, as well as NREL's subject matter expertise that is crucial for providing fuel-neutral information and tools that enable data-driven decision-making to support a clean energy future.

Alternative Fueling Station Locator Boosts Experience for Mobile Users

With more than 60% of people accessing the Alternative Fueling Station Locator on mobile devices, providing a mobile-friendly user experience is essential to ensure people can find alternative fueling stations on the go and access key information like available charging connectors, access hours, and station contact information. In FY 2022, the Station Locator main page was the most visited page on DOE's Office of Energy Efficiency and Renewable Energy website, with 8 million page views and 35 million web service/API hits. Recognizing that an increasing number of users are accessing the tool on mobile devices, in FY 2023, NREL overhauled the Station Locator to provide a new user interface optimized for these users, allowing a smoother, more convenient navigation of the map and search features for anyone using the tool on mobile devices. These enhancements expand use of the Station Locator as a trusted resource for finding alternative fueling stations and increase opportunities for users to engage with the tool on smaller screens. Improving the mobile experience was a frequent request from Clean Cities coalitions, and this update to the website version of the tool on the AFDC was an important step. In the future, NREL will update the iPhone and Android apps to further enhance the user experience.

AFDC Expands Audience and Impact of Laws and Incentives Data

In response to requests from a number of organizations, including the National Conference of State Legislatures (NCSL) and Clean Cities coalitions, NREL developed a new search tool for laws and incentives on the AFDC. This new tool provides a widget that enables entities to easily embed the laws and incentives data on their own websites without needing to maintain content or have software development expertise. This new approach increases the utility of the AFDC laws and incentives data while expanding its reach by making the data set more accessible for organizations in the transportation sector to share the information with their audiences. Previously, NCSL manually downloaded the data from the AFDC, applied filters in the data set, and posted information relevant to their stakeholders on their website. With the new widget, NCSL can now filter the data directly in the tool on the AFDC and embed the results on their website, which will automatically display new data and updates. To further expand the impact of the laws and incentives data, NREL also developed a new map of states that have adopted California's standards to help people visualize the nation's progress toward ZEVs, low-emission vehicles, and advanced clean trucks. Going forward, NREL plans to create a snapshot of laws and incentives for EVs to contextualize the changing market for EVs and charging infrastructure.

AFDC Leads the Charge in Resources for EV Infrastructure

The resources NREL develops and publishes on the AFDC are more important than ever as the United States builds a national network for EV charging. With tools like the Station Locator on the AFDC, NREL is uniquely positioned to provide crucial data sets, information, and tools for key audiences leading the future of transportation, including the Joint Office of Energy and Transportation, Clean Cities coalitions, fleet managers, transportation planners, fuel providers, and utilities. In FY 2023, NREL integrated four charging networks into the Station Locator to pull data directly from their Open Charge Point Interface (OCPI) application programming interfaces (APIs) daily, including Blink, EV Connect, FLASH, and Volta. NREL also started OCPI API connections for EVGateway, EV Range, Noodoe, and ZEF Energy, and added stations from 17 charging networks without APIs, including 7Charge, ChargeNet, ChargeUp, Chargie, CircleK Charge, EnviroSpark, EV Range, EVmatch, Evoke Systems, Graviti Energy, HoneyBadger Charging, Jule, Loop, Noodoe, Red E Charging, Revel, and WAVE. NREL's efforts to capture stations from all EV charging networks as they develop makes the AFDC a go-to resource for people who need a comprehensive, reliable data set on the current landscape for EV charging. In the future, NREL will expand the Station Locator data to include information about the power output for EV chargers.

Automated Mobility District Design and Analysis Incorporates Full Vehicle Automation and Curb-Front Operations

As the nation and world evolves to automated forms of transportation, automated mobility district (AMD) adoption can grow to meet the mobility needs of the majority of residents and workers in such places. The AMD term refers to high-density areas such as central business districts and business and academic campuses that require comprehensive solutions to connect people with area amenities. Research in 2023 builds on two marquee publications: the first edition and second edition of the AMD Implementation Catalog, which document the experiences of 10 automated shuttle deployment sites and provide related guidance and lessons learned. This year, new and expanded efforts have focused on operating such shuttle fleets under full automation as well as curb-front operations enabling efficient passenger pickup and drop-off. Researchers shared results, insights, and guidance via multiple conference papers and panel discussions and are planning a six-part lecture series. Looking ahead, NREL will continue its work with public mobility providers to help design responsive systems that are time efficient, energy efficient, and equitable to all users. The focus of one such initiative is Houston's 3rd Ward, a historically disadvantaged community. Houston Metro has already implemented on-demand public transit in several communities and foresees using automated vehicles to provide core services connecting patrons to inter-regional bus and rail via smart phone apps (in essence, an AMD).

ALTERNATIVE FUELS REGULATORY PROGRAM

EPAct Annual Reports Submitted and Efficiently Approved, Ensuring Manageable Burden for Covered Fleets

All EPAct Program fleet Alternative Fuel Transportation Program Model Year (MY) 2022 annual reports due to DOE were submitted, processed, reviewed, and approved efficiently, and all fleets are in compliance for MY22 due to continued upfront communication with reporting fleets and more seamless interaction among team members. An unusually high number of covered fleet contacts new to the annual compliance effort caused lags in the review process, but NREL's significant outreach and compliance assistance, as well as continued deployment of improved web tools for both covered fleets and administration of the database helped work through these setbacks. All reports, delinquent reporting fleets, and fleets seeking exemptions have been addressed to completion, resulting in a net savings of resources for the EPAct Program and DOE. In addition to maintaining the database and required backup information for EPAct, NREL will continue to implement a recently developed web tool that will add improved user and administrator functionality to the Alternative Compliance tools for fleets.

Analysis

DATA

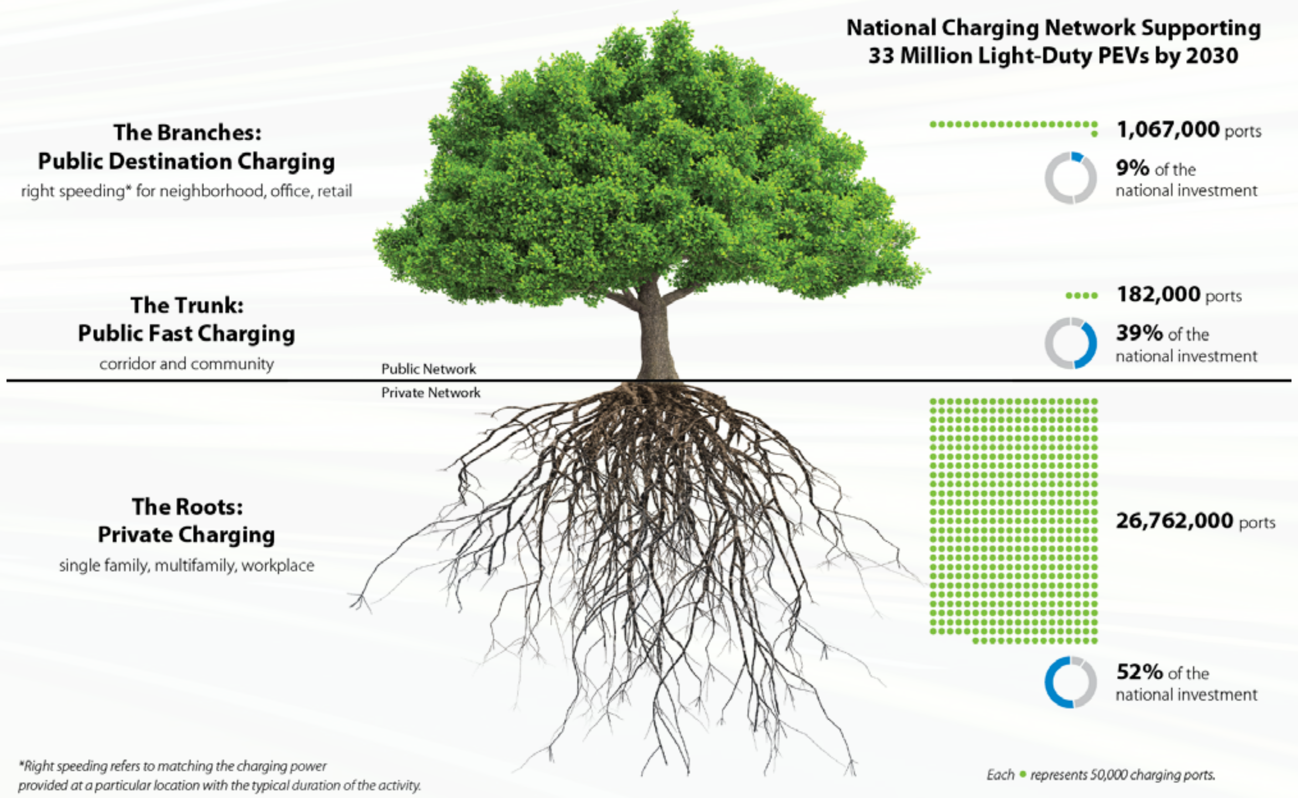
New Commercial Vehicle Data Portal Aggregates Insights To Address Largest Contributors to Transportation Sector's Carbon Emissions

Commercial vehicles are some of the transportation sector's most significant greenhouse gas contributors, but addressing their emissions is challenging. Manufacturers and operators are highly sensitive to the cost of zero-emissions alternatives, and advanced analytics on their efficacy are lacking. To address this need, NREL has made the Fleet Research, Energy Data, and Insights (FleetREDI) web portal available to the research community and commercial vehicle industry stakeholders. The new website fills a critical need for data and analysis using real-world data on commercial vehicle operations by providing stakeholders with access to anonymized data and data products. Using NREL's Fleet DNA database, geospatial data, and other data sources, FleetREDI is continuously updated through strategic data collection, third-party data contributions, and novel analyses that address key knowledge gaps and turn data insights into intelligence. Looking forward, the team will build on the initial public web release by developing a secure, access-controlled environment to enable project partners to view and download their own contributed data after it has been cleansed, augmented, and analyzed by the FleetREDI team.

NREL ANALYSIS SUPPORTS U.S. ADMINISTRATION'S CLEAN ENERGY GOALS

NREL researchers have released *The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure*, a quantitative needs assessment for a national charging network capable of supporting the U.S. transition to EVs.

The study was created in collaboration with the Joint Office and VTO. In turn, it will support the Joint Office's work to deploy a network of EV chargers, zero-emission fueling infrastructure, and zero-emission transit and school buses nationwide. As the Joint Office works with all 50 states, Washington, D.C., and Puerto Rico to develop state- and community-level plans for EV charging infrastructure, the study's findings will fuel the office's vision of building a future where "everyone can ride and drive electric."



The 2030 National Charging Network report's research team created a new conceptual model to guide planning for a national EV charging network, captured in the infographic above.

MODELING

Seminal Study Quantifies Infrastructure Needs for Convenient, Reliable, and Affordable EV Charging for All Americans

With ambitious federal clean energy policies, pledges by automotive companies to transition to ZEVs, and accelerating consumer demand for EVs, analysts have projected that by 2030, EVs could account for 30–42 million light-duty vehicles on the road. The 2030 National Charging Network study leverages NREL's cutting-edge analytical tools and advanced computing capabilities to account for the many ways Americans travel by car: commuting, running errands, taking road trips, hailing rides, and more. With a never-before-seen level of detail, the study estimates that a national network of 26.8 million private charging ports and 1.2 million public charging ports (including 182,000 DC chargers and 1 million Level 2 chargers) are necessary to support the Joint Office's vision of a future where everyone can ride and drive electric. While continued investments in U.S. charging infrastructure are necessary, existing announcements put the United States on a path to achieving federal clean energy goals. NREL's analysis is currently being expanded in collaboration with Lawrence Berkeley National Laboratory to account for charging demands from medium- and heavy-duty vehicles.

Transportation Forecasting Model Enhancements Improve Scope and Robustness of Forward-Looking Scenarios

Forward-looking national scope models—such as NREL's TEMPO model—are essential to account for current polices like the Inflation Reduction Act (IRA) and understand the role of both technology-driven and non-technology-driven decarbonization pathways, including travel demand management (TDM) strategies, to support U.S. transportation decarbonization. NREL conducted preliminary system-level modeling of TDM strategies, confirming TEMPO's ability to represent changing urbanization trends affecting travel demand (e.g., vehicle miles traveled) and emissions. In addition, an initial implementation of transportation-related IRA tax credits has been completed and reviewed with modeling and industry experts in the TEMPO Steering Committee. These modeling improvements are critical to understanding the national-level impacts of TDM strategies and IRA provisions, allowing TEMPO to better inform transportation decarbonization analyses and decision-making at the national level. Next steps include (1) refining IRA-related assumptions to better reflect supply-side constraints, (2) modeling in TEMPO to confirm representation of transit TDM strategies (e.g., transit-oriented development), (3) aligning urbanization and transit TDM strategies with observed trends in literature, (4) continuing model enhancement to support teleworking TDM analyses, and (5) improving representation of real-world constraints with trip-level decisions (e.g., further enhancing TEMPO's representation of EV use and adoption).

Smart Mobility Systems

COMPUTATIONAL MODELING AND SIMULATION

Mobility Energy Productivity Tool Incorporates Level of Traffic Stress To Aid Transportation System Investment Planning for Equitable Non-Motorized Travel

City, regional, and state policymakers often face the challenging task of planning for equitable infrastructure investments that minimize the level of traffic stress (LTS). The LTS approach characterizes the discomfort that people experience when they walk or bike close to vehicular traffic. To aid in decision-making, the Mobility Energy Productivity (MEP) tool team incorporated a widely recognized LTS framework into MEP and leveraged open data sources through OpenStreetMap to develop a scalable approach for evaluating the impact of infrastructure characteristics on MEP scores for non-motorized travel. MEP analysis of the Denver metro region's transportation system with the new LTS and infrastructure data indicates up to a 35% drop in efficient access for e-bikes. This signifies that traditional access calculations (that do not consider LTS) provide an "inflated" view of the level of access offered by micromobility. Results of several LTS scenario analyses revealed that allowing micromobility access on sidewalks was less impactful than implementing traffic-calming measures and increasing bicycle lane coverage. This research can help transportation planners and stakeholders identify and prioritize transportation network enhancements that enable greater micromobility and non-motorized travel. The next steps for this project are to identify additional infrastructure attributes (e.g., the presence of traffic lights) to robustly define and fine-tune MEP's LTS component. The team also plans to perform sensitivity analyses on speed penalty assumptions made for various LTS levels and extend the analysis to other cities to demonstrate the scalability of the approach.

Analysis of State-Level E-Bike Program Informs Development of Similar Programs

In the United States, privately owned e-bikes are sold in greater numbers than light-duty EVs. While e-bikes are poised to continue to grow in popularity as several state-level e-bike incentive programs come online, their energy impact is poorly quantified. Shared e-bike systems have previously been studied, as certain types of data are automatically generated through the operation of such systems. A first-of-its-kind private-ownership e-bike program in Colorado (with partners Colorado Energy Office and Bicycle Colorado)—in which NREL OpenPATH collected data from participants—revealed differences in the use of private e-bikes and a strong capacity to replace car use, with 34% of e-bike trips replacing car trips and averaging 2.3 kWh of energy savings per trip. Colorado was first to implement city-level (Denver) and state-level e-bike incentive programs, and several other locations, including in California, New York, Washington, Ohio, and Massachusetts, are currently or will soon be offering e-bike incentives. Considering this as well as the proposed national-scale e-bike rebate, evaluating potential e-bike energy impacts within the transportation system is crucial. NREL OpenPATH-informed MEP calculations show that 10% of the Denver metro population resides in locations where energy-efficient access to opportunities using e-bikes is comparable to the access efficiency realized through driving. Looking ahead, NREL will continue to coordinate with several city- and state-level e-bike programs across the nation to collect private-ownership e-bike data to further inform the energy and emissions outcomes picture, while also exploring the behavioral and equity impacts of e-bike incentives.

New Capabilities for Users and Federated Data Bring Increased Engagement to the Livewire Data Platform

The Livewire Data Platform saw an increase in the number of site user accounts, site visits, and page views in FY 2023 due to enhancement of the user interface and addition of relevant data to the platform. The initial mechanism for the federation of datasets from the Federal Highway Administration's data.transportation.gov (DTG) is in place, and selected DTG datasets are now accessible within the Livewire catalog. Livewire now also provides an application programming interface (API) that exposes selected Livewire datasets, which are available for federation to external catalogs such as DTG, further expanding datasets listed within each catalog and broadening the exposure of DOE's research projects, resulting data, and publications. The NREL Livewire team and partners INL and Pacific Northwest National Laboratory also updated the site's user interface to display additional data attributes and user-provided reference documents. NREL will continue to grow Livewire's catalog of energy efficiency and mobility data and expand upon the features that make sharing and discovering data easier for users.

RouteE-Powertrain Energy Prediction Refined Using More Real-World Driving Data

Large quantities of on-road training data are required for accurately predicting vehicle energy consumption at road network link-level resolution for driving that has not yet occurred or has minimal available data for characteristics like vehicle position and speed. The original RouteE-Powertrain training data for light-duty vehicles were from the Transportation Secure Data Center and consisted of about 200,000 real-world drive cycles. This was expanded to include drive cycles from a commercial data set from Wejo that included 250 million real-world drive cycles from California and New York and 25 million from across the United States. This expanded training data enables more sophisticated machine-learning techniques (e.g., neural networks) to improve the accuracy and robustness of the RouteE-Powertrain model. Vehicle and driver behavior are highly variable; therefore, it is critical to have large data sets to describe real-world behavior across the full spectrum of driving conditions. Further refinement of the prediction methods and accuracy using more complex machine-learning methods, such as Bayesian neural network, will be explored now that sufficient training data are available and the baseline predictive models have improved.

Machine-Learning Model Enables Traffic State Estimation for Traffic Control Development

Traffic state estimation is a precursor to the development of traffic controls. However, historical methods of traffic state observation are expensive and have limited upstream visibility. The culminating paper in this project proposes using real-time probe vehicle data with machine learning to estimate lane density upstream signalized corridors for scalable and accurate traffic state estimation to be used in connected corridors for optimized signal control. The model calculates traffic state estimation based on streaming probe data. Real-time state estimates informed traffic signal control for 39 intersections in Chattanooga, Tennessee, and results show that this state estimation model can inform optimal control decisions. With the ability to expand on this research, research would include longer real-time experiments to confirm the model's capabilities for signal control applications and explore extensions of this model, including an online learning model that continuously trains itself based on new data seen after deployment.

SUCCESS METRICS

Patents & Records of Invention

Records of Invention

- Removing Deadweight: Ultra-thin Current Collectors for Lithium-ion Batteries
- Charge Control Box (CCB)
- Hybrid Reinforced and Recyclable Composites for Enhanced Ductility
- Polyester Covalently Adaptable Networks with Amines for Enhanced Recyclability and Cure
- Pultrusion Of Polyester Covalently Adaptable Networks for Faster Cures Than Epoxy Amines
- Heatsink Design with Variable Effective Heat Transfer Coefficient
- Double-Sided Cooling with Counter-Flowing Coolant
- Dual Motor Planetary Gearset Architecture for Fuel Cell Air-Side Plant
- AI-Powered Battery Anomaly Detection for Safer Electric Vehicles

Patent Provisional Applications

- Casing for Pouch Cell Batteries
- Ultra-Thin Current Collectors for Lithium-Ion Batteries

Patent Applications

- Mechanical Pulverization of Cobalt-Free Nickel-Rich Cathodes

Patent Awards

- Evaporator Stacks and Electronic Assemblies
- Stabilized Electrodes for Ion Batteries and Methods of Making the Same
- Cathode Recycling of End-Of-Life Lithium Batteries
- Methods for Cathode Recycling of End-Of-Life Lithium Batteries
- Jet Impingement Manifolds for Cooling Power Electronics Modules
- Heat Flux Micro Coolers Having Multi-Stepped Features and Fluid Wicking

Publications & Communications

Vehicle Technologies Publication Metrics

Publication Type	Q1	Q2	Q3	Q4	Total
Journal Articles	27	20	17	13	**77**
Technical Reports, Conference Papers, Book Chapters, and Subcontractor Reports	23	12	16	10	**61**
Patents	1	2	0	3	**6**
Presentations and Posters	33	27	24	28	**112**
Brochures, Fact Sheets, and Other Outreach Materials	6	3	4	5	**18**
Management Reports	5	0	0	0	**5**
Total Publications	**95**	**64**	**61**	**59**	**279**

Publications

Brochures

1. 2022. *Co-Optimization of Fuels & Engines Findings & Impact (Citation Only)*.
2. 2022. *The Road Ahead: Toward a Net-Zero-Carbon Transportation Future (Citation Only)*.
3. 2022. *Transforming Energy Through Sustainable Mobility: Expanding Low-Carbon Transportation R&D Solutions*. https://www.nrel.gov/docs/fy23osti/84377.pdf

Conference Papers

4. Appukuttan, Sreejith Nadakkal; Perry, Bruce; Yellapantula, Shashank; Esclapez, Lucas; Sitaraman, Hariswaran; Day, Marc. 2023. "Simulations of Fuel-Air Mixing in a 7 Element Lean Direct Injection (LDI) Aviation Combustor: Preprint." Presented at the 13th U.S. National Combustion Meeting, 19–22 March 2023, College Station, TX. https://www.nrel.gov/docs/fy23osti/85119.pdf
5. Badheka, Aaditya; Eagon, Matthew John; Fakhimi, Setayesh; Wiringa, Peter; Miller, Eric; Kotz, Andrew; Northrop, William. 2023. "Development of a Heavy-Duty Electric Vehicle Integration and Implementation (HEVII) Tool." Presented at WCX SAE World Congress Experience, 11 April 2023. https://doi.org/10.4271/2023-01-0708
6. Baker, Chad Allan; Moniot, Matthew; Borlaug, Brennan; Lustbader, Jason; Akhtar, Saad; Jehlik, Forrest; Agnew, Scott; Lee, Jason; Lee, Insu; Ha, Jinho. 2023. "Assessing the National Off-Cycle Benefits of 2-Layer HVAC Technology Using Dynamometer Testing and a National Simulation Framework." Presented at WCX SAE World Congress Experience, 11 April 2023. https://doi.org/10.4271/2023-01-0942
7. Basnet, Prasant; Fang, Xin; Panossian, Nadia. 2023. "Impact of Transportation Electrification on the System's Dynamic Frequency Response: Preprint." Presented at the 2023 IEEE Kansas Power and Energy Conference (KPEC), 27–28 April 2023, Manhattan, KS. https://www.nrel.gov/docs/fy23osti/85990.pdf
8. Borlaug, Brennan; Alexander, Marcus; Muratori, Matteo. 2023. "Charging Needs for Battery Electric Semi Trucks." Presented at the 36th International Electric Vehicle Symposium and Exhibition (EVS36), 11–14 June 2023, Sacramento, CA. http://evs36.com/wp-content/uploads/finalpapers/FinalPaper_Borlaug_Brennan.pdf
9. Cebol Sundarrajan, Manoj Kumar; Bennett, Jesse; Scoffield, Don; Chaudhari, Kalpesh; Meintz, Andrew; Pennington, Timothy; Zhang, Bo. 2023. "Performance and Implementation Requirements for Residential EV Smart Charge Management Strategies." Presented at the 2023 IEEE Transportation Electrification Conference & Expo (ITEC), 21–23 June 2023, Detroit, MI. https://dx.doi.org/10.1109/ITEC55900.2023.10186998
10. Chowdhury, Anik; Siddiquee, Ashraf; Mishra, Partha; Haque, Md. Ehsanul; Kisacikoglu, Mithat J.; Thurlbeck, Alastair; Watt, Edward; Rahman, Mohammad Arifur; Sozer, Yilmaz; Holt, Jeff. 2023. "Design of a Multi-Chemistry Battery Pack System for Behind-the-Meter Storage Applications." Presented at the 2023 IEEE Applied Power Electronics Conference and Exposition (APEC), 19–23 March 2023, Orlando, FL. https://dx.doi.org/10.1109/APEC43580.2023.10131167
11. Chowdhury, T.; Koushan, S.; Al-Qarni, A.; El-Refaie, A.; Bennion, Kevin; Cousineau, Emily; Feng, Xuhui; Kekelia, Bidzina. 2022. "Thermal Management System for an Electric Machine with Additively Manufactured Hollow Conductors with Integrated Heat Pipes." Presented at 2022 International Conference on Electrical Machines (ICEM), 5–8 Sept. 2022, Valencia, Spain. https://dx.doi.org/10.1109/ICEM51905.2022.9910918
12. Chowdhury, Towhid; Koushan, Salar; Al-Qarni, Ali; El-Refaie, A.; Bennion, Kevin; Cousineau, Emily; Feng, Xuhui; Kekelia, Bidzina. 2022. "Thermal Management System for an Electric Machine with Additively Manufactured Hollow Conductors with Integrated Heat Pipes: Preprint." https://www.nrel.gov/docs/fy23osti/82597.pdf
13. Collath, Nils; Gasper, Paul; Jossen, Andreas; Smith, Kandler; Hesse, Holger. 2022. "The Economic Impact of Battery Degradation Modelling Uncertainty." Presented at the 2022 IEEE Power & Energy Society General Meeting, 17–21 July 2022, Denver, CO. https://doi.org/10.1109/PESGM48719.2022.9916844
14. Franz, M. L.; Young, Stanley; Cappellucci, Jeffrey; Xiong, C.; Holden, Jake; Zhou, W. 2022. "Quantifying the Impact of Transportation on Climate - Energy Analytics Dashboard: Preprint." https://www.nrel.gov/docs/fy23osti/83634.pdf
15. Haque, Tohfa; Hanif, Abu; Khan, Faisal. 2022. "Optimizing Sensor Count and Placement to Detect Bond Wire Lift-Offs and Surface Defects in High-Power IGBT Modules Using Low-Cost Piezo-Electric Resonators." Presented at the 2022 IEEE Energy Conversion Congress and Exposition (ECCE), 9–13 Oct. 2022, Detroit, MI. https://dx.doi.org/10.1109/ECCE50734.2022.9947859
16. Khan, Faisal; Islam, Sarwar; Major, Joshua; Usman, Adil; Moreno, Gilbert; Narumanchi, Sreekant. 2023. "A Smart Silicon Carbide Power Module With Pulse Width Modulation Over Wi-Fi and Wireless Power Transfer-Enabled Gate Driver, Featuring Onboard State of Health Estimator and High-Voltage Scaling Capabilities." Presented at the 2023 IEEE Applied Power Electronics Conference and Exposition (APEC), 19–23 March 2023, Orlando, FL. https://dx.doi.org/10.1109/APEC43580.2023.10131317
17. Khan, Faisal; Islam, Sarwar; Major, Joshua; Usman, Adil; Moreno, Gilbert; Narumanchi, Sreekant. 2023. "A Smart Silicon Carbide Power Module With Pulse Width Modulation Over Wi-Fi and Wireless Power Transfer-Enabled Gate Driver, Featuring Onboard State of Health Estimator and High-Voltage Scaling Capabilities: Preprint." Presented at the 2023 IEEE Applied Power Electronics Conference (APEC), 19–23 March 2023, Orlando, FL. https://www.nrel.gov/docs/fy23osti/83691.pdf

18. Kim, Yeonjoon; Cho, Jaeyoung; Naser, Nimal; Kumar, Sabari; Jeong, Keunhong; McCormick, Robert L.; St. John, Peter C.; Kim, Seonah. 2022. "Physics-Informed Graph Neural Networks for Predicting Cetane Number with Systematic Data Quality Analysis (Citation Only)."

19. Lott, J. Sam; Young, Stanley E. 2023. "Automated Electric Vehicle Fleet Operations for On-Demand Service: Challenges and Opportunities." Presented at the International Conference on Transportation and Development 2023, 14–17 June 2023, Austin, TX. *https://dx.doi.org/10.1061/9780784484883.048*

20. Moreno, Gilberto; Major, Joshua; DeVoto, Douglas; Khan, Faisal; Narumanchi, Sreekant; Feng, Xuhui; Paret, Paul. 2022. "Thermal Optimization of a Silicon Carbide, Half-Bridge Power Module." Presented at the ASME 2022 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, 25–27 Oct. 2022, Garden Grove, CA. *https://dx.doi.org/10.1115/IPACK2022-97283*

21. O'Meally, Franz; Holden, Jacob; Gilleran, Madeline. 2023. "Vehicle Powertrain Simulation Accuracy for Various Drive Cycle Frequencies and Upsampling Techniques." Presented at WCX SAE World Congress Experience, 11 April 2023. *https://doi.org/10.4271/2023-01-0345*

22. Paret, Paul; Glaws, Andrew; Moreno, Gilberto; Major, Joshua; Khan, Faisal; Narumanchi, Sreekant. 2023. "Automated Design-for-Reliability of a Power Electronics Module." Presented at the 2023 22nd IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 30 May–2 June 2023, Orlando, FL. *https://dx.doi.org/10.1109/ITherm55368.2023.10177598*

23. Park, Jiho; Liu, Tong; Wang, Chieh; Berres, Andy; Severino, Joseph; Ugirumurera, Juliette; Kohls, Airton G.; Wang, Hong; Sanyal, Jibonananda; Jiang, Zhong-Ping. 2022. "Adaptive Urban Traffic Signal Control for Multiple Intersections: An LQR Approach." Presented at the 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), 8–12 Oct. 2022, Macau, China. *https://doi.org/10.1109/ITSC55140.2022.9922033*

24. Paudyal, Priti; Jain, Rishabh; Moniot, Matthew; Thibeault, Andrew. 2023. "A Framework to Evaluate the Grid Impacts of EV Fleet Charging Solutions." Presented at the 2022 North American Power Symposium (NAPS), 9–11 Oct. 2022, Salt Lake City, UT. *https://dx.doi.org/10.1109/NAPS56150.2022.10012170*

25. Perry, Bruce A.; Eiden, Kiran; Henry de Frahan, Marc T.; Yellapantula, Shashank; Esclapez, Lucas; Mueller, Michael E.; Day, Marc S. 2023. "Simulation of a Jet Flame with Inhomogeneous Inlets Using Tabulated and Neural Network Manifold Models (Citation Only)."

26. Rallabandi, Vandana; Chowdhury, Shajjad; Barua, Himel; Paranthaman, M. Parans; Mohammad, Mostak; Bullock, Steve; Cousineau, Emily. 2023. "Traction Motor Design Trade-Offs with Additively Manufactured Anisotropic Bonded Magnets." Presented at the 2023 IEEE Transportation Electrification Conference & Expo (ITEC), 21–23 June 2023, Detroit, MI. *https://dx.doi.org/10.1109/ITEC55900.2023.10187005*

27. Sanabria, David E.; Appert, Randy; Pronko, Steven G. E.; Major, Joshua; DeVoto, Douglas; Heinselman, Karen; Lehr, Jane M.; Gonzalez, Nicolas; Ginley, David S. 2022. "Development of a 250 Degree C 15kV Supercascode Switch Using SiC JFET Technology." Presented at the 2022 IEEE 9th Workshop on Wide Bandgap Power Devices & Applications (WiPDA), 7–9 Nov. 2022, Redondo Beach, CA. *https://dx.doi.org/10.1109/WiPDA56483.2022.9955247*

28. Wang, Qichao; Severino, Joseph; Sorensen, Harry; Sanyal, Jibonananda; Ugirumurera, Juliette; Wang, Chieh (Ross); Berres, Andy; Jones, Wesley; Kohls, Airton; VenkataDurga, Rajesh Paleti Ravi. 2022. "Deploying a Model Predictive Traffic Signal Control Algorithm - A Field Deployment Experiment Case Study." Presented at the 25th IEEE International Conference on Intelligent Transportation Systems (IEEE ITSC 2022), 8–12 Oct. 2022, Macau, China. *https://doi.org/10.1109/ITSC55140.2022.9921839*

29. Wang, Qichao; Severino, Joseph; Sorensen, Harry; Sanyal, Jibonananda; Ugirumurera, Juliette; Wang, Chieh (Ross); Berres, Andy; Jones, Wesley; Kohls, Airton; VenkataDurga, Rajesh Paleti Ravi. 2022. "Deploying a Model Predictive Traffic Signal Control Algorithm - A Field Deployment Experiment Case Study: Preprint." *https://www.nrel.gov/docs/fy23osti/83322.pdf*

30. Wang, Qichao; Severino, Joseph; Ugirumurera, Juliette; Phillips, Caleb. 2022. "High-Fidelity Modeling of Curbside Driving Behavior in SUMO: Preprint." *https://www.nrel.gov/docs/fy23osti/80870.pdf*

31. Wimer, Nicholas T.; Esclapez, Lucas; Henry de Frahan, Marc; Rahimi, Mohammad; Hassanaly, Malik; Perry, Bruce; Rood, Jon; Yellapantula, Shashank; Sitaraman, Hariswaran; Martin, Michael; Doronina, Olga; Appukuttan, Sreejith Nadakkal; Rieth, Martin; Day, Marc. 2023. "Examination of a Methane/Diesel RCCI Engine Using Pele: Preprint." Presented at the 13th U.S. National Combustion Meeting, 19–22 March 2023, College Station, TX. *https://www.nrel.gov/docs/fy23osti/84700.pdf*

Fact Sheets

32. 2022. *Clean Cities Coalitions: Advancing Affordable, Domestic Transportation Fuels and Technologies Across the Country*. *https://www.nrel.gov/docs/fy23osti/84769.pdf*

33. 2022. *Evaluation of Lightweighting Cost Targets to Provide Affordable, Efficient, and Clean Advanced Light-Duty Vehicles*. *https://www.energy.gov/sites/default/files/2022-05/2021_U.S._DRIVE_Accomplishments_Report__1.pdf*

34. 2023. *At a Glance: Electric Vehicles*. *https://www.nrel.gov/docs/fy23osti/87123.pdf*

35. 2023. *Clean Cities Coalitions: Advancing Affordable, Domestic Transportation Fuels and Technologies Across the Country*. *https://www.nrel.gov/docs/fy23osti/85556.pdf*

36. 2023. *Clean Cities Coalitions: Advancing Affordable, Efficient, and Clean Transportation Fuels and Technologies*. *https://www.nrel.gov/docs/fy23osti/86043.pdf*

37. 2023. *Community Engagement Tips for EV Infrastructure Deployment*. *https://www.nrel.gov/docs/fy23osti/86681.pdf*

38. 2023. *Electric Vehicle Basics*. *https://www.nrel.gov/docs/fy23osti/87125.pdf*

39. 2023. *Electric Vehicles for Consumers*. *https://www.nrel.gov/docs/fy23osti/85246.pdf*

40. 2023. *Electrifying the U.S. Transportation System with the Joint Office*. *https://www.nrel.gov/docs/fy23osti/86420.pdf*

41. 2023. *State and Alternative Fuel Provider Fleets: Fleet Compliance Annual Report - Model Year 2021, Fiscal Year 2022*. *https://www.nrel.gov/docs/fy23osti/85247.pdf*

42. 2023. *The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure*. *https://www.nrel.gov/docs/fy23osti/85970.pdf*

43. 2023. *Un Vistazo a Los Vehiculos Electricos*. *https://www.nrel.gov/docs/fy23osti/87313.pdf*

Journal Articles

44. Bhatt, Arpit H.; Zhang, Yimin; Milbrandt, Anelia; Newes, Emily; Moriarty, Kristi; Klein, Bruno; Tao, Ling. "Evaluation of Performance Variables to Accelerate the Deployment of Sustainable Aviation Fuels at a Regional Scale." *Energy Conversion and Management* 275: 116441, 19 Nov. 2022. *https://dx.doi.org/10.1016/j.enconman.2022.116441*

45. Borlaug, Brennan; Moniot, Matthew; Birky, Alicia; Alexander, Marcus; Muratori, Matteo. "Charging Needs for Electric Semi-Trailer Trucks." *Renewable and Sustainable Energy Transition* 2: 100038, 12 Oct. 2022. *https://www.nrel.gov/docs/fy23osti/82100.pdf*

46. Borlaug, Brennan; Yang, Fan; Pritchard, Ewan; Wood, Eric; Gonder, Jeff. "Public Electric Vehicle Charging Station Utilization in the United States." *Transportation Research Part D: Transport and Environment* 114: 103564, 12 Dec. 2022. *https://doi.org/10.1016/j.trd.2022.103564*

47. Browning, Morgan; McFarland, James; Bistline, John; Boyd, Gale; Muratori, Matteo; Binstead, Matthew; Harris, Chioke; Mai, Trieu; Blanford, Geoff; Edmonds, Jae; Fawcett, Allen A.; Kaplan, Ozge; Weyant, John. 2023. "Net-Zero CO_2 by 2050 Scenarios for the United States in the Energy Modeling Forum 37 Study." *Energy and Climate Change* 4: 100104, 10 April 2023. *https://doi.org/10.1016/j.egycc.2023.100104*

48. Caballero, Luis C.; Thornburg, Nicholas E.; Nigra, Michael M. "Catalytic Ammonia Reforming: Alternative Routes to Net-Zero-Carbon Hydrogen and Fuel." *Chemical Science* 13: 12945–12956, 17 Oct. 2022. *https://www.nrel.gov/docs/fy23osti/81574.pdf*

49. Carlson, Nicholas A.; Singh, Avantika; Talmadge, Michael S.; Jiang, Yuan; Zaimes, George G.; Li, Shuyun; Hawkins, Troy R.; Sittler, Lauren; Brooker, Aaron; Gaspar, Daniel J.; McCormick, Robert L.; Ramirez-Corredores, M. M. 2022. "Economic Analysis of the Benefits to Petroleum Refiners for Low Carbon Boosted Spark Ignition Biofuels." *Fuel* 334 (1): 126183, 11 Nov. 2022. *https://doi.org/10.1016/j.fuel.2022.126183*

50. Chalise, Divya; Saxon, Aron; Zeng, Yuqiang; Srinivasan, Venkat; Lubner, Sean; Keyser, Matthew; Prasher, Ravi S. 2023. "Non-Invasive Accurate Time Resolved Inverse Battery Calorimetry." *Energy Storage Materials* 60: 102810, 17 May 2023. *https://doi.org/10.1016/j.ensm.2023.102810*

51. Cheng, A. S. 'Ed'; Ratcliff, Matthew A.; McCormick, Robert L. 2023. "Modeling Ethanol-Blend Fuel Sprays under Direct-Injection Spark-Ignition Engine Conditions." *Energy & Fuels* 37 (4): 3031–3047, 3 Feb. 2023. *https://doi.org/10.1021/acs.energyfuels.2c03108*

52. Cho, Jaeyoung; Luecke, Jon; Rahimi, Mohammad J.; Kim, Yeonjoon; Zigler, Bradley T.; Kim, Seonah. "Enhancing φ-sensitivity of ignition delay times through dilution of fuel-air mixture." *Proceedings of the Combustion Institute*, 14 Nov. 2022. *https://doi.org/10.1016/j.proci.2022.09.055*

53. Dede, Ercan M.; Zhang, Chi; Wu, Qianying; Seyedhassantehrani, Neda; Shattique, Muhammad; Roy, Souvik; Palko, James W.; Narumanchi, Sreekant; Kekelia, Bidzina; Hazra, Sougata; Goodson, Kenneth E.; Giglio, Roman; Asheghi, Mehdi. 2022. "Techno-Economic Feasibility Analysis of an Extreme Heat Flux Micro-Cooler." *iScience* 26 (1): 105812, 16 Dec. 2022. *https://doi.org/10.1016/j.isci.2022.105812*

54. Dobzhanskyi, Oleksandr; Gouws, Rupert; Bennion, Kevin; Kekelia, Bidzina; Tomerlin, J.; Cousineau, E.; Narumanchi, Sreekant. 2022. "Electromechanical Evaluation of a Double-Core Motor With Ceramic Elements." *IEEE Access* (10): 133698–133707, 22 Dec. 2022. *https://doi.org/10.1109/ACCESS.2022.3231740*

55. Feng, Xuhui; Kotecha, Ramchandra; Narumanchi, Sreekant; Singh, Akanksha; Mather, Barry; Wang, Ke; Hu, Boxue; Wang, Jin. 2023. "Multiscale Electrothermal Design of a Modular Multilevel Converter for Medium-Voltage Grid-Tied Applications." *IEEE Transactions on Industry Applications* 59 (3): 3773–3784, 14 March 2023. *https://doi.org/10.1109/TIA.2023.3256389*

56. Finegan, Donal P.; Squires, Isaac; Dahari, Amir; Kench, Steve; Jungjohann, Katherine L.; Cooper, Samuel J. "Machine-Learning-Driven Advanced Characterization of Battery Electrodes." *ACS Energy Letters* 7 (12): 4368–4378, 9 Nov. 2022. *https://www.nrel.gov/docs/fy23osti/84720.pdf*

57. Fink, Kae; Gasper, Paul; Major, Joshua; Brow, Ryan; Schulze, Maxwell C.; Colclasure, Andrew M.; Keyser, Matthew A. 2023. "Optimized Purification Methods for Metallic Contaminant Removal from Directly Recycled Li-Ion Battery Cathodes." *Frontiers in Chemistry* 11, 8 Feb. 2023. *https://doi.org/10.3389/fchem.2023.1094198*

58. Fransson, Matilda; Broche, Ludovic; Buckwell, Mark; Pfaff, Jonas; Reid, Hamish; Kirchner-Burles, Charlie; Pham, Martin; Moser, Stefan; Rack, Alexander; Nau, Siegfried; Schopferer, Sebastian; Finegan, Donal P.; Shearing, Paul. 2023. "Sidewall Breach During Lithium-Ion Battery Thermal Runaway Triggered by Cell-to-Cell Propagation Visualized Using High-Speed X-Ray Imaging." *Journal of Energy Storage* 71: 108088, 11 July 2023. *https://doi.org/10.1016/j.est.2023.108088*

59. Furat, Orkun; Finegan, Donal P.; Yang, Zhenzhen; Tanim, Tanvir R.; Smith, Kandler; Schmidt, Volker. "Quantifying the Impact of Charge Rate and Number of Cycles on Structural Degeneration of Li-Ion Battery Electrodes." *Journal of the Electrochemical Society* 169 (10): 100541, 27 Oct. 2022. *https://www.nrel.gov/docs/fy23osti/84781.pdf*

60. Gasper, Paul; Schiek, Andrew; Smith, Kandler; Shimonishi, Yuta; Yoshida, Shuhei. "Predicting Battery Capacity from Impedance at Varying Temperature and State of Charge Using Machine Learning." *Cell Reports Physical Science* 3 (12): 101184, 14 Dec. 2022. *https://www.nrel.gov/docs/fy23osti/82892.pdf*

61. Ha, Yeyoung; Trask, Stephen E.; Zhang, Yicheng; Jansen, Andrew N.; Burrell, Anthony. 2023. "Designing $Li_4Ti_5O_{12}$/$LiMn_2O_4$ Cells: Negative-to-Positive Ratio and Electrolyte." *Journal of The Electrochemical Society* 150 (5): 050520, 16 May 2023. *https://doi.org/10.1149/1945-7111/acd304*

62. Hassanaly, Malik; Perry, Bruce A.; Mueller, Michael E.; Yellapantula, Shashank. 2023. "Uniform-in-Phase-Space Data Selection with Iterative Normalizing Flows." *Data-Centric Engineering* 4, 25 April 2023. *https://doi.org/10.1017/dce.2023.4*

63. He, Rong; Zhou, Larissa; Tenent, Robert; Zhou, Meng. 2023. "Basics of the Scanning Electrochemical Microscope and its Application in the Characterization of Lithium-Ion Batteries: A Brief Review." *Materials Chemistry Frontiers* 7: 662–678, 10 Jan. 2023. *https://doi.org/10.1039/D2QM01079H*

64. He, Yi; Liu, Zhaocai; Song, Ziqi. 2023. "Joint Optimization of Electric Bus Charging Infrastructure, Vehicle Scheduling, and Charging Management." *Transportation Research Part D: Transport and Environment* 117: 103653, 2 March 2023. *https://doi.org/10.1016/j.trd.2023.103653*

65. He, Yi; Liu, Zhaocai; Zhang, Yiming; Song, Ziqi. 2023. "Time-Dependent Electric Bus and Charging Station Deployment Problem." *Energy* 282: 128227, 22 June 2023. https://doi.org/10.1016/j.energy.2023.128227

66. Hoehne, Chris; Hanrahan, Max; Shankari, K.; Garikapati, Venu. 2023. "Mobility Energy Productivity and Equity: E-Bike Impacts for Low-Income Essential Workers in Denver." *Transportation Research Record*, 7 Sept. 2023. https://doi.org/10.1177/03611981231193628

67. Huey, Zoey; Ha, Yeyoung; Frisco, Sarah; Norman, Andrew; Teeter, Glenn; Jiang, Chun-Sheng; DeCaluwe, Steven C. 2023. "Multi-Modal Characterization Methods of Solid-Electrolyte Interphase in Silicon-Graphite Composite Electrodes." *Journal of Power Sources* 564: 232804, 2 March 2023. *https://doi.org/10.1016/j.jpowsour.2023.232804*

68. Islam, Mohammad A.; Bouldin, Jared; Yang, Junghoon; Han, Sang-Don. "Electrochemical Sodiation Mechanism in Magnetite Nanoparticle-Based Anodes: Understanding of Nanoionics-Based Sodium Ion Storage Behavior of Fe_3O_4." *ACS Applied Materials & Interfaces* 14 (45): 50773–50782, 1 Nov. 2022. *https://dx.doi.org/10.1021/acsami.2c13016*

69. Jiang, Yuan; Zaimes, George G.; Li, Shuyun; Hawkins, Troy R.; Singh, Avantika; Carlson, Nicholas; Talmadge, Michael; Gaspar, Daniel J.; Ramirez-Corredores, M. M.; Beck, Andrew W.; Young, Ben; Sittler, Lauren; Brooker, Aaron. 2022. "Economic and Environmental Analysis to Evaluate the Potential Value of Co-Optima Diesel Bioblendstocks to Petroleum Refiners." *Fuel* 333 (1): 126233, 20 Oct. 2022. *https://doi.org/10.1016/j.fuel.2022.126233*

70. Kargar, Mohammadali; Zhang, Chen; Song, Xingyong. 2023. "Integrated Optimization of Powertrain Energy Management and Vehicle Motion Control for Autonomous Hybrid Electric Vehicles." *IEEE Transactions on Vehicular Technology*: 1–11, 19 May 2023. *https://doi.org/10.1109/TVT.2023.3270127*

71. Kekelia, Bidzina; Narumanchi, Sreekant. 2023. "Thermal Management of Integrated Traction Drives in Electric Vehicles." *Electronics Cooling*, 3 Oct. 2022. https://www.electronics-cooling.com/2022/10/thermal-management-of-integrated-traction-drives-in-electric-vehicles/

72. Kim, Jinyong; Mallarapu, Anudeep; Santhanagopalan, Shriram; Newman, John. "A Robust Numerical Treatment of Solid-Phase Diffusion in Pseudo Two-Dimensional Lithium-Ion Battery Models." *Journal of Power Sources* 556: 232413, 26 Nov. 2022. *https://doi.org/10.1016/j.jpowsour.2022.232413*

73. Kim, Jinyong; Yang, Chuanbo; Lamb, Joshua; Kurzawski, Andrew; Hewson, John; Torres-Castro, Loraine; Mallarapu, Anudeep; Santhanagopalana, Shriram. "A Comprehensive Numerical and Experimental Study for the Passive Thermal Management in Battery Modules and Packs." *Journal of the Electrochemical Society* 169: 110543, 28 Nov. 2022. *https://www.nrel.gov/docs/fy23osti/84172.pdf*

74. Kim, Minkyu; Harvey, Steven P.; Huey, Zoey; Han, Sang-Don; Jiang, Chun-Shen; Son, Seoung-Bum; Yang, Zhenzhen; Bloom, Ira. 2022. "A New Mechanism of Stabilizing SEI of Si Anode Driven by Crosstalk Behavior and its Potential for Developing High Performance Si-Based Batteries." *Energy Storage Materials* 55: 436–444, 9 Dec. 2022. *https://doi.org/10.1016/j.ensm.2022.12.004*

75. Kim, Yeonjoon; Cho, Jaeyoung; Naser, Nimal; Kumar, Sabari; Jeong, Keunhong; McCormick, Robert L.; St. John, Peter C.; Kim, Seonah. "Physics-Informed Graph Neural Networks for Predicting Cetane Number with Systematic Data Quality Analysis." *Proceedings of the Combustion Institute*, 19 Nov. 2022. *https://dx.doi.org/10.1016/j.proci.2022.09.059*

76. Konz, Zachary M.; Wirtz, Brendan M.; Verma, Ankit; Huang, Tzu-Yang; Bergstrom, Helen K.; Crafton, Matthew J.; Brown, David E.; McShane, Eric J.; Colclasure, Andrew M.; McCloskey, Bryan D. 2023. "High-Throughput Li Plating Quantification for Fast-Charging Battery Design." *Nature Energy*, 2 Feb. 2023. *https://doi.org/10.1038/s41560-023-01194-y*

77. Landera, Alexander; Monroe, Eric; Myllenbeck, Nicholas R; Carlson, Joseph; George, Anthe; Kolodziej, Christopher P.; Hoth, Alexander; Luecke, Jon; Fioroni, Gina M.; Davis, Ryan W. 2023. "Validation of Octane Hyperboosting Phenomenon in Prenol and Structurally Related Olefinic Alcohols." *Fuel* 353: 129184, 20 July 2023. https://doi.org/10.1016/j.fuel.2023.129184

78. Li, Zhifei; Stetson, Caleb; Frisco, Sarah; Harvey, Steve; Huey, Zoey; Teeter, Glenn; Engtrakul, Chaiwat; Burrell, Anthony; Li, Xiaolin; Zakutayev, Andriy. "The Role of Oxygen in Lithiation and Solid Electrolyte Interphase Formation Processes in Silicon-Based Anodes." *Journal of the Electrochemical Society* 169: 120512, 16 Dec. 2022. *https://dx.doi.org/10.1149/1945-7111/aca833*

79. Liu, Zhaocai; Wang, Qichao; Sigler, Devon; Kotz, Andrew; Kelly, Kenneth J.; Lunacek, Monte; Phillips, Caleb; Garikapati, Venu. "Data-Driven Simulation-Based Planning for Electric Airport Shuttle Systems: A Real-World Case Study." *Applied Energy* 332: 120483, 15 Dec. 2022. *https://doi.org/10.1016/j.apenergy.2022.120483*

80. Lokachari, Nitin; Kukkadapu, Goutham; Etz, Brian D.; Fioroni, Gina M.; Kim, Seonah; Steglich, Mathias; Bodi, Andras; Hemberger, Patrick; Matveev, Sergey S.; Thomas, Anna; Song, Hwasup; Vanhove, Guillaume; Zhang, Kuiwen; Dayma, Guillaume; Lailliau, Maxence; Serinyel, Zeynep; Konnov, Alexander A.; Dagaut, Philippe; Pitz, William J.; Curran, Henry J. 2022. "A Comprehensive Experimental and Kinetic Modeling Study of Di-Isobutylene Isomers: Part 2." *Combustion and Flame* 251: 112547, 13 Dec. 2022. *https://doi.org/10.1016/j.combustflame.2022.112547*

81. Lu, Xuekun; Lagnoni, Marco; Bertei, Antonio; Das, Supratim; Owen, Rhodri E.; Li, Qi; O'Regan, Kieran; Wade, Aaron; Finegan, Donal P.; Kendrick, Emma; Bazant, Martin Z.; Brett, Dan J. L.; Shearing, Paul R. 2023. "Multiscale Dynamics of Charging and Plating in Graphite Electrodes Coupling Operando Microscopy and Phase-Field Modelling." *Nature Communications* 14: 5127, 24 Aug. 2023. https://doi.org/10.1038/s41467-023-40574-6

82. Martin, Jonathan A.; Ratcliff, Matthew A.; Rahimi, Mohammad J.; Burton, Jonathan L.; Sindler, Petr; Hays, Cameron K.; McCormick, Robert L. 2023. "φ-Sensitivity of Gasoline/Oxygenate Blends in an Advanced Compression Ignition Engine." *Energy & Fuels* 37 (16): 12243–12258, 26 July 2023. https://doi.org/10.1021/acs.energyfuels.3c01537

83. Martin, Trevor; Rynearson, Leah; Kuller, Mackenzie; Quinn, Joseph; Wang, Chongmin; Lucht, Brett; Neale, Nathan. "Conjugated Imine Polymer Synthesized via Step-Growth Metathesis for Highly Stable Silicon Nanoparticle Anodes in Lithium-Ion Batteries." *ChemRxiv*, 30 Oct. 2022. *https://doi.org/10.26434/chemrxiv-2022-bphpr*

84. Martin, Trevor R.; Teeter, Glenn; Jiang, Chun-Sheng; Park, Kyusung. 2023. "Sulfur Polymers as Flexible Interfacial Additives for Low Stack-Pressure Solid-State Lithium-Ion Batteries." *Batteries & Supercaps*: e202300255, 17 Aug. 2023. https://doi.org/10.1002/batt.202300255

85. Miller, Jacob H.; Tifft, Stephen M.; Wiatrowski, Matthew R.; Benavides, Pahola Thathiana; Huq, Nabila A.; Christensen, Earl D.; Alleman, Teresa; Hays, Cameron; Luecke, Jon; Kneucker, Colin M.; Haugen, Stefan J.; Sanchez i Nogue, Violeta; Karp, Eric M.; Hawkins, Troy R.; Singh, Avantika; Vardon, Derek R. 2022. "Screening and Evaluation of Biomass Upgrading Strategies for Sustainable Transportation Fuel Production with Biomass-Derived Volatile Fatty Acids." *iScience* 25 (11): 105384, 18 Oct. 2022. *https://doi.org/10.1016/j.isci.2022.105384*

86. Monasterial, Abigale P.; Weddle, Peter J.; Atkinson, Kristen; Wragg, David S.; Colclasure, Andrew M.; Usseglio-Viretta, Francois L. E.; Seitzman, Natalie; Park, Jun-Sang; Almer, Jonathan; Smith, Kandler; Finegan, Donal P. 2023. "Dynamic In-Plane Heterogeneous and Inverted Response of Graphite to Fast Charging and Discharging Conditions in Lithium-Ion Pouch Cells." *Small Science*, 19 April 2023. *https://doi.org/10.1002/smsc.202200067*

87. Muratori, Matteo; Borlaug, Brennan; Ledna, Catherine; Jadun, Paige; Kailas, Aravind. 2023. "Road to Zero: Research and Industry Perspectives on Zero-Emission Commercial Vehicles." *iScience* 26 (5): 106751, 26 April 2023. *https://doi.org/10.1016/j.isci.2023.106751*

88. Oakleaf, Brett; Cary, Scott; Meeker, Darin; Arent, Doug; Farrell, John; Day, Marc; McCormick, Robert; Abdullah, Zia; Young, Stanley; Cochran, Jaquelin; Gearhart, Chris. 2023. "A Roadmap Toward a Sustainable Aviation Ecosystem." *Amplify* 36 (5), 31 May 2023. https://www.cutter.com/article/roadmap-toward-sustainable-aviation-ecosystem

89. Okaeme, Charles C.; Yang, Chuanbo; Saxon, Aron; Lustbader, Jason A.; Villeneuve, Darek; Mac, Chihao; Reed, Thomas. "Thermal Design Analysis for SuperTruck II Lithium-Titanate Battery Pack." *Journal of Energy Storage* 56 (A): 105753, 21 Oct. 2022. *https://dx.doi.org/10.1016/j.est.2022.105753*

90. Osman, Ammar; Moreno, Gilberto; Myers, Steve; Major, Joshua; Feng, Xuhui; Narumanchi, Sreekant; Joshi, Yogendra. 2023. "Automotive Silicon Carbide Power Module Cooling With A Novel Modular Manifold And Embedded Heat Sink." *Journal of Electronic Packaging*, 29 June 2023. https://doi.org/10.1115/1.4062869

91. Osman, Ammar; Moreno, Gilberto; Myers, Steve; Narumanchi, Sreekant V. J.; Joshi, Yogendra. 2023. "Single-Phase Jet Impingement Cooling for a Power-Dense Silicon Carbide Power Module." *IEEE Transactions on Components, Packaging and Manufacturing Technology* 13 (5): 615–627, 15 May 2023. *https://doi.org/10.1109/TCPMT.2023.3276712*

92. Panossian, Nadia V.; Laarabi, Haitam; Moffat, Keith; Chang, Heather; Palmintier, Bryan; Meintz, Andrew; Lipman, Timothy E.; Waraich, Rashid A. 2023. "Architecture for Co-Simulation of Transportation and Distribution Systems with Electric Vehicle Charging at Scale in the San Francisco Bay Area." *Energies* 16 (5): 2189, 24 Feb. 2023. *https://doi.org/10.3390/en16052189*

93. Paret, Paul; Finegan, Donal; Narumanchi, Sreekant. "Artificial Intelligence for Power Electronics in Electric Vehicles: Challenges and Opportunities." *Journal of Electronic Packaging, Transactions of the ASME* 145 (3): 034501, 9 Dec. 2022. *https://dx.doi.org/10.1115/1.4056306*

94. Pesaran, Ahmad A. 2023. "Lithium-Ion Battery Technologies for Electric Vehicles: Progress and Challenges." *IEEE Electrification Magazine* 11 (2): 35–43, 5 June 2023. *https://doi.org/10.1109/MELE.2023.3264919*

95. Pfaff, Jonas; Fransson, Matilda; Broche, Ludovic; Buckwell, Mark; Finegan, Donal; Moser, Stefan; Schopferer, Sebastian; Nau, Siegfried; Shearing, Paul R.; Rack, Alexander. 2023. "In Situ Chamber for Studying Battery Failure Using High-Speed Synchrotron Radiography." *Journal of Synchrotron Radiation* 30: 192–199, 1 Jan. 2023. *https://doi.org/10.1107/S1600577522010244*

96. Poubeau, Adele; Vinay, Guillaume; Kekelia, Bidzina; Bennion, Kevin. 2023. "Numerical Simulations of High Prandtl Number Liquid Jets Impinging on a Flat Plate." *International Journal of Heat and Mass Transfer* 205: 123889, 2 Feb. 2023. *https://doi.org/10.1016/j.ijheatmasstransfer.2023.123889*

97. Rodrigues, Marco-Tulio F.; Rajendran, Sathish; Trask, Stephen E.; Dunlop, Alison R.; Singh, Avtar; Allen, Jeffery M.; Weddle, Peter J.; Preimesberger, Juliane I.; Coyle, Jaclyn; Colclasure, Andrew M.; Yang, Zhenzhen; Ingram, Brian J.; Jansen, Andrew N. 2023. "Cell-Format-Dependent Mechanical Damage in Silicon Anodes." *ACS Applied Energy Materials* 6 (18): 9243–9248, 6 Sept. 2023. https://doi.org/10.1021/acsaem.3c01531

98. Romero-Lankao, Patricia; Rosner, Nicole; Brandtner, Christof; Rea, Christopher; Mejia Montero, Adolfo; Pilo, Francesca; Dokshin, Fedor; Castan-Broto, Vanesa; Burch, Sarah; Schnur, Scott. 2023. "A Framework to Centre Justice in Energy Transition Innovations." *Nature Energy*, 21 Sept. 2023. https://doi.org/10.1038/s41560-023-01351-3

99. Sattarzadeh, Sara; Padisala, Shanthan K.; Shi, Ying; Mishra, Partha Pratim; Smith, Kandler; Dey, Satadru. 2023. "Feedback-Based Fault-Tolerant and Health-Adaptive Optimal Charging of Batteries." *Applied Energy* 343: 121187, 4 May 2023. *https://doi.org/10.1016/j.apenergy.2023.121187*

100. Schaeffer, Joachim; Gasper, Paul; Garcia-Tamayo, Esteban; Gasper, Raymond; Adachi, Masaki; Gaviria-Cardona, Juan Pablo; Montoya-Bedoya, Simon; Bhutani, Anoushka; Schiek, Andrew; Goodall, Rhys; Findelsen, Rolf; Braatz, Richard D.; Engelke, Simon. 2023. "Machine Learning Benchmarks for the Classification of Equivalent Circuit Models from Electrochemical Impedance Spectra." *Journal of the Electrochemical Society* 170: 060512, 6 June 2023. https://doi.org/10.1149/1945-7111/acd8fb

101. Schulze, Maxwell C.; Fink, Kae; Palmer, Jack; Carroll, Gerald M.; Dutta, Nikita S.; Zweifel, Christof; Engtrakul, Chaiwat; Han, Sang-Don; Neale, Nathan R.; Tremolet de Villers, Bertrand J. 2023. "Pitch Carbon-Coated Ultrasmall Si Nanoparticle Lithium-Ion Battery Anodes Exhibiting Reduced Reactivity with Carbonate-Based Electrolyte." *Batteries & Supercaps* 6 (9): e202300186, 29 June 2023. https://doi.org/10.1002/batt.202300186

102. Schulze, Maxwell C.; Urias, Fernando; Dutta, Nikita S.; Huey, Zoey; Coyle, Jaclyn; Teeter, Glenn; Doeren, Ryan; Tremolet de Villers, Bertrand J.; Han, Sang-Don; Neale, Nathan R.; Carroll, G. Michael. 2023. "Control of Nanoparticle Dispersion, SEI Composition, and Electrode Morphology Enables Long Cycle Life in High Silicon Content Nanoparticle-Based Composite Anodes for Lithium-Ion Batteries." *Journal of Materials Chemistry A* 11: 5257–5266, 3 Feb. 2023. *https://doi.org/10.1039/D2TA08935A*

103. Shattique, Muhammad R.; Giglio, Roman; Dede, Ercan M.; Narumanchi, Sreekant; Ashegi, Mehdi; Goodson, Kenneth E.; Palko, James W. 2023. "Permeability of Single-Layer-Free-Standing Meshes at Varying Capillary Pressure via a Novel Method." *Advanced Materials Interfaces*: 2300326, 24 July 2023. https://doi.org/10.1002/admi.202300326

104. Song, Hwasup; Kang, Dongil; Fioroni, Gina; Kukkadapu, Goutham; Fenard, Yann; Naser, Nimal; Goldsborough, S. Scott; Dauphin, Roland; Wagnon, Scott W.; Pitz, William J.; Westbrook, Charles K.; Vanhove, Guillaume. 2023. "Isomeric Effects on the Reactivity of Branched Alkenes: An Experimental and Kinetic Modeling Study of Methylbutenes." *Combustion and Flame* 254: 112849, 26 May 2023. *https://doi.org/10.1016/j.combustflame.2023.112849*

105. Sunderlin, Nathaniel; Colclasure, Andrew; Yang, Chuanbo; Major, Joshua; Fink, Kae; Saxon, Aron; Keyser, Matthew. 2023. "Effects of Cryogenic Freezing Upon Lithium-Ion Battery Safety and Component Integrity." *Journal of Energy Storage* 63: 107046, 13 March 2023. *https://doi.org/10.1016/j.est.2023.107046*

106. Tanim, Tanvir R.; Weddle, Peter J.; Yang, Zhenzhen; Colclasure, Andrew M.; Charalambous, Harry; Finegan, Donal P.; Lu, Yanying; et al. "Enabling Extreme Fast-Charging: Challenges at the Cathode and Mitigation Strategies." *Advanced Energy Materials* 12 (46): 2202795, 1 Nov. 2022. *https://dx.doi.org/10.1002/aenm.202202795*

107. Thornburg, Nicholas E.; Feng, Xuhui; Zigler, Bradley T.; Day, Marc S.; Yellapantula, Shashank; Narumanchi, Sreekant. 2023. "Model Assessment of Synthetic Jets for Turbulent Combustion Experiments." *Flow, Turbulence and Combustion*, 28 March 2023. *https://doi.org/10.1007/s10494-023-00410-9*

108. Tian, Xingyue; Jia, Niu; DeVoto, Douglas; Paret, Paul; Bai, Hua; Tolbert, Leon M.; Cui, Han. 2023. "PCB-on-DBC GaN Power Module Design with High-Density Integration and Double-Sided Cooling." *IEEE Transactions on Power Electronics*, 5 Sept. 2023. https://doi.org/10.1109/TPEL.2023.3311440

109. Verma, Ankit; Schulze, Maxwell C.; Colclasure, Andrew; Rodrigues, Marco-Tulio Fonseca; Trask, Stephen E.; Pupek, Krzysztof; Johnson, Christopher S.; Abraham, Daniel P. 2023. "Assessing Electrolyte Fluorination Impact on Calendar Aging of Blended Silicon-Graphite Lithium-Ion Cells Using Potentiostatic Holds." *Journal of the Electrochemical Society* 170: 070516, 19 July 2023. https://doi.org/10.1149/1945-7111/ace65d

110. Ward, Logan; Babinec, Susan; Dufek, Eric J.; Howey, David A.; Viswanathan, Venkat; Aykol, Muratahan; Beck, David A. C.; et al. "Principles of the Battery Data Genome." *Joule* 6 (10): 2253–2271, 19 Oct. 2022. https://dx.doi.org/10.1016/j.joule.2022.08.008

111. Weddle, Peter J.; Kim, Sangwook; Chen, Bor-Rong; Yi, Zonggen; Gasper, Paul; Colclasure, Andrew M.; Smith, Kandler; Gering, Kevin L.; Tanim, Tanvir R.; Dufek, Eric J. 2023. "Battery State-of-Health Diagnostics During Fast Cycling Using Physics-Informed Deep-Learning." *Journal of Power Sources* 585: 233582, 22 Sept. 2023. https://doi.org/10.1016/j.jpowsour.2023.233582

112. Weddle, Peter J.; Spotte-Smith, Evan Walter Clark; Verma, Ankit; Patel, Hetal D.; Fink, Kae; Tremolet de Villers, Bertrand J.; Schulze, Maxwell C.; Blau, Samuel M.; Smith, Kandler A.; Persson, Kristin A.; Colclasure, Andrew M. 2023. "Continuum-Level Modeling of Li-Ion Battery SEI by Upscaling Atomistically Informed Reaction Mechanisms." *Electrochimica Acta* 468: 143121, 3 Sept. 2023. https://doi.org/10.1016/j.electacta.2023.143121

113. Weigl, Dustin; Young, David. 2023. "Impact of Automated Battery Sorting for Mineral Recovery from Lithium-Ion Battery Recycling in the United States." *Resources, Conservation and Recycling* 192: 106936, 24 Feb. 2023. *https://doi.org/10.1016/j.resconrec.2023.106936*

114. Wilson, Alana M.; Romero-Lankao, Patricia; Zimny-Schmitt, Daniel; Sperling, Joshua; Young, Stanley. 2023. "Linking Transportation Agent-Based Model (ABM) Outputs with Micro-Urban Social Types (MUSTs) via Typology Transfer for Improved Community Relevance." *Transportation Research Interdisciplinary Perspectives* 17: 100748, 17 Jan. 2023. *https://doi.org/10.1016/j.trip.2022.100748*

115. Xu, Chengjian; Behrens, Paul; Gasper, Paul; Smith, Kandler; Hu, Mingming; Tukker, Arnold; Steubing, Bernhard. 2023. "Electric Vehicle Batteries Alone Could Satisfy Short-Term Grid Storage Demand by as Early as 2030." *Nature Communications* 14: 119, 17 Jan. 2023. *https://doi.org/10.1038/s41467-022-35393-0*

116. Xu, Haowen; Berres, Andy; Yoginath, Srikanth B.; Sorensen, Harry; Nugent, Phil J.; Severino, Joseph; Tennille, Sarah A.; Moore, Alex; Jones, Wesley; Sanyal, Jibonananda. 2023. "Smart Mobility in the Cloud: Enabling Real-Time Situational Awareness and Cyber-Physical Control Through a Digital Twin for Traffic." *IEEE Transactions on Intelligent Transportation Systems* 24 (3): 3145–3156, 16 Jan. 2023. *https://doi.org/10.1109/TITS.2022.3226746*

117. Yang, Junghoon; Park, Sungwon; Lee, Sungsik; Kim, Jungpil; Huang, Di; Gim, Jihyeon; Lee, Eungje; Kim, Gilseob; Park, Kyusung; Kang, Yong-Mook; Paek, Eunsu; Han, Sang-Don. 2023. "High-Voltage Deprotonation of Layered-Type Materials as a Newly Identified Cause of Electrode Degradation." *Journal of Materials Chemistry A* 11: 3018–3027, 9 Jan. 2023. *https://doi.org/10.1039/D2TA07496F*

118. Zhang, Yicheng; Teeter, Glenn; Dutta, Nikita S.; Frisco, Sarah; Han, Sang-Don. 2023. "Mechanistic Understanding of Aging Behaviors of Critical-Material-Free $Li_4Ti_5O_{12}$//$LiNi_{0.9}Mn_{0.1}O_2$ Cells with Fluorinated Carbonate-Based Electrolytes for Safe Energy Storage with Ultra-Long Life Span." *Chemical Engineering Journal* 460: 141239, 4 Jan. 2023. *https://doi.org/10.1016/j.cej.2022.141239*

119. Zhang, Yicheng; Teeter, Glenn; Kim, Young Jin; Burrell, Anthony; Park, Kyusung. 2023. "xLi_2MnO_3 (1-x)$LiMeO_2$ and $Li_4Ti_5O_{12}$ Cell Chemistry for Behind-the-Meter Storage Applications." *Journal of Energy Storage* 64: 107226, 3 April 2023. *https://doi.org/10.1016/j.est.2023.107226*

120. Zhu, Xiangqi; Mishra, Partha; Mather, Barry; Zhang, Mingzhi; Meintz, Andrew. 2023. "Grid Impact Analysis and Mitigation of En-Route Charging Stations for Heavy-Duty Electric Vehicles." *IEEE Open Access Journal of Power and Energy* 10: 141–150, 3 Jan. 2023. *https://doi.org/10.1109/OAJPE.2022.3233804*

Management Reports

121. Bennion, Kevin; Rogers, Susan. 2023. *I.1.8 - Electric Motor Thermal Management (National Renewable Energy Laboratory)*. https://www.energy.gov/eere/vehicles/articles/2021-electrification-annual-progress-report

122. DeVoto, Douglas; Rogers, Susan. 2023. *I.1.7 - Advanced Packaging Designs - Reliability and Prognostics (National Renewable Energy Laboratory)*. https://www.energy.gov/eere/vehicles/articles/2021-electrification-annual-progress-report

123. Kekelia, Bidzina; Rogers, Susan A. 2023. *I.1.13 - Integrated Traction Drive Thermal Management (National Renewable Energy Laboratory)*. https://www.energy.gov/eere/vehicles/articles/2021-electrification-annual-progress-report

124. Moreno, Gilbert; Rogers, Susan. 2023. *I.1.5 - Power Electronics Thermal Management (National Renewable Energy Laboratory)*. https://www.energy.gov/eere/vehicles/articles/2021-electrification-annual-progress-report

125. Paret, Paul; Rogers, Susan A. 2023. *I.1.14 - Power Electronics Materials and Bonded Interfaces - Reliability and Lifetime (National Renewable Energy Laboratory)*. https://www.energy.gov/eere/vehicles/articles/2021-electrification-annual-progress-report

Other Marketing Materials

126. 2022. *TSDC: Transportation Secure Data Center and Livewire Data Platform*. *https://www.nrel.gov/docs/fy23osti/84765.pdf*

127. 2023. *Data and Tools for Integrated Mobility Systems*. *https://www.nrel.gov/docs/gen/fy23/84671.pdf*

128. 2023. *NREL OpenPATH: Open Platform for Agile Trip Heuristics*. *https://www.nrel.gov/docs/gen/fy23/84829.pdf*

Patents

129. Moreno, Gilbert; Narumanchi, Sreekant Venkat Jagannath; Bennion, Kevin Scott; Kotecha, Ramchandra Mahendrabhai; Paret, Paul Philip; Feng, Xuhui. 2023. "Jet Impingement Manifolds for Cooling Power Electronics Modules." U.S. Patent No. 11,751,365 B2.

130. Neale, Nathan Richard; Carroll, Gerard Zachary; Pach, Gregory Frank; Schulze, Maxwell Connor; Martin, Trevor Russell. 2022. "Stabilized Electrodes for Ion Batteries and Methods of Making the Same." U.S. Patent No. 11,459,242.

131. Park, Kyusung. 2023. "Cathode Recycling of End-of-Life Lithium Batteries." U.S. Patent No. 11,605,844 B2.

132. Park, Kyusung; Burrell, Anthony Keiran. 2023. "Methods for Cathode Recycling of End-of-Life Lithium Batteries." U.S. Patent No. 11,715,849 B2.

133. Roan, Thomas J.; Singh, Brij N.; Moreno, Gilberto; Bennion, Kevin Scott. 2023. "Evaporator Stacks and Electronic Assemblies." U.S. Patent No. 11,594,468 B2.

134. Zhang, Chi; Wu, Qianying; Shattique, Muhammad; Seyedhassantehrani, Neda; Roy, Souvik; Palko, James; Narumanchi, Sreekant; Kekelia, Bidzina; Hazra, Sougata; Goodson, Kenneth E.; Giglio, Roman; Dede, Ercan M.; Asheghi, Mehdi. 2023. "Heat Flux Micro Coolers Having Multi-stepped Features and Fluid Wicking." U.S. Patent No. 11,729,951 B2.

Posters

135. Allen, Michael; Shankari, K. 2023. "Count Every Trip: Finding the Uncertainty in Energy Estimates Made from Inferred Travel Modes." Presented at TRB Innovations in Travel Analysis and Planning, 4–6 June 2023, Indianapolis, IN. https://www.nrel.gov/docs/fy23osti/86240.pdf

136. Bennion, Kevin; Cousineau, Emily; DeVoto, Doug; Feng, Xuhui; Kekelia, Bidzina; Tomerlin, Jeff; Mohammad, Mostak; Anderson, Iver; Monson, Todd; Joshi, Yogendra; Kumar, Satish; Sarlioglu, Bulent; Jahns, Thomas. 2023. "Electric Motor Thermal Management." Presented at the Vehicle Technologies Office Annual Merit Review, 21–23 June 2022, Washington, D.C. https://www.nrel.gov/docs/fy23osti/82675.pdf

137. Binswanger, Adam L.; Appukuttan, Sreejith Nadakkal; Day, Marc; Yellapantula, Shashank; Perry, Bruce. 2023. "Initial Evaluation of Multi-Component Evaporation Model for Sustainable Aviation Fuel Simulations (Citation Only)."

138. Carroll, G. Michael; Martin, Trevor R.; Schulze, Maxwell C.; Pach, Greg F.; Neale, Nathan R. 2023. "Nanoparticle Surface Passivation Strategies to Improve the Cycle and Calendar Lifetime of Silicon Anodes in Standard Carbonate Electrolytes." Presented at the Nanomaterials for Applications in Energy Technology Gordon Research Conference, 26 Feb.–3 March 2023. https://www.nrel.gov/docs/fy23osti/85316.pdf

139. Castelli, Alessandro Francesco; Helman, Samuel; Johnson, Graham; Jones, Wesley B.; Knueven, Bernard; Larson, Clara; Liu, Zhaocai; Maack, Jonathan; Panda, Kinshuk; Satkauskas, Ignas; Severino, Joseph Allen; Sigler, Devon; Ugirumurera, Juliette; Vaidhynathan, Deepthi; Wang, Qichao. 2023. "ESIF F&I Modeling, Simulation and Optimization Capability for Grid Modernization, Energy Systems Integration and Mobility Electrification (Citation Only)."

140. Chabot, Olivier; Nozari, Mohammadreza; Vabre, Martin; Fan, Luming; Vena, Patrizio; Day, Marc; Esclapez, Lucas; Savard, Bruno. 2023. "Direct Numerical Simulation of Flame-Wall Interaction for Low-Carbon Gas Turbine Combustion." *https://www.nrel.gov/docs/fy23osti/85717.pdf*

141. Coyle, Jaclyn; Gaulding, Ashley; Veith, Gabriel; Keyser, Matthew. 2023. "PV Si Recovery for Lithium Ion Battery Anodes (Citation Only)."

142. Coyle, Jaclyn; Gaulding, Ashley; Veith, Gabriel; Keyser, Matthew. 2023. "PV Si Recovery for Lithium Ion Battery Anodes (Citation Only)."

143. DeVoto, Douglas; Moreno, Gilbert; Major, Joshua; Paret, Paul; Khan, Faisal; Narumanchi, Sreekant; Steinmark, Adam; Ivanov, Itso; Farias, Stephen; Peters, Adam; Paulsen, Andrew; Zimmerman, Terri; Steele, Matt. 2023. "Breaking the Board: Bringing 3D Packaging and Thermal Management to Power Electronics (Citation Only)."

144. Fink, Kae; Gasper, Paul; Coyle, Jaclyn E.; Sunderlin, Nathaniel; Santhanagopalan, Shriram. 2022. "Impacts of Solvent Washing on the Electrochemical Remediation of Commercial End-of-Life Cathodes." *https://www.nrel.gov/docs/fy23osti/80727.pdf*

145. Gasper, Paul; Schiek, Andrew; Smith, Kandler; Shimonishi, Yuta; Yoshida, Shuhei. 2023. "Monitoring Battery State Using Impedance (Citation Only)."

146. Hodge, Cabell; Desai, Ranjit. 2023. "EVI-LOCATE - Electric Vehicle Infrastructure: Localized Charging Assessment Tool and Estimator." Presented at the ESTCP Symposium, 29 Nov.–2 Dec. 2022, Arlington, VA. https://www.nrel.gov/docs/fy23osti/84617.pdf

147. Hoehne, Chris; Hanrahan, Max; Shankari, K.; Garikapati, Venu. 2023. "MEP and Equity: E-Bike Impacts on the MEP Scores of Low-Income Essential Workers in Denver (Citation Only)."

148. Hoehne, Chris; Hanrahan, Max; Shankari, K.; Garikapati, Venu. 2023. "Mobility Energy Productivity and Equity: E-Bike Impacts on the MEP Scores of Low-Income Essential Workers in Denver (Citation Only)."

149. Hoehne, Christopher; Sharda, Shivam; Garikapati, Venu; Cui, Yuna; Huang, Yantao; Chestnut, Joe; Acharya, Sailesh; Sun, Bingrong; He, Mingyi. 2023. "Insights from MEP Utilization by Three State DOTs: Lessons Learned and Future Pathways (Citation Only)."

150. Huey, Zoey; Carroll, G. Michael; Walker, Patrick; DeCaluwe, Steven; Jiang, Chun-Sheng. 2023. "Characterization of Annealing-Induced Phase Segregation in Composite Silicon Anodes for Li-ion Batteries." Presented at the Materials Research Society Spring 2023, 10–14 April 2023, San Francisco, CA. *https://www.nrel.gov/docs/fy23osti/85797.pdf*

151. Huey, Zoey; Stetson, Caleb; Han, Sang-Don; Finegan, Donal; Ha, Yeyoung; Walker, Patrick; Jiang, Chun-Sheng; Norman, Andrew; DeCaluwe, Steven; Al-Jassim, Mowafak. 2022. "Nanoscale Three-Dimensional Imaging of Degradation in Composite Si-Containing Anodes." *https://www.nrel.gov/docs/fy23osti/78247.pdf*

152. Hunting, Erika; Martin, Trevor; Neale, Nathan. 2023. "Green Chemistry Processing of Boron-Doped-Silicon Nanoparticle Lithium-Ion Batteries Anodes (for EVs?) (Citation Only)."

153. Janicke, Lauren; Yip, Arthur; Shankari, K. 2022. "Reorganizing the Mobility Landscape to Improve Interrelations and the User Experience (Citation Only)."

154. Jeong, Kyungsoo; Birky, Alicia. 2022. "Multimodal Freight Energy Model for Emerging Freight Technology Analysis." *https://www.nrel.gov/docs/fy23osti/78940.pdf*

155. Jeong, Kyungsoo; Ugirumurera, Juliette; Xu, Xiaodan; Laarabi, Haitam. 2023. "Modeling Online Shopping Behavior and Delivery for an Agent-Based Freight Model (NREL Internal Use Only)." Presented at the TRB Annual Meeting, 8–12 Jan. 2023, Washington, D.C.

156. Kim, Jae Ho; Neale, Nathan R.; Carroll, G. Michael; Pach, Gregory F. 2023. "Study on the Carbon Nanostructures for Nanosized Si Electrodes." Presented at 243rd ECS Meeting, 5 May 2023, Boston, MA. https://www.nrel.gov/docs/fy23osti/85919.pdf

157. Kirwa, Cyrus; Coyle, Jaclyn; Luo, Hongmei. 2023. "Direct Recycling of End-of-Life Cathode Material Using Redox Mediator (Citation Only)."

158. Kosmacher, Gabriel; Shankari, K. 2023. "I Know I'm Right, But Does My Phone?" Presented at the TRB Annual Meeting, 8–12 Jan. 2023, Washington, D.C. https://www.nrel.gov/docs/fy23osti/84966.pdf

159. Ledna, Catherine; Muratori, Matteo; Yip, Arthur; Jadun, Paige; Hoehne, Chris. 2022. "Decarbonizing Medium & Heavy-Duty On-Road Vehicles." *https://www.nrel.gov/docs/fy23osti/84486.pdf*

160. Lu, Hannah; Shankari, K. 2023. "Label Assist: Personalized Travel Models for Longitudinal Data Collection." Presented at the TRB Annual Meeting, 8–12 Jan. 2023, Washington, D.C. https://www.nrel.gov/docs/fy23osti/84502.pdf

161. Moreno, Gilbert; Bennion, Kevin; Feng, Xuhui; Kotecha, Ram; Major, Josh; Tomerlin, Jeff. 2023. "Power Electronics Thermal Management." Presented at the Vehicle Technologies Office Annual Merit Review, 21–23 June 2022, Washington, D.C. https://www.nrel.gov/docs/fy23osti/82714.pdf

162. Ruzekowicz, Jenna; Shankari, K.; Fitzsimmons, Kyle. 2022. "OpenPATH and Itinerum Integration: A Case Study of Merging Open Source Projects (Citation Only)."

163. Schulze, Maxwell C.; Fink, Kae; Palmer, Jack; Carroll, Gerard M.; Dutta, Nikita; Zwiefel, Christof; Engtrakul, Chaiwat; Han, Sang-Don; Neale, Nathan R.; Tremolet de Villers, Bertrand. 2023. "A04-0491 - Reduced Electrolyte Reactivity of Pitch-Carbon Coated Si Nanoparticles for Li-Ion Battery Anodes." Presented at 242nd Electrochemical Society Meeting, 9–13 Oct. 2022, Atlanta, GA. https://www.nrel.gov/docs/fy23osti/84240.pdf

164. Sigler, Devon; Wang, Qichao; Liu, Zhaocai; Garikapati, Venu; Kotz, Andrew; Kelly, Kenneth J.; Lunacek, Monte; Phillips, Caleb. 2022. "Route Optimization for Energy Efficient Airport Shuttle Operations - A Case Study from Dallas Fort Worth International Airport." *https://www.nrel.gov/docs/fy23osti/78893.pdf*

165. Sun, Bingrong; Sharda, Shivam; Garikapati, Venu M.; Bouzaghrane, Amine; Caicedo, Juan; Ravulaparthy, Srinath; Viegas De Lima, Isabel; Jin, Ling; Spurlock, Anna; Waddell, Paul. 2023. "Demographic Microsimulator for Integrated Urban Systems: Adapting Panel Survey of Income Dynamics to Capture the Continuum of Life." Presented at the TRB Annual Meeting, 8–12 Jan. 2023, Washington, D.C. https://www.nrel.gov/docs/fy23osti/84809.pdf

166. Tremolet de Villers, Bertrand J.; Finegan, Donal. 2023. "High Throughput Laser Processing for Enhanced Battery Performance and Manufacturing." Presented at the AMMTO & IDEO Joint Peer Review Meeting, 16–18 May 2023, Washington, D.C. *https://www.nrel.gov/docs/fy23osti/86150.pdf*

167. Vabre, Martin; Savard, Bruno; Day, Marc; Bourque, Gilles; Jella, Sandeep; Versailles, Phillipe. 2023. "DNS of a Simplified Gas Turbine Premixer: Auto-Ignition and Flame Stabilization." Presented at the Internal Academic Conference at Polytechnique Montréal, 27 March 2023, Montreal, Canada. *https://www.nrel.gov/docs/fy23osti/85712.pdf*

168. Wilson, Alana M.; Kavikondala, Rohit; Young, Stanley; Duvall, Andrew. 2023. "Equitable Employment Access Assessed Through the Mobility Energy Productivity (MEP) Metric." Presented at the Transportation Research Board Annual Meeting, 9–13 Jan. 2022, Washington, D.C. *https://www.nrel.gov/docs/fy23osti/81812.pdf*

169. Yellapantula, Shashank; Day, Marc; Nadakkal Appukuttan, Sreejith; Perry, Bruce; Esclapez, Lucas; Fioroni, Gina; McCormick, Robert. 2023. "Computational Projects Supporting Decarbonization of Aviation & Power Generation (Citation Only)."

170. Young, Stanley Aaron; Sun, Bingrong; Fish, Joseph; Duvall, Andrew. 2023. "Quantifying and Understanding the Access Time to Dockless Micromobility: A Case Study in Washington, D.C." Presented at the Transportation Research Board (TRB) 102nd Annual Meeting, 8–12 Jan. 2023. https://www.nrel.gov/docs/fy23osti/84890.pdf

Presentations

171. Allen, Jeffery M.; Weddle, Peter J.; Verma, Ankit; Usseglio-Viretta, Francois; Colclasure, Andrew M.; Smith, Kandler. 2023. "Enhancing Lithium-Ion Battery Aging Simulations: Coupling a High-Resolution, 3D, Grain-Scale Electromechanical Model to a Single-Particle Model." Presented at the 242nd Electrochemical Society Meeting, 9 Oct. 2022. https://www.nrel.gov/docs/fy23osti/83439.pdf

172. Allen, Michael; Shankari, K. 2023. "Count Every Trip: Finding the Uncertainty in Energy Estimates Made from Inferred Travel Modes." Presented at TRB Innovations in Travel Analysis and Planning, 4–6 June 2023. https://www.nrel.gov/docs/fy23osti/86201.pdf

173. Bennett, Jesse. 2023. "Advancing Federal Infrastructure Through Innovation: Selecting Electric Vehicle Charging Infrastructure Wisely." Presented at Energy Exchange, 25–27 Oct. 2022, Cincinnati, OH. https://www.nrel.gov/docs/fy23osti/84232.pdf

174. Borlaug, Brennan. 2023. "Charging Needs for Battery Electric Semi-Trucks." Presented at the 36th Electric Vehicle Symposium & Exposition (EVS36), 11–14 June 2023, Sacramento, CA. https://www.nrel.gov/docs/fy23osti/86549.pdf

175. Borlaug, Brennan; Wood, Eric; Moniot, Matt; Lee, D.-Y.; Ge, Yanbo; Yang, Fan; Liu, Zhaocai. 2023. "Modeling U.S. Light-Duty Demand for EV Charging Infrastructure in 2030." https://www.nrel.gov/docs/fy23osti/86980.pdf

176. Boyce, Leidy. 2022. "Data Resources to Empower Your Fleet." *https://www.nrel.gov/docs/fy23osti/84210.pdf*

177. Boyce, Leidy; Bennett, Jesse; Desai, Ranjit. 2022. "Yellowstone National Park Federal Fleet Tiger Team EVSE Site Assessment." *https://www.nrel.gov/docs/fy23osti/84084.pdf*

178. Brooker, Aaron; Gonder, Jeff; Yang, Fan. 2022. "Light-Duty Vehicle Choice Modeling and Transportation Decarbonization Analysis." *https://www.nrel.gov/docs/fy23osti/82748.pdf*

179. Cryar, Ryan. 2023. "Emulation and Adversarial Analysis of EV Charging Networks." Presented at ESCAR, 20–22 June 2023. https://www.nrel.gov/docs/fy23osti/86301.pdf

180. Desai, Ranjit. 2023. "Advancing Federal Infrastructure Through Innovation: Cost of Charging Station Installation." Presented at Energy Exchange, 25–27 Oct. 2022, Cincinnati, OH. https://www.nrel.gov/docs/fy23osti/84297.pdf

181. DeVoto, Douglas. 2023. "Advanced Power Electronics Designs - Reliability and Prognostics (Keystone Project 1)." Presented at the Vehicle Technologies Office Annual Merit Review, 21–23 June 2022, Washington, D.C. https://www.nrel.gov/docs/fy23osti/82652.pdf

182. Dunlap, Nathan; Sulas-Kern, Dana; Usseglio-Viretta, Francois; Weddle, Peter; Finegan, Donal; Tremolet de Villers, Bertrand J. 2022. "Electrochemical and Material Characterization of Laser Micro-Structured Thick Battery Electrodes." *https://www.nrel.gov/docs/fy23osti/82342.pdf*

183. Dunlap, Nathan; Sulas-Kern, Dana; Usseglio-Viretta, Francois; Weddle, Peter; Sunderlin, Nathaniel; Finegan, Donal; Han, Sang-Don; Tremolet de Villers, Bertrand J. 2022. "Laser Ablation for Enhanced Performance of Lithium-Ion Battery Electrodes and In-Situ Multi-Modal Characterization of High-Nickel Cathodes (NREL Internal Use Only)." *https://www.nrel.gov/docx/gen/fy23/84005.pdf*

184. Dunlap, Nathan; Sulas-Kern, Dana; Usseglio-Viretta, Francois; Weddle, Peter; Sunderlin, Nathaniel; Finegan, Donal; Tremolet de Villers, Bertrand J. 2022. "Engineering Micro-Structured Lithium-Ion Battery Electrodes for Enhanced Performance Using High-Throughput Ultrafast Laser Ablation (NREL Internal Use Only)." *https://www.nrel.gov/docx/gen/fy23/84003.pdf*

185. Duvall, Andrew. 2022. "Micromobility Integrated Transit and Infrastructure for Efficiency (MITIE)." *https://www.nrel.gov/docs/fy23osti/80003.pdf*

186. Duvall, Andrew; Wenzel, Tom; Iliev, Simeon; Garikapati, Venu; Sun, Bingrong; Wilson, Alana; Henao, Alejandro; Martin, Elliot. 2023. "Micromobility Integrated Transit and Infrastructure for Efficiency (MITIE)." Presented at the Vehicle Technologies Office Annual Merit Review, 21–23 June 2022, Washington, D.C. https://www.nrel.gov/docs/fy23osti/82737.pdf

187. Duvall, Andy. 2023. "Evolving Ground Mobility at Airports." https://www.nrel.gov/docs/fy23osti/86422.pdf

188. Fink, Kae; Colclasure, Andrew. 2023. "Purification of Lithium-Ion Battery Black Mass through Tailored Alkaline Corrosion." Presented at ACS Fall 2021, 22–26 Aug. 2021, Atlanta, GA. *https://www.nrel.gov/docs/fy23osti/80758.pdf*

189. Fink, Kae; Gasper, Paul; Schulze, Max; Brow, Ryan; Major, Joshua; Colclasure, Andrew; Keyser, Matthew. 2022. "Purification of Lithium-Ion Battery Black Mass Through Tailored Alkaline Corrosion." *https://www.nrel.gov/docs/fy23osti/84258.pdf*

190. Fink, Kae; Palmer, Jack; Zweifel, Christof; Schulze, Maxwell; Carroll, Gerard M.; Engtrakul, Chaiwat; Han, Sang-Don; Neale, Nathan R.; Tremolet de Villers, Bertrand. 2022. "Evaluating Contributions of Pitch-Carbon Coating to Improved Stability of Si Anodes Through Voltage-Resolved Multi-Phase Characterization." *https://www.nrel.gov/docs/fy23osti/83012.pdf*

191. Fink, Kae; Soto, Mel; Schulze, Maxwell C.; Carroll, Gerard Michael; Weddle, Peter J.; Verma, Ankit; Palmer, Jack; Zweifel, Christof; Neale, Nathan R.; Colclasure, Andrew M.; Tremolet de Villers, Bertrand J. 2023. "Gas-Phase Composition as a Predictive Metric for Calendar Life Behavior of Next-Generation Silicon Anodes." 2023 MRS Spring Meeting, 14 April 2023, San Francisco, CA. https://www.nrel.gov/docs/fy23osti/86003.pdf

192. Garikapati, Venu. 2022. "TCF: Ubiquitous Traffic Volume Estimation (NREL Internal Use Only)." *https://www.nrel.gov/docx/gen/fy23/80005.pdf*

193. Garikapati, Venu. 2023. "Understanding and Modeling Complex Travel Behaviors (Focus on Emerging Modes)." Presented at Envisioning Tomorrow's Sustainable Mobility Systems, 10–11 May 2023, Golden, CO. *https://www.nrel.gov/docs/fy23osti/86404.pdf*

194. Garikapati, Venu. 2023. "Understanding and Modeling Complex Travel Behaviors (Focus on Impacts of the Pandemic)." Presented at Envisioning Tomorrow's Sustainable Mobility Systems, 10–11 May 2023, Golden, CO. *https://www.nrel.gov/docs/fy23osti/86405.pdf*

195. Gasper, Paul; Laws, Nick; Rathod, Bhavesh; Olis, Dan; Smith, Kandler; Thakkar, Foram. 2023. "Optimization of Energy Storage System Economics and Controls by Incorporating Battery Degradation Costs in REopt." Presented at ECS 2023, 28 May–2 June 2023, Boston, MA. *https://www.nrel.gov/docs/fy23osti/85472.pdf*

196. Gasper, Paul; Saxon, Aron; Shi, Ying; Smith, Kandler; Thakkar, Foram. 2023. "Experimental Aging and Lifetime Prediction in Grid Applications for Large-Format Commercial Li-Ion Batteries." Presented at ECS 2023, 28 May–2 June 2023, Boston, MA. *https://www.nrel.gov/docs/fy23osti/85470.pdf*

197. Gasper, Paul; Schiek, Andrew; Shimonishi, Yuta; Yoshida, Shuhei; Smith, Kandler. 2023. "Lithium-Ion Battery Diagnostics Using Electrochemical Impedance via Machine-Learning." Presented at ECS 2023, 28 May–2 June 2023, Boston, MA. *https://www.nrel.gov/docs/fy23osti/86394.pdf*

198. Gasper, Paul; Schiek, Andrew; Smith, Kandler; Yoshida, Shuhei; Shimonishi, Yuta. 2023. "Machine-Learning for Battery Health Diagnosis." Presented at MRS Spring 2022, 8 May 2022, Honolulu, HI. *https://www.nrel.gov/docs/fy23osti/82551.pdf*

199. Gasper, Paul; Smith, Kandler; Collath, Nils; Hesse, Holger; Jossen, Andreas. 2023. "Machine-Learning Assisted Identification of Battery Life Models." ECS Boston 2023, A01-415. https://www.nrel.gov/docs/fy23osti/86369.pdf

200. Gasper, Paul; Smith, Kandler; Schiek, Andrew; Finegan, Donal; Keyser, Matt; Saxon, Aron; Fink, Kae; Coyle, Jaclyn; Verma, Ankit; Colclasure, Andrew; Guittet, Darice; Mirletz, Brian; Olis, Dan; Laws, Nick; Rathod, Bhavesh; Sunderlin, Nathaniel; Kibichi, Cyrus; Mann, Maggie; Putsche, Vicky; Weigl, Dustin. 2023. "Lithium-Ion Battery Monitoring, Lifetime Prediction, and Recycling at NREL (Citation Only)."

201. Hanig, Lily; Ledna, Catherine; Nock, Destenie; Yip, Arthur; Harper, Corey; Wood, Eric. 2023. "Comparing Electric Vehicle Charging Station Coverage (Citation Only)."

202. Harper, Jason D.; Meintz, Andrew. 2023. "Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings: Smart Charge Management and Vehicle Grid Integration (FUSE) Research, Development and Demonstration." Presented at the Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings, 18 May 2023. *https://www.nrel.gov/docs/fy23osti/86457.pdf*

203. Hodge, Cabell. 2023. "Advancing Federal Infrastructure Through Innovation." Presented at Energy Exchange, 25–27 Oct. 2022, Cincinnati, OH. https://www.nrel.gov/docs/fy23osti/84217.pdf

204. Jeong, Kyungsoo; Birky, Alicia. 2023. "Emerging Trends in Freight." Presented at Envisioning Tomorrow's Sustainable Mobility Systems, 10–11 May 2023, Golden, CO. *https://www.nrel.gov/docs/fy23osti/86402.pdf*

205. Joshi, Prateek; Powell, Bonnie; Weigl, Dustin; Johnson, Caley; Man, Derina. 2023. "Advancing Transportation Efficiency and Electric Vehicles in Tonga: A Review of Relevant Trends, Best Practices, and Future Work." Presented at the Pacific Islands Workshop on Electric Mobility, Nov. 2022. https://www.nrel.gov/docs/fy23osti/84922.pdf

206. Kekelia, Bidzina. 2022. "Thermal Management of an Integrated Traction Drive (NREL Internal Use Only)." *https://www.nrel.gov/docx/gen/fy23/84303.pdf*

207. Kekelia, Bidzina. 2023. "Integrated Traction Drive Thermal Management: Keystone Project 3." Presented at the Vehicle Technologies Office Annual Merit Review, 21–23 June 2022, Washington, D.C. https://www.nrel.gov/docs/fy23osti/82653.pdf

208. Lee, Dong-Yeon (D.-Y.). 2022. "Electrified Road Trips, Charging Infrastructure, and Equity." *https://energyoffice.colorado.gov/zero-emissions-vehicles/stakeholder-engagement-transportation*

209. Lustbader, Jason. 2023. "Truck Duty Cycle Analysis (NREL Internal Use Only)." Presented at the DOE Hydrogen Program Annual Merit Review and Peer Evaluation Meeting, 6 June 2022.

210. Meintz, Andrew. 2023. "A Summary of EVs@Scale Consortium." Presented at the Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings, 18 May 2023. *https://www.nrel.gov/docs/fy23osti/85338.pdf*

211. Meintz, Andrew; Bennett, Jesse; Harper, Jason D.; Jun, Myungsoo; Bohn, Theodore. 2022. "EVs@Scale Deep Dive - SCM/VGI (Day 2: SCM/VGI Demonstration)." *https://www.nrel.gov/docs/fy23osti/84294.pdf*

212. Meintz, Andrew; Bennett, Jesse; Liu, Zhaocai; Borlaug, Brennan; Zhang, Mingzhi; Jones, Christian Birk; Ghosh, Shibani; Panossian, Nadia; Pennington, Timothy; Sundarrajan, Manoj. 2022. "EVs@Scale Deep Dive - SCM/VGI (Day 1: SCM/VGI Analysis)." *https://www.nrel.gov/docs/fy23osti/84273.pdf*

213. Meintz, Andrew; Slezak, Lee; Thurston, Sam; Carlson, Barney; Thurlbeck, Alastair; Kisacikoglu, John; Kandula, Prasad; Rowden, Brian; Chinthavali, Madhu; Wojda, Rafal; Harter, Jonathan; Campbell, Steven; Boone, Christian; Ali, Akram Syed; Ucer, Emin. 2023. "Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings: High Power Charging (HPC) Summary Report." Presented at the Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings, 18 May 2023. *https://www.nrel.gov/docs/fy23osti/86407.pdf*

214. Miller, Jacob H.; Al Abri, Mayadhin; Huq, Nabila; Stunkel, James J.; Vardon, Derek R.; Fioroni, Gina; McCormick, Robert L. 2023. "Conversion of Wet Waste to Sustainable Aviation Fuel and Chemical Intermediates via Catalytic Upgrading." American Chemical Society Fall Meeting 2023, 16 Aug. 2023, San Francisco, CA. https://www.nrel.gov/docs/fy23osti/87121.pdf

215. Mohamed, Ahmed; Sigler, Cory; Neuman, Chris; Meintz, Andrew. 2023. "Lab Call 3B: High Power and Dynamic Wireless Charging of Electric Vehicles (Citation Only)."

216. Moreno, Gilbert. 2022. "Automotive Power Electronics Cooling Technology Research at NREL." *https://www.nrel.gov/docs/fy23osti/83645.pdf*

217. Moreno, Gilbert. 2023. "Power Electronics Cooling Technology Research at NREL." Presented at the 2022 Department of Energy Digital Twin Simulation Conference, 8 June 2022. https://www.nrel.gov/docs/fy23osti/83014.pdf

218. Moreno, Gilbert; Major, Josh; DeVoto, Doug; Khan, Faisal; Narumanchi, Sreekant; Feng, Xuhui; Paret, Paul. 2023. "Thermal Optimization of a Silicon Carbide, Half-Bridge Module (Citation Only)."

219. Moreno, Gilbert; Narumanchi, Sreekant. 2023. "Advanced Power Electronics and Electric Machines." Presented at the University of Toronto, 6 April 2022. https://dx.doi.org/10.2172/1957766

220. Muratori, Matteo. 2023. "Enabling a Sustainable Future - E-Mobility Session: The Rollout of Electric Vehicle Charging Infrastructure and Their Respective Clusters Grid Flexibility (Citation Only)."

221. Muratori, Matteo. 2023. "Whole-of-Government Strategy to Decarbonize Transportation." https://www.nrel.gov/docs/fy23osti/84847.pdf

222. Muratori, Matteo; Borlaug, Brennan. 2023. "Electric Transportation and Distribution Infrastructure: A Heavy-Duty Vehicle Deep Dive." Presented at the ESIG 2021 Fall Technical Workshop, 26 Oct. 2021. https://www.nrel.gov/docs/fy23osti/81308.pdf

223. N. A., Sreejith; Perry, Bruce; Yellapantula, Shashank; Esclapez, Lucas; Sitaraman, Hariswaran; Day, Marc. 2023. "Simulations of Fuel-Air Mixing in a 7 Element Lean Direct Injection (LDI) Aviation Combustor." Presented at the 13th U.S. National Combustion Meeting, 21 March 2023. *https://www.nrel.gov/docs/fy23osti/85689.pdf*

224. Narumanchi, Sreekant. 2022. "Advanced Power Electronics and Electric Machines for Electric-Drive Mobility Applications: Packaging, Thermal Management, and Reliability Aspects (Citation Only)."

225. Narumanchi, Sreekant. 2022. "Advanced Power Electronics and Electric Machines for Electric-Drive Mobility Applications: Packaging, Thermal Management, and Reliability Aspects (Citation Only)."

226. Narumanchi, Sreekant. 2022. "Advanced Power Electronics and Electric Machines for Electric-Drive Vehicles (Citation Only)."

227. Narumanchi, Sreekant. 2023. "Advanced Power Electronics and Electric Machines (Citation Only)."

228. Neale, Nathan R. 2022. "Status and Opportunities in Next-Generation Lithium- Ion Battery Anodes (Citation Only)."

229. Neale, Nathan R.; Martin, Trevor R.; Coyle, Jaclyn E.; Schulze, Maxwell C.; Veith, Gabriel M. 2023. "Probing Silicon Anodes in Lithium-Ion Batteries Using In Situ FTIR Spectroscopy (Citation Only)."

230. Pesaran, Ahmad; Putsche, Vicky; Mann, Margaret. 2023. "North American Lithium-Ion Battery Supply Chain Database Development - Phase II." Presented at the 22nd Annual Advanced Automotive Battery Conference, 5–8 Dec. 2022. *https://www.nrel.gov/docs/fy23osti/85610.pdf*

231. Powell, Bonnie; Endsley, Colin; Young, Stan; Duvall, Andy; Sperling, Josh; Grahn, Rick. 2023. "Fort Erie Case Study - Transition from Fixed-Route to On-Demand Transit." Presented at the Transportation Research Board Conference, 10 Jan. 2023, Washington, D.C. https://www.nrel.gov/docs/fy23osti/83229.pdf

232. Powell, Bonnie; Young, Stan; Grahn, Rick; Duvall, Andy; Endsley, Colin; Sperling, Josh. 2023. "NREL On-Demand Transit Research and Fort Erie Case Study." Presented at the Washington State Transportation Commission Meeting, 14 March 2023. https://www.nrel.gov/docs/fy23osti/85483.pdf

233. Putsche, Vicky; Witter, Erik; Santhanagopalan, Shriram; Mann, Maggie; Pesaran, Ahmad. 2023. "NAATBatt North American Lithium-Ion Battery Supply Chain Database Documentation and User Guide." https://www.nrel.gov/docs/fy23osti/80874.pdf

234. Reichelt, Lauren; Young, Stan. 2023. "Strengthening Connections Between Research and Deployment." Presented at Envisioning Tomorrow's Sustainable Mobility Systems, 10–11 May 2023, Golden, CO. *https://www.nrel.gov/docs/fy23osti/86406.pdf*

235. Rorrer, Nicholas A. 2022. "Bio-Based, Inherently Recyclable Epoxy Resins to Enable Facile Carbon-Fiber-Reinforced Composites Recycling." *https://www.nrel.gov/docs/fy23osti/82692.pdf*

236. Sharda, Shivam; Garikapati, Venu M.; Goulias, Konstadinos; Reyna, Janet L.; Sun, Bingrong; Spurlock, C. Anna; Needell, Zachary. 2022. "Is the Adoption of Electric Vehicles (EVs) and Solar Photovoltaics (PVs) Interdependent or Independent? An Integrated EVs-PVs Modeling Framework." *https://www.nrel.gov/docs/fy23osti/84543.pdf*

237. Sigler, Devon; Liu, Zhaocai; Wang, Qichao; Ugirumurera, Juliette; Ge, Yanbo; Severino, Joseph; Phillips, Caleb; Lunacek, Monte; Knueven, Bernard. 2023. "Airport Infrastructure Planning Using Multi-Stage Stochastic Programming." https://www.nrel.gov/docs/fy23osti/80951.pdf

238. Singer, Mark. 2022. "Advancing Federal Infrastructure Through Innovation: Connecting to Utilities with EV U-Finder." *https://www.nrel.gov/docs/fy23osti/84269.pdf*

239. Tang, Yihao; Hassanaly, Malik; Barwey, Shivam; Raman, Venkat. 2022. "Ignition Probability Estimation for High-Altitude Relight of Aircraft Engines (Citation Only)."

240. Usseglio-Viretta, Francois L. E.; Patel, Prehit; Bernhardt, Elizabeth; Allen, Jeffery; Smith, Kandler. 2023. "MATBOX, an Open-Source Microstructure Analysis Toolbox for Meshing, Generation, Segmentation, and Characterization of 3D Heterogenous Volumes." Presented at InterPore2021, 31 May–4 June 2021. https://www.nrel.gov/docs/fy23osti/80049.pdf

241. Wimer, Nicholas T.; Henry de Frahan, Marc T.; Kiyabu, Steven; Yellapantula, Shashank; Grout, Ray. 2022. "Machine Learning for Combustion System Control and Simulation (NREL Internal Use Only)." *https://www.nrel.gov/docx/gen/fy23/83932.pdf*

242. Wimer, Nicholas T.; Henry de Frahan, Marc T.; Yellapantula, Shashank; Grout, Ray; Day, Marc. 2022. "Deep Reinforcement Learning to Discover Multi-Fuel Injection Strategies for Compression Ignition Engines (Citation Only)."

243. Wimer, Nicholas T.; Henry de Frahan, Marc T.; Yellapantula, Shashank; Grout, Ray; Day, Marc. 2022. "Reinforcement Learning for Advanced Combustion (Citation Only)."

244. Yip, Arthur. 2023. "Decarbonizing Heavy-Duty Vehicles in the U.S." Presented at the HEC Workshop on Decarbonizing Heavy-Duty Long-Haul Trucking in Eastern Canada, April 2023. *https://www.nrel.gov/docs/fy23osti/86114.pdf*

245. Young, Stanley E. 2023. "Cutting-Edge Operations Concepts: Intelligent Infrastructure, Cooperative Driving, Signal Control, and Curbside Management." https://www.nrel.gov/docs/fy23osti/86449.pdf

246. Young, Stanley E. 2023. "Transit and Underserved Communities." https://www.nrel.gov/docs/fy23osti/86448.pdf

Technical Reports

247. Akcicek, Cemal; Aemmer, Zack; Shankari, K.; Duvall, Andrew. 2023. *Freewheeling: What Six Locations, 61,000 Trips, and 242,000 Miles in Colorado Reveal About How E-Bikes Improve Mobility Options*. *https://www.nrel.gov/docs/fy23osti/86388.pdf*

248. Bennett, Jesse; Mishra, Partha; Miller, Eric; Borlaug, Brennan; Meintz, Andrew; Birky, Alicia. 2022. *Estimating the Breakeven Cost of Delivered Electricity to Charge Class 8 Electric Tractors*. *https://www.nrel.gov/docs/fy23osti/82092.pdf*

249. Binsted, Matthew; Suchyta, Harry; Zhang, Ying; Vimmerstedt, Laura; Mowers, Matt; Ledna, Catherine; Muratori, Matteo; Harris, Chioke. 2022. *Renewable Energy and Efficiency Technologies in Scenarios of U.S. Decarbonization in Two Types of Models: Comparison of GCAM Modeling and Sector-Specific Modeling*. *https://www.nrel.gov/docs/fy23osti/84243.pdf*

250. Brown, Abby; Cappellucci, Jeff; White, Emily; Heinrich, Alexia; Cost, Emma. 2022. *Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: Second Quarter 2022*. *https://www.nrel.gov/docs/fy23osti/84263.pdf*

251. Brown, Abby; Cappellucci, Jeff; White, Emily; Heinrich, Alexia; Cost, Emma. 2023. *Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: First Quarter 2023*. https://www.nrel.gov/docs/fy23osti/86446.pdf

252. Brown, Abby; Cappellucci, Jeff; White, Emily; Heinrich, Alexia; Cost, Emma. 2023. *Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: Fourth Quarter 2022*. https://www.nrel.gov/docs/fy23osti/85801.pdf

253. Brown, Abby; Cappellucci, Jeff; White, Emily; Heinrich, Alexia; Cost, Emma. 2023. *Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: Third Quarter 2022*. https://www.nrel.gov/docs/fy23osti/84817.pdf

254. Brown, Abby; Erickson, Haley; White, Emily. 2023. *E85 Fueling Infrastructure Trends: A Decade in Review*. https://dx.doi.org/10.2172/1909898

255. Brown, Abby; Schayowitz, Alexis; White, Emily; Carlson, D'Arcy. 2023. *Propane Fueling Infrastructure Trends: A Decade in Review*. https://dx.doi.org/10.2172/1923486

256. Cappellucci, Jeff; Weigl, Dustin; Esterly, Sean; Lucas, Hallie. 2023. *USAID Colombia Young Leaders Workforce Training Program Action Plans: Planning for Electric Vehicle Charging Infrastructure in Bogota*. https://dx.doi.org/10.2172/1958281

257. Chu, Jean; Gilmore, Bridget; Hassol, Joshua; Jenn, Alan; Lommele, Steve; Myers, Lissa; Richardson, Heather; Schroeder, Alex; Shah, Monisha. 2023. *National Electric Vehicle Infrastructure Formula Program Annual Report: Plan Year 2022-2023*. https://www.nrel.gov/docs/fy23osti/86157.pdf

258. Duvall, Andrew; Young, Stanley; Fish, Joe; Henao, Alejandro; Sperling, Josh; Powell, Bonnie; Lott, Sam. 2022. *Roadmap to Automated Mobility Systems: Informing the Planning of a Sustainable, Resilient Transportation Ecosystem for Dallas/Fort Worth International Airport*. *https://www.nrel.gov/docs/fy23osti/82470.pdf*

259. Ficenec, Karen; Miller, Eric; Kotz, Andrew. 2023. *Fleet Chromosomes: Uncovering Patterns in Real-World Heavy-Duty Driving (NREL Internal Use Only)*.

260. Gilleon, Spencer; Penev, Michael; Hunter, Chad. 2022. *Powertrain Performance and Total Cost of Ownership Analysis for Class 8 Yard Tractors and Refuse Trucks*. *https://www.nrel.gov/docs/fy23osti/83968.pdf*

261. Hodge, Cabell; Desai, Ranjit R. 2022. *Camp Lejeune Federal Fleet Tiger Team EVSE Site Assessment*. *https://www.nrel.gov/docs/fy23osti/83625.pdf*

262. Jeffers, Matthew; Kelly, Kenneth; Lipman, Timothy; Fernandes Tomon Avelino, Andre; Johnson, Caley; Li, Mengming; Post, Matthew; Zhang, Yimin. 2022. *Comprehensive Review of California's Innovative Clean Transit Regulation: Phase I Summary Report*. *https://www.nrel.gov/docs/fy23osti/83232.pdf*

263. Johnson, Caley; Cappellucci, Jeff; Spath Luhring, Lauren; St. Louis-Sanchez, Maria; Yang, Fan; Brown, Abby; Sipiora, Austin; Kolpakov, Alexander; Li, Xiaopeng; Li, Qianwen; White, Sean; Gonzales, John; Nobler, Erin; Wood, Eric. 2022. *Florida Alternative Transportation Fuel Resilience Plan*. *https://www.nrel.gov/docs/fy23osti/83795.pdf*

264. Joshi, Prateek; Powell, Bonnie; Weigl, Dustin; Johnson, Caley; Man, Derina. 2023. *Advancing Transportation Efficiency and Electric Vehicles in Tonga: A Review of Relevant Trends and Best Practices*. https://dx.doi.org/10.2172/1922815

265. Kotz, Andrew; Jeffers, Matt; Henao, Alejandro; Esterly, Sean; Lucas, Hallie. 2023. *USAID Colombia Young Leaders Workforce Training Program Action Plans: Early Adopters Work to Accelerate Electric Vehicle Transitions in Boyaca, Colombia*. https://dx.doi.org/10.2172/1958609

266. Kotz, Andrew; Kelly, Kenneth; Lustbader, Jason; Cary, Scott; Oakleaf, Brett. 2022. *Port of New York and New Jersey Drayage Electrification Analysis (NREL Internal Use Only)*. *https://www.nrel.gov/docx/gen/fy23/83400.pdf*

267. Lee, Dong-Yeon; Bopp, Kaylyn; Moniot, Matthew; Kandt, Alicen. 2023. *Fast Charging Infrastructure for Electrifying Road Trips to and from National Parks in the Western United States*. https://www.nrel.gov/docs/fy23osti/87100.pdf

268. Lynch, Lauren; Payne, Grant. 2022. *NREL Fleet Analysis Support Through Technology Integration Collaboration*. *https://www.nrel.gov/docs/fy23osti/83738.pdf*

269. McCormick, Robert; Moriarty, Kristi. 2023. *Biodiesel Handling and Use Guide: Sixth Edition*. https://www.nrel.gov/docs/fy23osti/86939.pdf

270. Pesaran, Ahmad; Roman, Lauren; Kincaide, John. 2023. *Electric Vehicle Lithium-Ion Battery Life Cycle Management*. https://dx.doi.org/10.2172/1924236

271. Powell, Bonnie; Endsley, Colin; Young, Stanley E.; Duvall, Andrew; Sperling, Josh; Grahn, Rick. 2023. *Fort Erie On-Demand Transit Case Study*. https://dx.doi.org/10.2172/1908698

272. Romero-Lankao, Paty; Rosner, Nicole; Efroymson, Rebecca A.; Parisch, Esther S.; Blanco, Lis; Smolinski, Sharon; Kline, Keith. 2023. *Community Engagement and Equity in Renewable Energy Projects: A Literature Review*. https://www.nrel.gov/docs/fy23osti/87113.pdf

273. Romero Lankao, Paty; Rosner, Nicole; Reichelt, Lauren; Allerhand, Joanna. 2023. *Clean Cities: A Model of Collaborative Technology Innovation Built Over 30 Years*. https://www.nrel.gov/docs/fy23osti/85510.pdf

274. Singer, Mark; Johnson, Caley; Rose, Edward; Nobler, Erin; Hoopes, Luna. 2023. *Electric Vehicle Efficiency Ratios for Light-Duty Vehicles Registered in the United States*. https://dx.doi.org/10.2172/1962550

275. Singer, Mark; Johnson, Caley; Wilson, Alana. 2023. Clean Cities Coalitions 2021 Activity Report. https://dx.doi.org/10.2172/1922619

276. Weigl, Dustin; Inman, Daniel; Hettinger, Dylan; Ravi, Vikram; Peterson, Steve. 2022. *Battery Energy Storage Scenario Analyses Using the Lithium-Ion Battery Resource Assessment (LIBRA) Model*. *https://www.nrel.gov/docs/fy23osti/81875.pdf*

277. Wood, Eric; Borlaug, Brennan; Moniot, Matthew; Lee, Dong-Yeon; Ge, Yanbo; Yang, Fan; Liu, Zhaocai. 2023. *The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure*. https://www.nrel.gov/docs/fy23osti/85654.pdf

278. Yip, Arthur; Hoehne, Christopher; Jadun, Paige; Ledna, Catherine; Hale, Elaine; Muratori, Matteo. 2023. *Highly Resolved Projections of Passenger Electric Vehicle Charging Loads for the Contiguous United States: Results From and Methods Behind Bottom-Up Simulations of County-Specific Household Electric Vehicle Charging Load (Hourly 8760) Profiles Projected Through 2050 for Differentiated Household and Vehicle Types*. https://www.nrel.gov/docs/fy23osti/83916.pdf

279. Zhou, Ella; Gadzanku, Sika; Hodge, Cabell; Campton, Mike; de la Rue du Can, Stephane; Zhang, Jingjing. 2023. *Best Practices in Electricity Load Modeling and Forecasting for Long-Term Power System Planning*. https://www.nrel.gov/docs/fy23osti/81897.pdf

Online NREL.gov Features, Press Releases, & News Items

1. Solutions Emerge for Decarbonizing Historically Difficult Off-Road Vehicle Sector (Oct. 3, 2022). https://www.nrel.gov/news/program/2022/solutions-emerge-for-decarbonizing-historically-difficult-off-road-vehicle-sector.html

2. A Vision for the Future: Flexible Data Sharing Could Accelerate Battery Breakthroughs (Oct. 19, 2022). https://www.nrel.gov/news/program/2022/flexible-data-sharing-could-accelerate-battery-breakthroughs.html

3. Stronger Supply Chain Links to a Clean Energy Future (Nov. 3, 2022). https://www.nrel.gov/news/features/2022/stronger-supply-chain-links-to-a-clean-energy-future.html

4. NREL-Authored Clean Energy Supply Chain Analysis Reports (Nov. 3, 2022). https://www.nrel.gov/news/program/2022/nrel-authored-clean-energy-supply-chain-analysis-reports.html

5. National Lab Collaboration Shows Biofuels Are Competitive Alternatives to Petroleum Across the Board (Nov. 10, 2022). https://www.nrel.gov/news/program/2022/national-lab-collaboration-shows-biofuels-are-competitive-alternatives-to-petroleum-across-the-board.html

6. Livewire Data Platform Expands Access to Transportation Project Data Sets (Nov. 11, 2022). https://www.nrel.gov/news/program/2022/livewire-data-platform-expands-access-to-transportation-project-data-sets.html

7. Collaborative Database Maps Lithium-Ion Supply Chain Landscape (Nov. 17, 2022). https://www.nrel.gov/news/program/2022/collaborative-database-maps-li-ion-supply-chain-landscape.html

8. Air Force Accelerator Adds NREL for Sustainable Aviation Expertise (Dec. 1, 2022). https://www.nrel.gov/news/program/2022/air-force-accelerator-adds-nrel-for-sustainable-aviation-expertise.html

9. Transit Data Shed Light on Ridership Trends, Service Impacts (Dec. 6, 2022). https://www.nrel.gov/news/program/2022/transit-data-shed-light-on-ridership-trends-service-impacts.html

10. Top 20 NREL Stories of 2022 (Dec. 28, 2022). https://www.nrel.gov/news/features/2022/top-20-nrel-stories-of-2022.html

11. NREL Coauthors Landmark National Blueprint for Transportation Decarbonization (Jan. 18, 2023). https://www.nrel.gov/news/program/2023/nrel-co-authors-landmark-national-blueprint-for-transportation-decarbonization.html

12. Powering the Future: NREL Research Finds Opportunities for Breakthrough Battery Designs (Jan. 19, 2023). https://www.nrel.gov/news/features/2023/powering-the-future-nrel-research-finds-opportunities-for-breakthrough-battery-designs.html

13. IN^2 Demonstration: Getting V2G Good To Go (Jan. 19, 2023). https://www.nrel.gov/news/program/2023/in2-demonstration-getting-v2g-good-to-go.html

14. Department of Energy Honors 12 From NREL (Jan. 26, 2023). https://www.nrel.gov/news/program/2023/department-of-energy-honors-11-from-nrel.html

15. NREL Receives $3.4M in Federal Funding To Evaluate Safety of Next-Generation Electric Vehicle Batteries (Jan. 30, 2023). https://www.nrel.gov/news/program/2023/nrel-receives-34m-in-federal-funding-to-evaluate-safety-of-next-generation-electric-vehicle-batteries.html

16. NREL Leads the Charge to Electric Trucks at Port of New York and New Jersey (Jan. 30, 2023). https://www.nrel.gov/news/program/2023/nrel-leads-the-charge-to-electric-trucks-at-port-of-new-york-and-new-jersey.html

17. NREL Teams With Australia's Fortescue Future Industries on a Colorado Innovation Center (March 14, 2023). https://www.nrel.gov/news/features/2023/nrel-teams-with-australias-fortescue-future-industries-on-a-colorado-innovation-center.html

18. NREL Regional Analysis Can Help Accelerate Production and Delivery of Sustainable Aviation Fuel (March 16, 2023). https://www.nrel.gov/news/program/2023/nrel-regional-analysis-can-help-accelerate-production-delivery-sustainable-aviation-fuel.html

19. New Infrastructure Perception and Control Lab Merges Transportation and Computational Science (March 20, 2023). https://www.nrel.gov/news/program/2023/new-infrastructure-perception-and-control-lab-merges-transportation-and-computational-science.html

20. Advanced Computing Powers 300-Plus Clean Energy Projects (March 28, 2023). https://www.nrel.gov/news/program/2023/advanced-computing-powers-300-plus-clean-energy-projects.html

21. NREL Study Shows Airport Energy Savings in Surprising Places: How You Find Your Way Around (March 29, 2023). https://www.nrel.gov/news/program/2023/nrel-study-shows-airport-energy-savings-in-surprising-places-how-you-find-your-way-around.html

22. LIBRA Model Guides Development of Sustainable Battery Supply Chain (April 6, 2023). https://www.nrel.gov/news/program/2023/libra-model-guides-development-sustainable-battery-supply-chain.html

23. NREL Tapped To Help Electrify 4 Major Freight Corridors (April 18, 2023). https://www.nrel.gov/news/program/2023/nrel-tapped-to-help-electrify-4-major-freight-corridors.html

24. New Interactive Map Shows EV Charging Stations Near National Parks (April 24, 2023). https://www.nrel.gov/news/program/2023/new-interactive-map-shows-ev-charging-stations-near-national-parks.html

25. NREL Researchers Reveal Concept To Curb Need for Battery Storage (April 27, 2023). https://www.nrel.gov/news/program/2023/nrel-researchers-reveal-concept-to-curb-need-for-battery-storage.html

26. NREL Model Cuts Through Complexity of Deploying Electric Buses at Airports (May 4, 2023). https://www.nrel.gov/news/program/2023/nrel-model-cuts-through-complexity-of-deploying-electric-buses-at-airports.html

27. Piloting Future Fuels: Calvin Mukarakate Sees a Problem, Solves a Problem (May 18, 2023). https://www.nrel.gov/news/program/2023/piloting-future-fuels-calvin-mukarakate-sees-a-problem-solves-a-problem.html

28. News Release: Inflation Reduction Act Invests $150 Million in NREL Projects (May 22, 2023). https://www.nrel.gov/news/press/2023/news-release-inflation-reduction-act-invests-150-million-in-nrel-projects.html

29. NREL Adds Lab Space With New Building, Preps Other Projects (May 23, 2023). https://www.nrel.gov/news/features/2023/nrel-adds-lab-space-with-new-building-preps-other-projects.html

30. NREL Collaborates With Volvo Group To Chart Course Toward Zero-Emission Commercial Vehicles (May 31, 2023). https://www.nrel.gov/news/program/2023/nrel-collaborates-with-volvo-group-to-chart-course-toward-zero-emission-commercial-vehicles.html

31. NREL's Gallium Oxide Power Module Represents Innovation on Nearly Every Front (June 5, 2023). https://www.nrel.gov/news/program/2023/nrels-gallium-oxide-power-module-represents-innovation-on-nearly-every-front.html

32. NREL Power Electronics Researcher Wins ASME Avram Bar-Cohen Memorial Medal (June 5, 2023). https://www.nrel.gov/news/program/2023/nrel-power-electronics-researcher-wins-asme-avram-bar-cohen-memorial-medal.html

33. Digital-Twin Project Green-Lights Traffic Congestion Improvements (June 8, 2023). https://www.nrel.gov/news/program/2023/digital-twin-project-green-lights-traffic-congestion-improvements.html

34. Clean Cities Thrives for 30 Years as Model for Collaborative Technology Deployment (June 8, 2023). https://www.nrel.gov/news/program/2023/clean-cities-thrives-for-30-years-as-model-for-collaborative-technology-deployment.html

35. NREL Researchers Traveled the Southwest To See the Future of Transportation in Action (June 20, 2023). https://www.nrel.gov/news/program/2023/nrel-researchers-traveled-the-southwest-to-see-the-future-of-transportation-in-action.html

36. Climate Justice Champions Celebrated at Finale of Inclusive Energy Innovation Prize (June 21, 2023). https://www.nrel.gov/news/program/2023/climate-justice-champions-celebrated-at-finale-of-inclusive-energy-innovation-prize.html

37. Colorado Shows Eagerness for Sustainable Aviation (June 21, 2023). https://www.nrel.gov/news/program/2023/colorado-shows-eagerness-for-sustainable-aviation.html

38. Building the 2030 National Charging Network (June 27, 2023). https://www.nrel.gov/news/program/2023/building-the-2030-national-charging-network.html

39. Small But Mighty: Electric Bicycles Can Bridge the Gap in Access to Transportation (July 3, 2023). https://www.nrel.gov/news/program/2023/small-but-mighty-electric-bicycles-can-bridge-the-gap-in-access-to-transportation.html

40. Quantum Computers Can Now Interface With Power Grid Equipment (July 17, 2023). https://www.nrel.gov/news/program/2023/quantum-computers-can-now-interface-with-power-grid-equipment.html

41. Full Speed Ahead: Modeling a Faster Future for Lithium-Ion Batteries (July 18, 2023). https://www.nrel.gov/news/program/2023/full-speed-ahead-modeling-faster-future-lithium-ion-batteries.html

42. Sparking Collaboration on Sustainable Transportation Across the Pacific (July 31, 2023). https://www.nrel.gov/news/program/2023/sparking-collaboration-on-sustainable-transportation-across-the-pacific.html

43. All Aboard! NREL Releases First Comprehensive, Open-Source Software for Freight Rail Decarbonization (Aug. 2, 2023). https://www.nrel.gov/news/program/2023/nrel-altrios-release.html

44. NREL Workshop Hosts Experts To Envision Tomorrow's Sustainable Mobility Systems (Aug. 4, 2023). https://www.nrel.gov/news/program/2023/eems-workshop.html

45. 5 NREL Partnerships Transforming Energy in Aviation (Aug. 17, 2023). https://www.nrel.gov/news/program/2023/5-nrel-partnerships-transforming-energy-in-aviation.html

46. Battery-Electric Fishing Vessel Marks a Sea Change for Small Commercial Fishers (Aug. 22, 2023). https://www.nrel.gov/news/program/2023/battery-electric-fishing-vessel-marks-a-sea-change-for-small-commercial-fishers.html

47. 10 Years of Leading Energy Systems Innovation (Aug. 23, 2023). https://www.nrel.gov/news/features/2023/10-years-of-leading-energy-systems-innovation.html

48. NREL Supports Efforts To Solve Drivers' Electric Vehicle Charging Experience Challenges (Sept. 14, 2023). https://www.nrel.gov/news/program/2023/nrel-supports-efforts-to-solve-drivers-electric-vehicle-charging-experience-challenges.html

49. Clean Cities Celebrates 30 Years of Acting Locally To Generate National Impact (Sept. 15, 2023). https://www.nrel.gov/news/program/2023/clean-cities-celebrates-30-years-of-acting-locally-to-generate-national-impact.html

50. A Tale of Two Cities (Powered by Clean Energy) (Sept. 22, 2023). https://www.nrel.gov/news/program/2023/a-tale-of-two-cities-powered-by-clean-energy.html

51. NREL Research Finds the Right TEMPO for National Electric Vehicle Grid Planning (Sept. 25, 2023). https://www.nrel.gov/news/program/2023/nrel-research-finds-the-right-tempo-for-national-electric-vehicle-grid-planning.html

Image Credits

Cover(front), photo by Werner Slocum, NREL 72378; pages 2-3, photo from iStock, 1268203592; page 4, photo by Werner Slocum, NREL 79579; page 5, photo by Joe DelNero, NREL; page 6, photo by Bryan Bechtold, NREL 82433; page 7, photo from iStock, 1427504279; page 8, photos from the Port Authority of New York and New Jersey and iStock, 1461002501; page 9, photos from iStock, 583994704, and Eric Jordan; page 10, photos by Dennis Schroeder, NREL 61178, and Werner Slocum, NREL 74583; page 11, photos by Joe DelNero, NREL 82170, and iStock, 1363424512; page 12, photo by Werner Slocum, NREL 67632, and logo from DOE; page 13, photo from Getty, 1461174736; page 14, photo from Getty, 1395297110; page 15, photos from Getty, 1410358773, 1323085178, 1470571662, 327573950, 1337274650, 1303310282, 960035492 and by Anna Squires, NREL; page 16, figure by Al Hicks, NREL; page 17, figures by Besiki Kazaishvili, NREL; page 18, photo from Getty, 1466761281; page 19, photo from Illinois Alliance for Clean Transportation, NREL 42821; page 20, figure by NREL and photo from Getty, 1162389380; page 21, photo from DFW; page 22, photo by Dennis Schroeder, NREL 46494; page 23, photo from Getty, 860097132; page 24, photo by Leslie Eudy, NREL 54538; page 26, illustration by Josh Bauer, NREL; page 28, illustration by Josh Bauer, NREL, photo by Josh Bauer and Bryan Bechtold, NREL 73063, and photo from iStock, 841429712; page 29, photo by Werner Slocum, NREL 76044; page 31, photo by Werner Slocum, NREL 70138; page 32, figure by Stan Young, NREL; page 33, photos by Josh Major and Brittany Conrad, NREL, and map image by NREL; page 34, photo by Katie Harrison; page 35, photos by Patrick Corkery, NREL 29211, Werner Slocum, NREL 83659, 74520, and 71509; page 36, photos by Werner Slocum, NREL 83566, 72574, 71216, Faisal Khan, and Jeff Gonder; page 37, photos by Werner Slocum, NREL 82048 and 83570, and K. Shankari; page 39, photo by Joe DelNero, NREL 81872; pages 40-41, photo by Werner Slocum, NREL 74589; page 47, photo from Getty, 1470571662; page 48, illustration by Al Hicks, NREL, and photos from Getty, 1151571867 and 1646031167; page 50, photo from Getty, 1149089650; page 51, photo by Dennis Schroeder, NREL 31487; page 52, photo from Getty, 1475559203; page 54, figure by NREL and photo from Getty, 1496368943; page 57, photo by Leslie Eudy, NREL 35803; page 76, photo by Werner Slocum, NREL 79291; cover (back), photo by Joe DelNero, NREL 74814

NREL'S VEHICLES & MOBILITY R&D TEAM

Technical Team and Facility Leaders

Advanced Biofuels and Combustion	**Robert McCormick**
Data Sciences	**Monte Lunacek**
Electric Vehicle Grid Integration	**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	**Ted Sears**
Lightweight and Recyclable Composite Materials	**Nicholas Rorrer**
Mobility Systems	**Stan Young**
Power Electronics & Electric Machines	**Doug DeVoto and Gilbert Moreno**
Technology Integration/Clean Cities	**Wendy Dafoe**
Vehicle Modeling and Analysis	**Eric Wood**

Directorate, Program & Center Leadership

Johney B. Green
Associate Lab Director
Mechanical & Thermal Engineering Sciences

John Farrell
Laboratory Program Manager, Vehicle Technologies Office

Chris Gearhart
Director
Integrated Mobility Sciences

Ray Grout
Director
Computational Science

Jao Van de Lagemaat
Director
Chemistry & Nanoscience

Tony Burrell
Chief Technologist
Energy Storage

Ken Kelly
Chief Engineer for Commercial Vehicle Electrification

Faisal Khan
Principal Researcher
Power Electronics

Andrew Meintz
Chief Engineer for EV Charging and Grid Integration

Ahmad Pesaran
Chief Energy Storage Engineer

Sarah Cardinali
Group Manager (Acting)
Transportation Technical Assistance

Marc Day
Group Manager
High-Performance Algorithms & Complex Fluids

Gina Fioroni
Group Manager
Fuels & Combustion Science

Jeff Gonder
Group Manager
Mobility, Behavior & Advanced Powertrains

Wesley Jones
Group Manager
Complex Systems Simulation and Optimization

Matt Keyser
Group Manager
Electrochemical Energy Storage

Johanna Levene
Group Manager
Transportation Applications & Data Analysis

Jason Lustbader
Group Manager
Advanced Vehicles & Charging Infrastructure

Margaret Mann
Group Manager
Mobility Infrastructure & Impacts Analysis

Margo Melendez
Group Manager (Acting)
Transportation Engagement & Outreach
Transportation Deployment Analysis

Juliane Mueller
Group Manager
AI, Learning, and Intelligent Systems

Matteo Muratori
Group Manager
Transportation Energy Transition Analysis

Sreekant Narumanchi
Group Manager
Advanced Power Electronics & Electric Machines

Nate Neale
Group Manager
Interfacial Materials Chemistry

Kristi Potter
Group Manager
Data, Analysis & Visualization

Jibo Sanyal
Group Manager
Hybrid Energy Systems

Affiliated Lab-Wide Leadership

Adam Bratis
Associate Lab Director
Bioenergy Science & Technology

Juan Torres
Associate Lab Director
Energy Systems Integration

Bill Tumas
Associate Lab Director
Materials, Chemical & Computational Sciences

VEHICLE AND MOBILITY TECHNOLOGIES
2023 ANNUAL IMPACT REPORT

NREL
Transforming ENERGY

National Renewable Energy Laboratory
15013 Denver West Parkway, Golden, CO 80401
303-275-3000 • www.nrel.gov

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

NREL/MP-5400-87835 • October 2023

NREL prints on paper that contains recycled content.