2022

Fiscal Year in Review

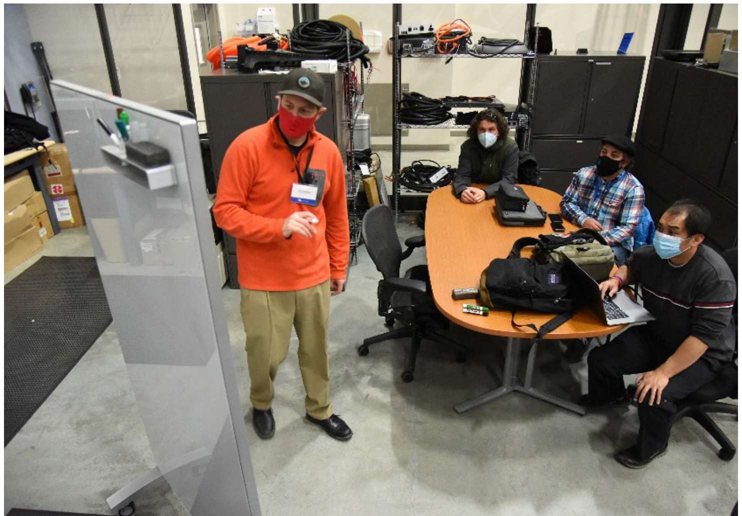
Electric Vehicles at Scale Laboratory Consortium

EVs@Scale
U.S. Department of Energy

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Disclaimer

Photos (left to right): NREL, INL, ORNL



About the Consortium

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ABOUT THE ELECTRIC VEHICLES AT SCALE LABORATORY CONSORTIUM

The U.S. Department of Energy's (DOE) Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium brings together six national laboratories—Argonne National Laboratory (ANL), Idaho National Laboratory (INL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL)—and key stakeholders to conduct electric vehicle (EV) charging and grid infrastructure research and development. R&D will address challenges and barriers to high-power EV charging at scale that enables increased safety, grid operation reliability, and consumer confidence. This will also move the nation closer to a net-zero-emissions future. As such, research activities will advance innovations in and support standards development for on-road and off-road vehicle charging. The effort will also develop technologies to integrate vehicle charging with the electric grid and develop cybersecurity measures to protect drivers, vehicles, equipment, and the grid from multifaceted threats.

The advanced technologies developed by the consortium will help make charging an EV as safe, convenient, and seamless as fueling a gas-powered vehicle as well as easy to find an EV charging station. This will motivate increased consumer adoption and benefit all communities, including those in underserved urban and rural areas. The consortium will also identify and develop technologies to charge the large batteries required for freight trucks and buses efficiently, affordably, and securely, to ultimately reduce transportation emissions. The smart charging strategies, technologies, and support to standards development by the consortium will help electrify air, marine, rail, and other off-road transportation modes.

Ensuring that the grid infrastructure remains reliable by defending against cyberthreats is crucial to supporting EV charging needs. Internet-connected systems help control everything from balancing the grid's electricity supply to processing charging station payments. The consortium's work to avert any possible attacks on the electric grid or a charging network will protect vehicle and electrical systems and increase consumer confidence in EVs. This consortium addresses key R&D opportunities:

- Develop grid planning strategies and vehicle control methods, also known as **vehicle-grid integration and smart charge management (SCM)**, to mitigate grid disruptions caused by the increase in higher-power electric vehicle supply equipment (EVSE).
- Expand **high-power charging** opportunities, including improving long-term efficiencies and reducing investment and operation costs. Efforts target increasing charging equipment power densities to address the lack of high-voltage, high-current devices for power electronics, interconnection requirements necessary for multimegawatt charging sites, and modularity across sites to support the correct balance and commonality.
- Advance the **dynamic wireless power transfer (DWPT)** technology required to transition proof-of-concept technology to practical real-world applications and assess key performance metrics to ensure safe, secure, and efficient power transfer. Lab-developed, high-power DWPT technologies have not yet been tested under real-world road conditions to understand the practical installation, operation, performance, and maintenance challenges to deployment.
- Address the evolving threats and challenges to the EV charging ecosystem through **cyber-physical security** research and validation of the most feasible solutions to ensure safe, secure, and resilient charging operation. The security of EV charging infrastructure is critical to protect EV users, the EV charging network, and the grid.
- Harmonize **codes and standards** by identifying and addressing challenges and barriers created by conflicting standards and requirements to help integrate at-scale EV charging with the grid. Technical standards are imperative to the development, deployment, and adoption of advanced EV charging and grid integration technologies; uncoordinated development of codes and standards will create inconsistencies that will impede the deployment of secure and scalable charging systems.

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Although 2022 saw the nation still recovering from the COVID-19 pandemic, our consortium members adapted quickly and continued research and collaboration. We also successfully hosted our first Semiannual Stakeholder Meeting in August 2022 with 40 members of industry and academia in person at NREL and more than 100 virtually. We convened in person with our external steering committee (ESC) members and hosted a series of deep-dive technical meetings to further engage our stakeholders, with an average of 70 attendees per session.

As fiscal year 2023 (FY23) begins, we continue our research into advancing EV technologies on all fronts. We thank the leadership of the Vehicle Technologies Office (VTO) under DOE's Office of Energy Efficiency & Renewable Energy (EERE) for their continued support of this consortium. We also thank our ESC for their continued feedback, which has made a positive impact on the achievements of this consortium in its first year.

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VEHICLE TECHNOLOGIES OFFICE

EVs@Scale
U.S. Department of Energy

Oak Ridge National Laboratory

Idaho National Laboratory

Pacific Northwest National Laboratory

Sandia National Laboratories

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NREL Transforming ENERGY

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Photo: NREL

Stakeholders Help Navigate EVs@Scale Priorities

DOE's Office of Energy Efficiency and Renewable Energy and Office of Electricity are moving the nation to 100% clean electricity with the Vehicle-Grid Integration (VGI) Initiative. The EVs@Scale team—along with many others advancing electric vehicle technologies to achieve this goal—are ambitiously attempting to electrify the transportation sector, which derives less than 1% of its energy from electricity. We are working at a rapid pace to focus on reducing high operating costs with actionable, specific plans. The consortium set out to engage stakeholders and the public over the Semiannual Stakeholder Meeting and the technical meeting series in FY22 to refine these plans with input on priorities and needs. Attendees spanned the electric vehicle industry, as well as from academia, government agencies, and research institutions.

Even with FY22 still facing residual challenges from the pandemic, the consortium hosted its first Semiannual Stakeholder Meeting in a hybrid format. The in-person component was hosted at NREL, and virtual attendees dialed in via Zoom. The event format enabled the consortium to share R&D targets, opportunities, and challenges with the larger research and stakeholder communities both virtually and in person. Partnership inquiries were fielded during both the research pillar presentations and the networking sessions. Participants were especially interested in staying up to date on consortium work beyond events and ensuring that more voices were heard during the consortium's activities to provide input. For example, no advocacy or fuel suppliers were present, and there was low attendance from fleet operators and automotive original equipment manufacturers (OEMs)/services. The consortium will continue to expand its outreach to fill this perspective gap, especially with ORNL set to host the second Semiannual Stakeholder Meeting in FY23 in person.

The EVs@Scale Lab Consortium also established an online presence to further engage the public, stakeholders, and potential partners. Participants from the Semiannual Stakeholder Meeting indicated that a website is helpful in staying connected with consortium activities and publications. The consortium's webpages are published under the VTO website's "Batteries, Charging, and Electric Vehicles" section. The web content shares the consortium's mission, partner laboratories, research areas, goals, publications, and contact information.

The consortium also invited industry members to join the ESC. The ESC is a smaller audience with key stakeholders to continue conversations about challenges and opportunities facing the consortium's research in greater depth. The consortium convened a hybrid meeting with the ESC members following the Semiannual Stakeholder Meeting. These members, along with the public, were invited to another follow-up series of technical research sessions. Over the course of two days for each research area, these technical meetings attracted on average 70 attendees, and included the following topics:

- **Cybersecurity Assessments** – Discussion on cybersecurity assessments of systems, features, and architectures.
- **Cyber Tools, Training, Mitigation Solutions, and Codes & Standards** – Discussion on the cybersecurity tools and mitigation solutions to improve security and training of the next generation of cybersecurity workforce, including relevant codes and standards.
- **Grid and Smart Charging Analysis** – Discussion on the approach to regional modeling activity for light-, medium-, and heavy-duty vehicles utilizing telematics and utility network data to understand the impact of uncontrolled charging and the benefits of SCM.
- **Development/Demonstration** – Discussion on background and applications of charge scheduling, EVrest workplace charge reservation development and demonstration, and OptiQ smart alternating-current (AC) Level 2 (L2) EVSE development and demonstration.
- **Codes and Standards** – Discussion on the existing standards of value and the gaps in standards based on analysis.

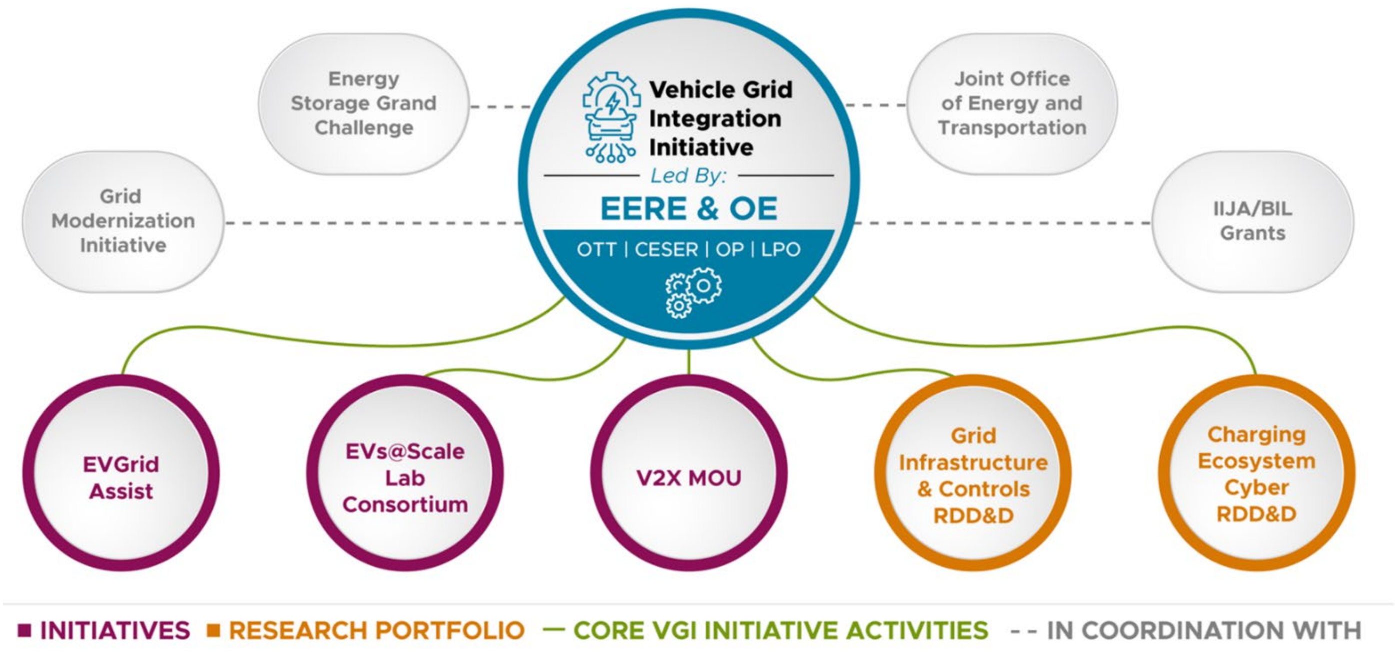
We are actively seeking partnerships to increase our impact. We bring together cutting-edge resources from DOE and our national laboratories and are well positioned to include stakeholders into our various research projects. We are ramping up our efforts to educate the public on our work and encourage partnership to increase visibility and impact.

EVs@Scale Supports DOE Vehicle-Grid Integration Initiative

EERE and the Office of Electricity are moving the nation to 100% clean electricity, and the transportation sector is no exception. As transportation is one of the largest contributors to the nation's carbon emissions, the VGI Initiative examines the potential impacts of EV integration with the grid—especially as the EV market continues to expand—on grid reliability and resiliency to achieve a carbon-free electricity sector by 2035.

Collaboration across offices is one way in which DOE is developing affordable, efficient, and clean transportation options to tackle the climate crisis and accelerate the development of innovative transportation technologies. The VGI Initiative focuses on driving a coordinated approach across the DOE, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Housing and Urban Development to fully decarbonize the transportation sector.

The EVs@Scale Lab Consortium is one of five core VGI initiatives. The EVs@Scale Lab Consortium conducts infrastructure research and development to address challenges and barriers for high-power EV charging infrastructure that enable greater safety, grid operation reliability, and consumer confidence. EVGrid Assist supports decision makers as they plan for the future of electrification with technical assistance. V2X MOU evaluates technical and economic feasibility as we integrate bidirectional charging into energy infrastructure and will also advance cybersecurity as a core component of V2X charging infrastructure. Taken together with two research portfolios, the VGI Initiative is well-aligned to help bring the transportation sector closer to a net-zero-emission future.



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DOE's national laboratories possess unique instruments and facilities, many of which are found nowhere else in the world. For 75 years, national laboratories have collaborated within the system to further U.S. energy independence and leadership in clean technologies, promote innovation that advances U.S. economic competitiveness, and conduct research of the highest caliber. The EVs@Scale Lab Consortium is proof of this.

Research institutions, federal agencies, nonprofits, academia, and industry often establish partnerships with our laboratories to help pinpoint R&D needs, potential issues, and mitigation strategies in all areas of our research. These partnerships produce world-class research that informs the best solutions for the greatest scientific challenges of our time—without regard to organizational boundaries. The national labs and EERE recognize that continued exchanges with these partners help focus and prioritize EVs@Scale R&D on areas with the greatest chance for near-term market impact.

Will you join us?

Contact us at evsscale@googlegroups.com.

See the following pages for more detail on the most significant EVs@Scale accomplishments. Learn more about our consortium partnerships on the EVs@Scale website: energy.gov/eere/vehicles/electric-vehicles-scale-consortium.

Photo: NREL

DEVELOPMENT & DEMONSTRATION OF OPTIQ: A SMART AC L2 EVSE ADVANCES SMART CHARGING ALGORITHMS

Achievement: Developed proof-of-concept AC L2 EVSE "OptiQ," based on the SpEC II communication controller that is capable of three modes of communication.

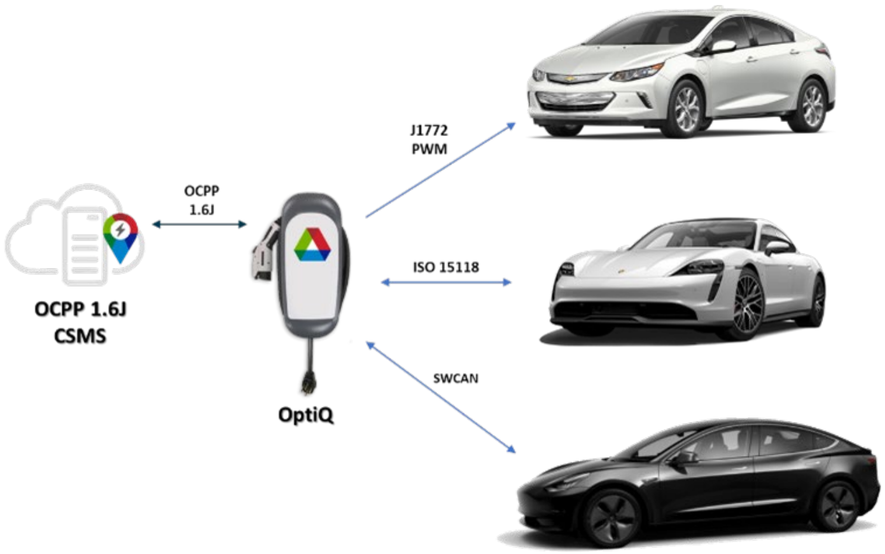
Impact: Provides a cutting-edge platform to implement advanced smart charging algorithms and demonstrate the benefits of digital-based communication for AC charging.

AC charging of electric vehicles involves either analog- or digital-based communication between the EV and EVSE. Despite the existence of two digital protocols—ISO 15118 and Tesla SAE J2411 (SWCAN)—automotive OEMs have been slow to implement digital-based communication, perhaps because the benefits have never been quantified. With no EVSE currently on the market capable of handling all three communication modes (one analog and two digital), ANL research engineers have developed and deployed proof-of-concept AC L2 EVSE.

The OptiQ EVSE is based on ANL's SpEC II communication controller, which is capable of all three modes. Researchers developed, tested, and debugged an Open Charge Point Protocol (OCPP) 1.6J-compliant client and wrote a custom application to accomplish SAE J1772 analog-based charging and ISO 15118-2 digital-based charging. The application integrates the charge sessions into an OCPP 1.6J charge station management system. Two proof-of-concept OptiQ EVSE have been deployed for ANL employee use at the Lemont, Illinois, campus.

OptiQ is a cutting-edge platform to implement advanced smart charging algorithms and educate industry stakeholders about the benefits of digital-based communication for AC charging. ANL research engineers will implement the Tesla SWCAN protocol next; with Tesla's market share of light-duty EVs in the United States at 70% in Q4 of 2021, the ability to communicate with these vehicles and integrate them into the smart grid could be significant.

As ANL pursues a commercial partner for the OptiQ EVSE, engineers will continue developing and refining the firmware to enable a station capable of choosing the correct communication mode and beginning the charge session with no driver intervention.



The OptiQ EVSE is based on ANL's SpEC II communication controller, which is capable of all three modes of communication—one analog and two digital—and a custom application integrates the charge sessions into an OCPP 1.6J charge station management system

ASSESSMENT OF SMART CHARGE MANAGEMENT STRATEGIES IN DIVERSE GRID CONDITIONS IDENTIFIES GAPS

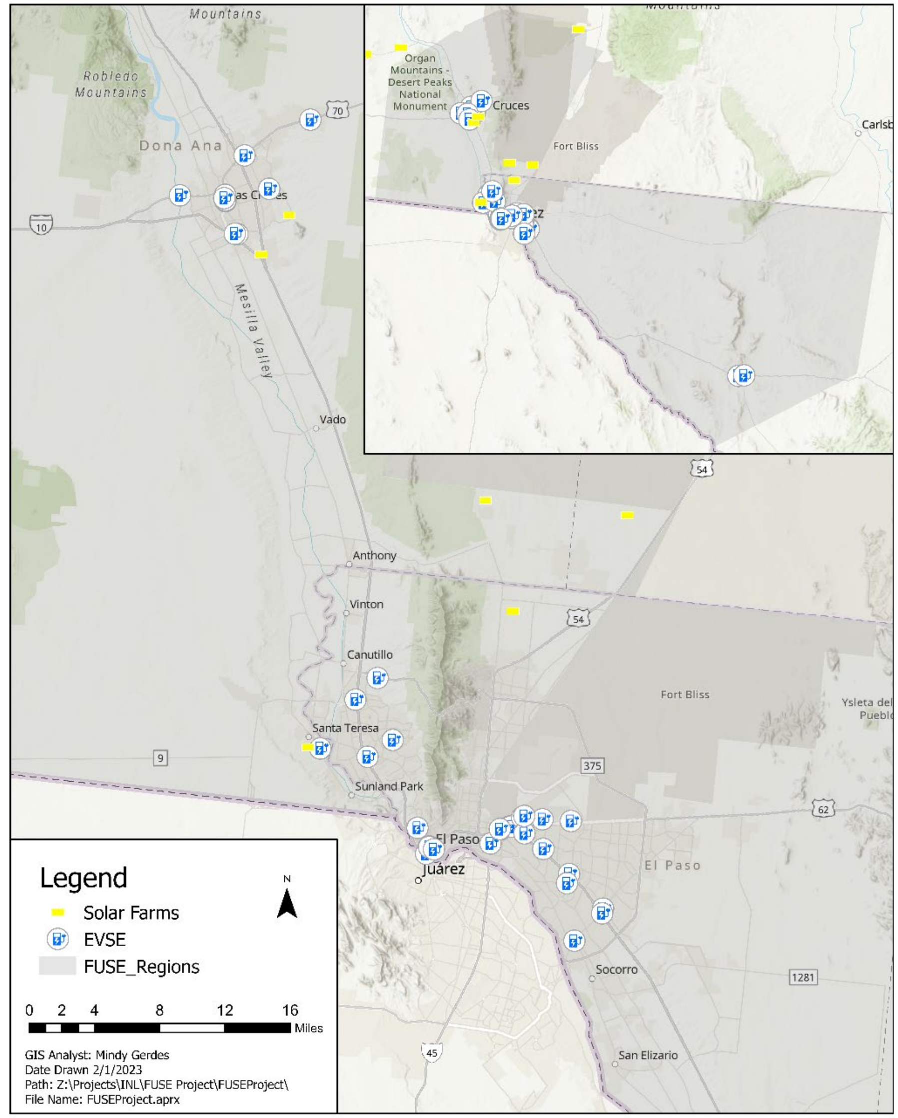
> **Achievement:** Conducted assessments of existing control strategies and their ability to best align load with generation for a diverse set of regions across the United States.
>
> **Impact:** These assessments enhance our understanding of what generation and load may look like in a future with significant renewable deployments, helping optimize infrastructure deployment today and the development of control strategies and incentives that will benefit grid integration as EV adoption increases.

SCM control strategies are developed to address specific needs of regional electrical grids. This regional research is critical to understand the impacts of EV charging on local distribution networks and to create infrastructure designs and control strategies that can shift the EV load to best align with the local grid's capacity. Understanding what generation and load may look like in a future with significant renewable deployments can allow for more effective infrastructure deployment today and the development of control strategies and incentives that will benefit grid integration as EV adoption increases However, each region will have different characteristics and needs depending on the nature of their non-EV load, amount of renewable deployment, and availability of generation. These differences may require adjusting the objective of control strategies or developing entirely new strategies.

An SCM study within the Flexible charging to Unify the grid and transportation Sectors for EVs at scale (FUSE) project selected a diverse set of regions to represent areas of summer/winter load peaks, high solar/wind deployment plans, and both rural and urban areas with existing industry and major highways carrying truck freight. A workflow was then created in the Caldera simulation platform to predict a possible EV charging load to compare with the anticipated generation profiles and non-EV load. Then, existing control strategies from previous research were implemented to assess their ability to best align load with generation. Initial results from the El Paso Electric region suggest that by 2040, solar generation will outproduce non-EV loads, requiring significant amounts of energy storage. Under a "work dominant" EV charging paradigm with a "random start" control strategy, some EV loads can be shifted into the solar period, but excess generation remains, and EV loads outside of the solar period still increase net load. A purpose-built control strategy and large amounts of daytime accessible EV charging infrastructure could best align load and generation. It is also noted that during periods of low solar generation it would be desirable to shift to overnight charging, requiring the availability of different infrastructure and dynamically shifting control strategies.

The FUSE project will continue to simulate the characteristics and needs of the selected regions. We will identify remaining gaps in control strategies created in previous research, develop new strategies to address these gaps, and demonstrate possible approaches that will benefit these regions not yet studied in detail.

El Paso Electric (EPE) Region



Map: INL

This study will evaluate the unique characteristics of several regions, including El Paso, TX, with significant renewable generation, and address the need for specific SCM strategies to align potential local EV load with this type of generation

Photo: ANL

ANALYSIS OF COMBINED PUBLIC DATA SETS AND TRAVEL BEHAVIORS INFORMS POTENTIAL FUTURE CHARGING DEMANDS FOR ELECTRIC VEHICLES AT SCALE

Achievement: Established partnership with Wejo Driving Events and obtained data for hundreds of millions of vehicle trips to inform simulations.

Impact: Securing vehicle trip data is critical to test and assess a multitude of future scenarios with EV charging and SCM strategies with minimal resources, which de-risks future SCM deployment.

Understanding the energy and power demands of EVs is key to electrifying the transportation sector. Planning for these EV charging demands will require an understanding of the energy and charging power requirements to satisfy travel needs and corresponding dwell periods.

To mitigate those impacts, the FUSE team is estimating future charging loads for EVs@Scale and will analyze the impacts of those future loads throughout the Dominion Energy service territory in Virginia. To estimate these loads, the FUSE team acquired data from Wejo for over 25 million origin-destination pair trips from September 2021 through February 2022. In conjunction with public data sets such as vehicle registrations, land use, and census information, these trips were processed using NREL's Electric Vehicle Infrastructure – Projection (EVI-Pro) tool to develop 30 million daily travel itineraries. These 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 impact loads on the grid. Leveraging a recently signed nondisclosure agreement between Dominion Energy and participating labs, the FUSE team will simulate these EV charging loads on models of real-world feeders using OpenDSS. This analysis will determine the potential grid impacts of EV charging under both controlled and uncontrolled scenarios to assess the effectiveness of SCM to mitigate these impacts. The next steps for this effort are to process the grid models and prepare them for the OpenDSS analysis, as well as develop and refine new and existing SCM strategies to determine their effectiveness under a range of grid conditions.

High-Power Charging Research

HARDWARE INTEGRATION DOCUMENT ENABLES COMMON APPROACH TO DEVELOPING SITE ENERGY MANAGEMENT-INTEGRATED CHARGING

Achievement: Developed hardware integration document that addresses development and integration requirements for high-power charging equipment, reliable communications controllers, and site energy management (SEM) systems.

Impact: Enables engineers to reference a current, standardized document that enhances collaborative module development and deployment.

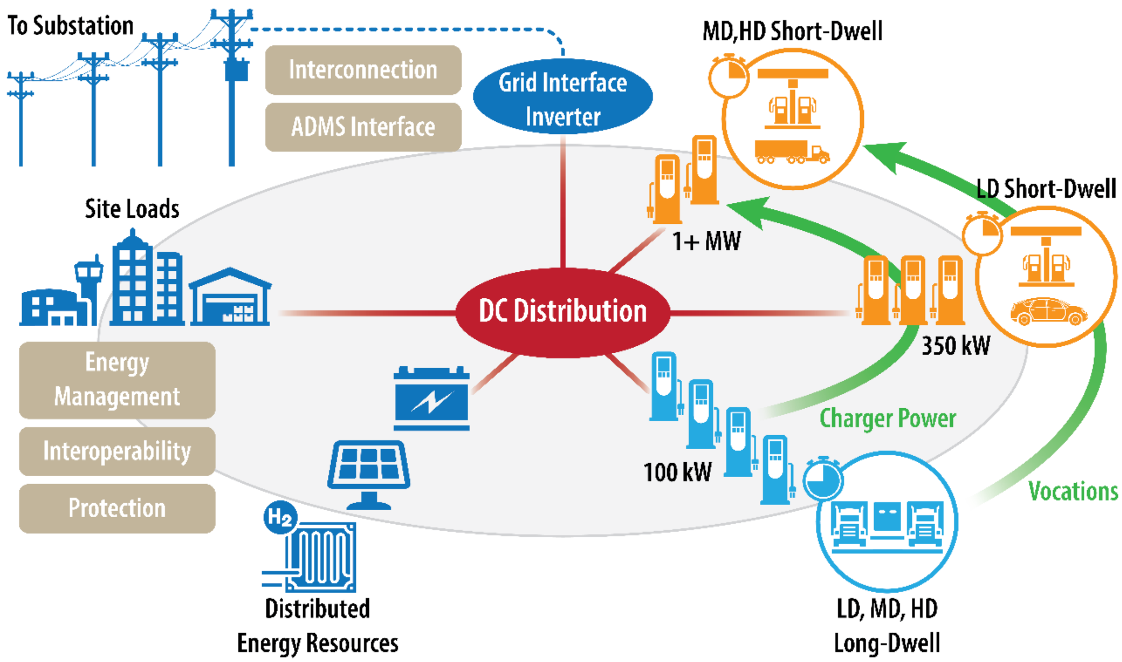
Large-scale, rapid adoption of EVs, especially heavy-duty and large transport EVs, poses new challenges in high-power charging, load management, and facility equipment operation. Validated efficient, low-cost, and interoperable hardware for high-power direct-current (DC)-hub charging, communication, and control architectures is crucial, as is proper software and hardware integration.

To research and demonstrate various integration approaches and technology solutions, the EVs@Scale Lab Consortium is designing and developing a high-power, interoperable charging experimental platform.

This project requires seamless integration of three key modules being developed by separate engineering teams: the supply equipment communication controller, which will communicate with a vehicle using the ISO 15118 standard; high-power electronics to provide the power needed for bidirectional charging; and an SEM system to provide real-time monitoring and control for all subsystems.

ANL, NREL, and ORNL research engineers have developed a hardware integration document that enables cooperation among engineering teams developing the high-power charging equipment, reliable communications controllers, and SEM systems. Because they are aware of each other's requirements, the teams can collaborate effectively to develop and implement a project at this scale.

Research engineers address development and integration of all three key modules in their integration document, which aids engineers in ultimately developing and deploying a DC-coupled bidirectional charger that integrates into an SEM system. Teams will continue developing the individual modules and planning for testing and implementation. This framework for development of the experimental platform will be published and could help form a framework for cross-industry collaboration on these sites in the future.



FIRST LABORATORY VALIDATION OF 200-KW DWPT SYSTEM DEMONSTRATES SYSTEM EFFICIENCY OVER 90% WITH SINGLE RECEIVER ARCHITECTURE

Achievement: Validated a 200-kW dynamic wireless power charging system in a laboratory using a dynamic inductive charging emulator, over 93% end-to-end system efficiency at 188-kW output.

Impact: Experimentally demonstrated for the first time that 200-kW wireless power transfer with over 90% efficiency is feasible with a single receiver architecture.

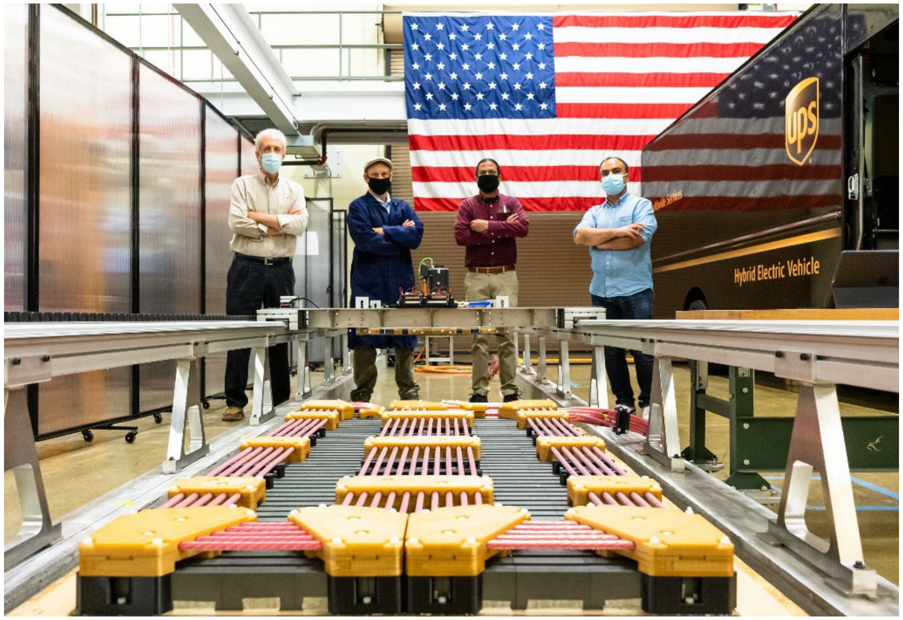
High-power and dynamic wireless charging can alleviate range anxiety and reduce the amount of required onboard energy storage. Current state-of-the art dynamic wireless EV charging systems are limited in power transfer to a level of approximately 20 kW. This leads to a higher percentage of the roadway needing to be electrified, thereby increasing infrastructure cost. It is estimated that a high power transfer level in the range of 200 kW would reduce infrastructure cost, as the percentage of roadway to be electrified would be in the range of 10% for charge-balanced mode of operation for a light-duty EV. This project develops and validates the technology needed to enable the transition of a 200-kW dynamic wireless charging system from a proof-of-concept stage to a solution suitable for integration with the real world at scale.

The 200-kW DWPT system was validated in the laboratory using the dynamic inductive charging emulator. With an input power limited to 200 kW, the end-to-end system efficiency was noted to be over 93% at 188-kW output. This is the first time it has been experimentally shown that efficient 200-kW wireless power transfer is feasible with a single receiver architecture.

Although it is envisioned that a 200-kW power transfer rate is sufficient for light-duty or passenger EVs, the system can be modularly scaled up to achieve higher power to enable dynamic charging for medium-duty and heavy-duty EVs used in freight transportation. Additionally, since the proof of concept is preliminarily validated, it paves the way to begin evaluation of barriers and solutions to real-world implementation at scale.

The planned next step is to validate and characterize a vehicle-integrated real-world system, and then identify the barriers to integration in the real world (roadway and grid) and develop solutions to transition the technology from the laboratory to a real-world system.

The dynamic inductive charging emulator used for the validation of 200-kW DWPT system in the laboratory



Photos: ORNL

The ORNL team that runs the dynamic inductive charging emulator in the laboratory

2022 CYBERAUTO CHALLENGE CONDUCTS INDEPENDENT EV CHARGING INFRASTRUCTURE VULNERABILITY ASSESSMENTS AND EXPLOIT ATTEMPTS

Achievement: Hosted an EV cybersecurity event for approximately 50 university students in Detroit, MI, including intensive tutorial sessions and assessment and exploit attempts.

Impact: Provided invaluable EV charging infrastructure cybersecurity training and hands-on learning experiences to students in pursuit of careers in cybersecurity. Industry collaborators also gained helpful data through the independent assessment and exploit attempts on their equipment hardware and software.

With the growth of electrified transportation and the charging infrastructure required to support its energy needs, cybersecurity of this infrastructure is critical to gain and maintain consumer confidence through safe and reliable operation since a coordinated attack could potentially lead to cascading failure. Existing cybersecurity training for EV charging infrastructure is insufficient to combat the growing threats to electrified transportation and charging infrastructure. Through direct education and outreach, national lab staff can significantly enrich EV charging infrastructure cybersecurity training for a diverse workforce.

At the 2022 CyberAuto Challenge, INL staff provided cybersecurity expertise, technical support, and instruction through EV charging infrastructure tutorial sessions. They also advised students on assessment and exploit attempts. The 24-hour event had six advanced light-duty vehicles (hybrid electric and all-electric vehicles) and EV charging infrastructure provided by the manufacturers. The three tutorial sessions conducted by INL staff focused on EV charging infrastructure architecture, communications protocols, operational functionality, and areas of potential vulnerabilities for investigation during the 24-hour “hands-on” event. Additionally, the tutorials also focused on EV charger architectures for power electronics, thermal management, communications between EVs, EVSE, smart energy management systems, and other manufacturer-specific communications used for internal controls and remote software management.

These student exploit attempt efforts, both successful and unsuccessful, resulted in valuable learning experiences in their pursuit of a career in cybersecurity. The successful exploits also provided valuable information back to the industry sponsors that provided the EV charging systems for the event. Prior VTO-funded research discovered significant security gaps in high-power electric vehicle charging infrastructure that, if exploited, could cause significant harm to the grid and EV users. New research and outreach are needed to develop novel countermeasures, help industry deploy best practices, and train the nation’s cybersecurity workforce.

The CyberAuto Challenge is an excellent learning opportunity for the next generation of the cybersecurity workforce, as well as a great opportunity for the industry collaborators to utilize the independent assessment and exploit attempts on their equipment hardware and software that was provided for the event. Future years of this annual event will increase focus on advanced electrified mobility systems including vehicles, charging infrastructure, energy management systems, and numerous communication pathways connecting their systems.

Photo: INL

Cybersecurity exploit attempts by university student competitors on advanced hybrid electric and all-electric vehicles and charging infrastructure at the 2022 CyberAuto Challenge supported by INL

DEVELOPMENT OF MORE CYBERSECURE CHARGING INFRASTRUCTURE BY REMOVING IMPLICIT TRUST

Achievement: Assessed the implementation of Zero Trust principles architectures by prototyping through case studies, on network chargers, and on a scalable testbed

Impact: Provides data on the security properties of the Zero Trust prototypes that will proactively mitigate emerging threats to the grid and critical infrastructure.

Researchers at PNNL are applying zero trust cybersecurity principles to electric vehicle charging infrastructure (EVCI). Zero trust security architecture removes implicit trust from the entire networked system. No connection, whether internal or external, is trusted while using the zero trust approach. Removing implicit trust from the entire system, including all connections to a network, application, or resource, means every connection must be explicitly authorized while using the zero trust approach.

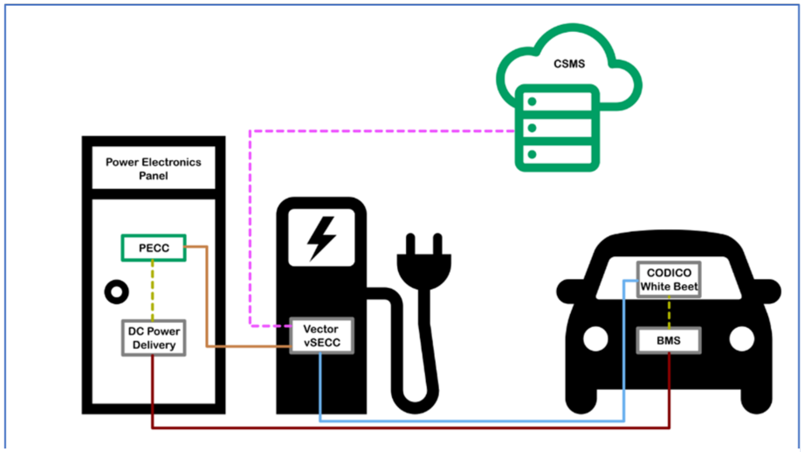
EVCI includes electric vehicle plug-in chargers, cloud-based applications, point-of-sale systems, microgrids, and energy storage systems. Because the EVCI in the United States is so diverse, PNNL is focused on researching how zero trust principles can apply to EVCI by investigating three thrust areas. The first thrust area was informed by INL's consequence-informed cybersecurity and existing demonstrated vulnerabilities. In this thrust, six use cases were developed to investigate EVCI security weaknesses, and three cases were prioritized. The prioritized case studies included unmanaged EVSE communication, unverified access policies, and unrestricted EVCI commissioning and administration interfaces. These three cases were chosen because they can tie into many high-consequence negative events.

The second thrust assessed the implementation of zero trust architectures on three different models used by network chargers: local area network (LAN), wide area network (WAN), and globally routable internet. Because each zero trust approach is influenced by which networking model it is run on, the approaches that work for one model may not work for another.

The third thrust prototyped the architectures in PNNL's NET, a scalable test bed that accelerates cyber research while reducing costs and time. Further work is being done to increase the fidelity of the evaluation through PNNL's development of a charging communication emulator. The emulator was designed with off-the-shelf components to keep costs low and increase the opportunity and access for practitioners to study EVCI.

In all three thrust areas, PNNL is partnering with Cisco Talos for their real-world zero trust expertise designing architectures and approaches. This work is important to proactively mitigate emerging threats to the grid and critical infrastructure.

The next steps are to identify testing scenarios and write a test plan based on the use cases. Testing will illuminate the security properties of the prototypes. PNNL's overall goal is to develop a demonstration for EV charging service providers. PNNL is currently looking for partners to provide input and feedback on their proposed approach and prototype.



PNNL prototyped the zero trust architectures in PNNL's NET, a scalable test bed that accelerates cyber research while reducing costs and time

Photo: PNNL

The emulator was designed with off-the-shelf components to keep costs low and increase the opportunity and access for practitioners to study zero trust architectures on EVCI

Photo: NREL

AUTO INDUSTRY TESTING EVENT SUPPORTS DEVELOPMENT OF MORE SECURE ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

Achievement: NREL hosted pre-competitive testing sessions with an industry working group that successfully demonstrated public key infrastructure (PKI)-based secure interoperable communications between vehicles and charging components

Impact: The collaboration between national laboratories and industry moves the implementation of PKI-based secure interoperable communications between vehicles and charging components closer to commercialization.

New research and outreach are needed to develop novel countermeasures to security gaps in high-power EV charging infrastructure, help industry deploy best practices, and train the nation's cyber workforce. One such opportunity is to implement security features of international standard ISO 15118 utilizing PKI to enhance interoperability and security of transactions and controls between vehicles, chargers, and charge network operations.

NREL collaborated with an SAE working group focused on PKI security to define key testing methods that could validate new PKI system functionality. As part of this collaboration, NREL hosted two pre-competitive testing sessions with more than 30 participants using the EV Research Infrastructure Laboratory in the Energy Systems Integration Facility. The working group successfully demonstrated PKI-based secure interoperable communications between vehicles and charging components.

Through this research, the consortium's national laboratories will continue to participate with industry to identify and develop solutions for the myriad gaps, ambiguities, and errors in the ISO 15118-2 standard that have made interoperability very difficult to achieve. This collaboration ultimately moves the implementation of PKI-based secure interoperable communications between vehicles and charging components closer to commercialization.

The remainder of this project will focus on testing adversarial activities and the scalability of PKI systems to ensure operational availability for charging stations. NREL and SNL researchers also expanded the scope of work to build an SAE-compliant PKI within a virtual simulation environment leveraging NREL and/or SNL high-performance computing and cyber range resources. The virtual environment will allow researchers to evaluate potential PKI scaling issues and red-team strategies for engaging with PKI for EV charging systems.

ROBUSTNESS TESTING SUPPORTS INFORMED DECISIONS ON ACCEPTABLE SIGNAL-TO-NOISE RATIO MARGINS IN MEGAWATT CHARGING

Achievement: Conducted robustness testing on charging ripple current and voltage on DC main power conductors (up to 640 A) with partners in industry and academia.

Impact: Validated acceptable signal-to-noise ratio margins in megawatt charging and created a file that can be replicated by an arbitrary waveform generator for future robustness testing.

The advent of the Megawatt Charging System (MCS) demands rigorous testing to verify charging noise and resulting noise margins on each of three communication physical layers (controller area network [CAN], powerline communication [PLC], and 10BASE-T1S ethernet) and validate assumptions on noise margin and net communication throughput. ANL research engineers developed a robustness test plan, procedure, and results.

SAE J1772 Combined Charging System (CCS) communication is based on single-ended PLC via pilot interlock signal, returning on the protective earth conductor. There are reliability issues on CCS charging below 500 A, prompting concerns about physical layer communication robustness for SAE J3271 MCS up to 3,000 A. MCS will push reliability limits in the presence of large DC fields with ripple current as high as 10%.

Researchers first collected information on charging ripple current and voltage on DC main power conductors (up to 640 A), as well as noise coupled to the pilot interlock conductor that may disrupt PLC. Collaborators included DEWETRON, which provided equipment to record the charging cycle, process data, and extract noise information; Zerology, which provided access to Tesla, Chevy, and Nissan test vehicles; and BTC Power, which shared generated charging noise on only the power conductors under lab test conditions.

A second round of testing, in partnership with Volvo and the University of Delaware, used a similar fixture with CCS charging cable noise as the source but coupled it to a differential CAN over twisted pair signal wires adjacent to the power conductors. A wider-bandwidth oscilloscope enabled smaller sample windows, with tests repeated at various power levels.

Recorded information will be synthesized into a file that can be replicated by an arbitrary waveform generator and injected into charging communication signals to assess robustness and noise margin for SAE J3271 MCS.

A similar cable/data acquisition system is planned for testing at BTC Power at 1-MW output power to a test load with production-grade DC EVSE. Output voltage will vary from 200–1,000-V DC. A side-by-side comparison of all three physical layer solutions will be conducted for inclusion into the SAE J3271 standards development process.

Photo: NREL

Prototype MCS connector undergoing physical evaluation at NREL

EVALUATION OF THERMAL PERFORMANCE OF CHARGING CONNECTORS SUPPORTS LAUNCH OF THE MEGAWATT CHARGING STANDARD

Achievement: Evaluated 21 combinations of next-generation multimegawatt electric vehicle charging connectors and inlets from four separate manufacturers at current levels of up to 3,000 A.

Impact: Delivers valuable insights into the thermal performance of prototype MCS connectors, advancing the development of the MCS standard for medium- and heavy-duty applications such as trucking and allowing manufacturers to refine their designs before they are deployed in the field.

Ensuring that multimegawatt electric vehicle charging connectors can dissipate the immense heat generated at high charge rates and operate seamlessly with mating components created by multiple manufacturers is critical for electrifying medium- and heavy-duty transportation.

Thermal performance evaluations and interoperability analysis, done in collaboration with the Charging Interface Initiative (CharIN) Megawatt Charging System task force, provided a snapshot of the ability of the in-development MCS connector standard to provide up to 3,000 A of current during a charge session, even between connectors and inlets made by different manufacturers. During the trials, 21 combinations of charging connectors and inlets (both molded and 3D-printed) from four different manufacturers were evaluated at current levels ranging from 350-3,000 A.

These data support continued development and finalization of the MCS standard, allowing manufacturers to identify issues and improve connector and inlet designs before the devices are deployed in the field. The development of this high-power charging standard is critical to accelerate the electrification of high-power, medium- and heavy-duty vehicles in the overland freight, aviation, and shipping industries.

The next evaluation event, taking place at NREL in spring 2023, will investigate the devices' thermal sensing performance to validate that the connectors/inlets can accurately detect over-temperature conditions. The team will also perform evaluations of the devices' mechanical characteristics, such as insertion/withdrawal forces and pin connection sequencing during mating. The next analysis will also include a higher percentage of molded components in the evaluation to ensure that the devices under test most closely mimic the performance of production-intent connectors. Currently, pre-event checks are being conducted at NREL to validate a new mechanical experimentation rig and confirm inter-manufacturer connector/inlet compatibility in advance of the spring event.

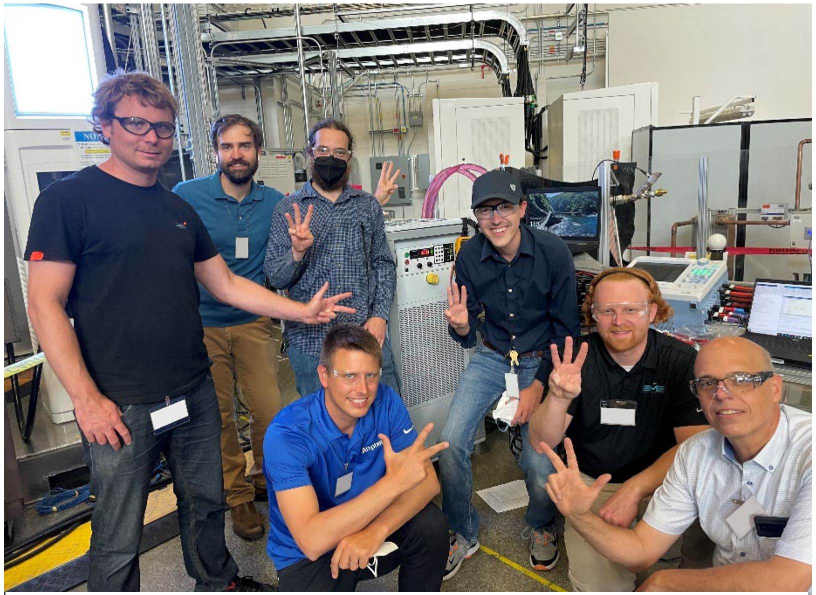


Photo: NREL

NREL MCS team with representatives from two participant companies thrilled to have successfully achieved 3,000 A during an assessment

Selected Publications and Notable Presentations

Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Annual Merit Review Presentation – A. Meintz, 2022. https://www.nrel.gov/docs/fy22osti/82828.pdf

EVs@Scale Lab Consortium Bi-Annual Stakeholder Meeting, 17 August 2022, Golden, Colorado Presentation – M. Berube, L. Slezak, A. Meintz, J. Bennett, J. Kisacikoglu, V. Galigekere, B. Carlson, T. Bohn, D. Dobrzynski, M. Starke, 2022. https://www.nrel.gov/docs/fy22osti/83838.pdf

EVs@Scale Lab Consortium SCM/VGI Deep Dive Discussion Day 1 Fall 2022 Presentation – L. Slezak, A. Meintz, J. Bennett, B. Borlaug, Z. Liu, M. Zhang, C.B. Jones, S. Ghosh, N. Panossian, T. Pennington, M. Sundarrajan, 2022. https://www.nrel.gov/docs/fy23osti/84273.pdf

EVs@Scale Lab Consortium SCM/VGI Deep Dive Discussion Day 2 Fall 2022 Presentation – J. Bennett, J. Harper, M. Jun, T. Bohn, 2022. https://www.nrel.gov/docs/fy23osti/84294.pdf

Estimating the Breakeven Cost of Delivered Electricity to Charge Class 8 Electric Tractors – J. Bennett, P. Mishra, E. Miller, B. Borlaug, A. Meintz, A. Birky, 2022. https://www.osti.gov/biblio/1894645/

Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings: High Power Charging (HPC) Summary Report – L. Slezak, A. Meintz, J. Kisacikoglu, P. Kandula, B. Rowden, M. Chinthavali, R. Wojda, M. Starke, J. Harter, S. Campbell, T. Bohn, E. Ucer, J. Harper, M. Mohanpurkar, 2022. https://www.nrel.gov/docs/fy22osti/84093.pdf

EVs@Scale High Power Charging Pillar 'Site-Level Energy Management: Integrating Chargers, DERs and the Grid' at the 2022 HPC Deep Dive Meeting – J. Harper, 2022. https://www.osti.gov/biblio/1890461

Design and Analysis of a 200-kW Dynamic Wireless Charging System for Electric Vehicles – L. Xue, V. Galigekere, G. Su, R. Zeng, M. Mohammad, E. Gurpinar, S. Chowdhury, O. Onar, 2022. https://doi.org/10.1109/APEC43599.2022.9773670

Modular Design of Receiver Side Power Electronics for 200-kW High Power Dynamic Wireless Charging System – L. Xue, V. Galigekere, E. Gurpinar, G. Su, S. Chowdhury, M. Mohammad, O. Onar, 2022. https://www.osti.gov/servlets/purl/1814273

Photos: ANL

Photos (top to bottom): INL, ORNL

Detecting Anomalies in Encrypted EV Charging Control Protocol Using a Hybrid LSTM Autoencoder-OCSVM Model – K.M. Arthur-Durett, T.E. Carroll, E.G. McNally, L. O'Neil, 2022. PNNL-SA-176105.

EVs@Scale Cybersecurity Pillar CyberAuto Challenge Presentation at the 2022 Cybersecurity Deep Dive Meeting – B. Carlson, 2022.
https://cet.inl.gov/ArticleDocuments/CyberPUNC_CyberAutoChallenge_DeepDiveSept2022.pdf

EVs@Scale Cybersecurity Pillar CyberPUNC Project Overview Presentation at the 2022 Cybersecurity Deep Dive Meeting – B. Carlson, 2022.
https://cet.inl.gov/ArticleDocuments/CyberPUNCOverview_DeepDiveSept2022.pdf

EVs@Scale Cybersecurity Pillar Overview at the 2022 Bi-Annual Meeting –
B. Carlson, J. Johnson, T. Carroll, O. Onar, T. Markel, 2022.
https://cet.inl.gov/ArticleDocuments/CyberPUNCOverview_Bi-AnnualMtgAug17.pdf

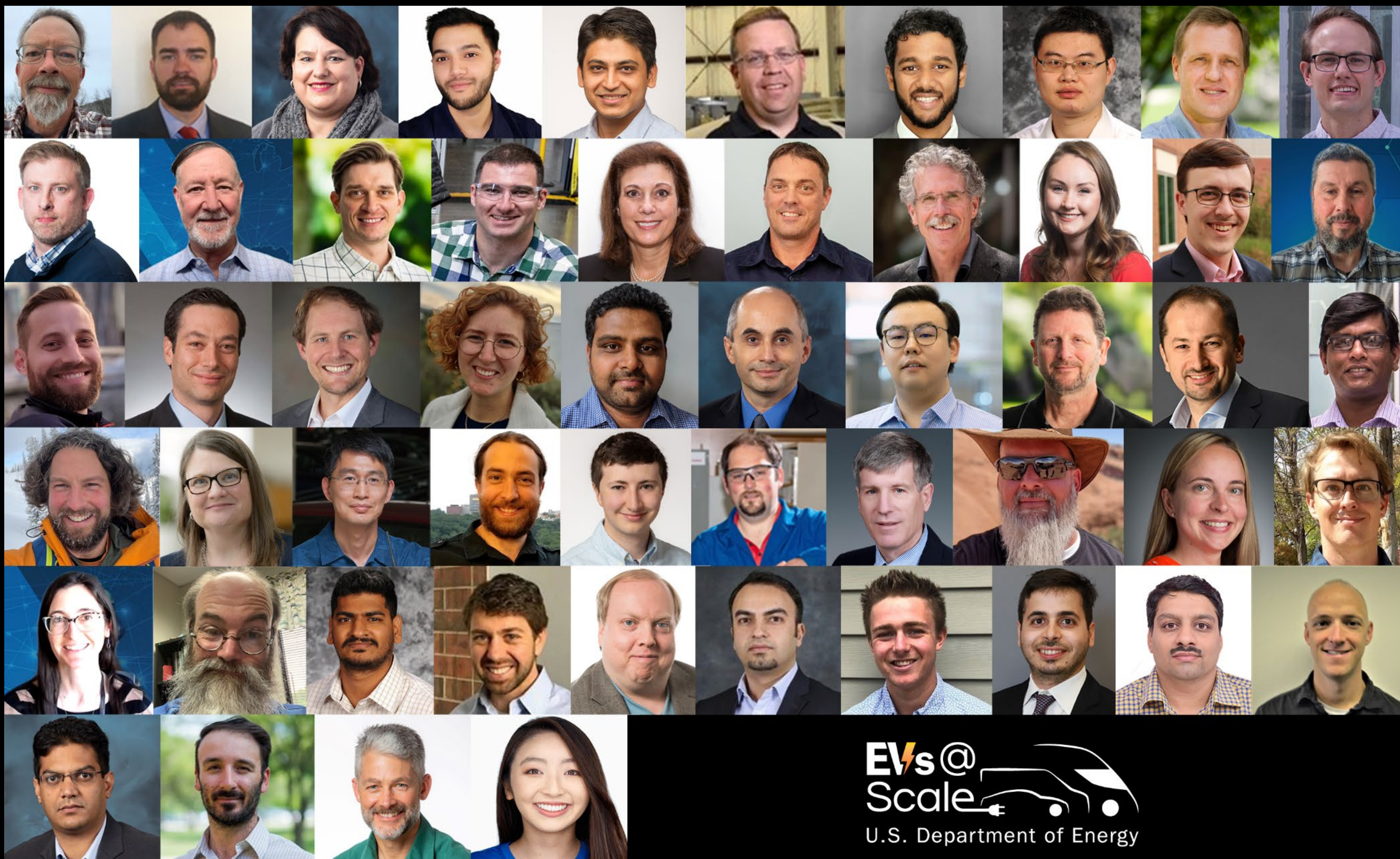
EVs@Scale Cybersecurity Pillar Related VGI Projects Presentation at the 2022 Cybersecurity Deep Dive Meeting – B. Carlson, M. Chinthavali, 2022.
https://cet.inl.gov/ArticleDocuments/CyberPUNCRelatedVGIProjects_DeepDiveSept2022.pdf

Acronyms and Abbreviations

AC .... alternating current
ANL .... Argonne National Laboratory
CAN .... controller area network
CCS .... Combined Charging System
DC .... direct current
DOE .... U.S. Department of Energy
DWPT .... dynamic wireless power transfer
EERE .... Office of Energy Efficiency and Renewable Energy (DOE)
ESC .... external steering committee
EV .... electric vehicle
EVCI .... electric vehicle charging infrastructure
EVs@Scale .... Electric Vehicles at Scale
EVSE .... electric vehicle supply equipment
FY .... fiscal year
INL .... Idaho National Laboratory
L2 .... Level 2
MCS .... Megawatt Charging System
NREL .... National Renewable Energy Laboratory
OCPP .... Open Charge Point Protocol
OE .... Office of Electricity
OEM .... original equipment manufacturer
ORNL .... Oak Ridge National Laboratory
PKI .... public key infrastructure
PLC .... powerline communication
PNNL .... Pacific Northwest National Laboratory
SCM .... smart charge management
SEM .... site energy management
SNL .... Sandia National Laboratories
VGI .... vehicle-grid integration
VTO .... Vehicle Technologies Office

Photos (top to bottom): INL, PNNL

EVs@Scale Team



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