2024 Electric Vehicles at Scale Semiannual Stakeholder Meeting

February 28-29, 2024
National Renewable Energy Laboratory

EVs@Scale
U.S. Department of Energy

NREL/PR-5400-89059

Agenda

8:30 a.m. – 9:00 a.m.	Plenary / Introduction Welcome and Overview of Consortium Process | Lee Slezak Consortium Structure and Scope | Andrew Meintz
9:00 a.m. – 10:00 a.m.	Pillar Presentations and Participant Feedback High-Power Charging – eCHIP | John Kisacikoglu High-Power Charging – NextGen Profiles | Sam Thurston
10:00 a.m. – 10:15 a.m.	Break
10:15 a.m. – 11:15 a.m.	Pillar Presentations and Participant Feedback ACGIT – eVISION | Madhu Chinthavali Codes and Standards | Ted Bohn
11:15 a.m. – 12:30 p.m.	Working Lunch Vehicle Grid Integration / Smart Charge Management use cases, implementation, and data gaps | Michael Kintner-Meyer

Agenda

12:30 p.m. – 1:00 p.m.	**Pillar Presentations and Participant Feedback** Vehicle Grid Integration and Smart Charge Mgmt | Jesse Bennett
1:00 p.m. – 1:15 p.m.	Break
1:15 p.m. – 3:15 p.m.	**Smart Charge Management Breakout Discussion** Breakout session to discuss barriers to and solutions for the at-scale adoption of SCM
3:15 p.m. – 5:15 p.m.	**Tours** NREL's EVs@Scale activities at the ESIF supporting Consortium activities in Smart-Charge Management, High-Power Charging, Cyber Security, and Codes and Standards

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Sarah Ollila

U.S. DOE VTO

EVs @ Scale

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Lee Slezak

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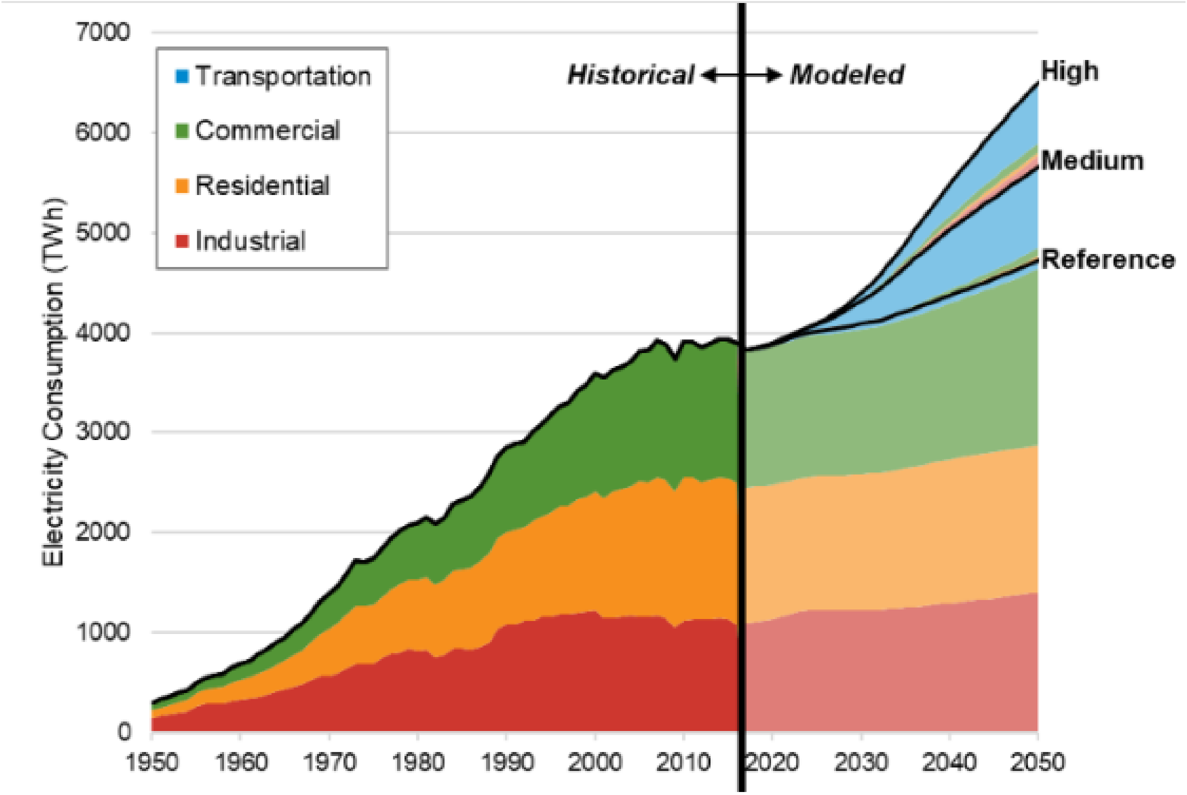
Consortium Overview and Stakeholder Engagement

Andrew Meintz

February 28, 2024

Impact of Transportation Electrification



Historical and Projected annual electricity consumption

EVs@Scale Consortium RD&D will support electrification by answering:

- How will electricity generation and the transportation sectors work together?
- What research can we do to ensure a safe, smooth, and seamless transition?
- How could a grid-integrated charging network support intermittent generation?

Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. NREL/TP-6A20-71500

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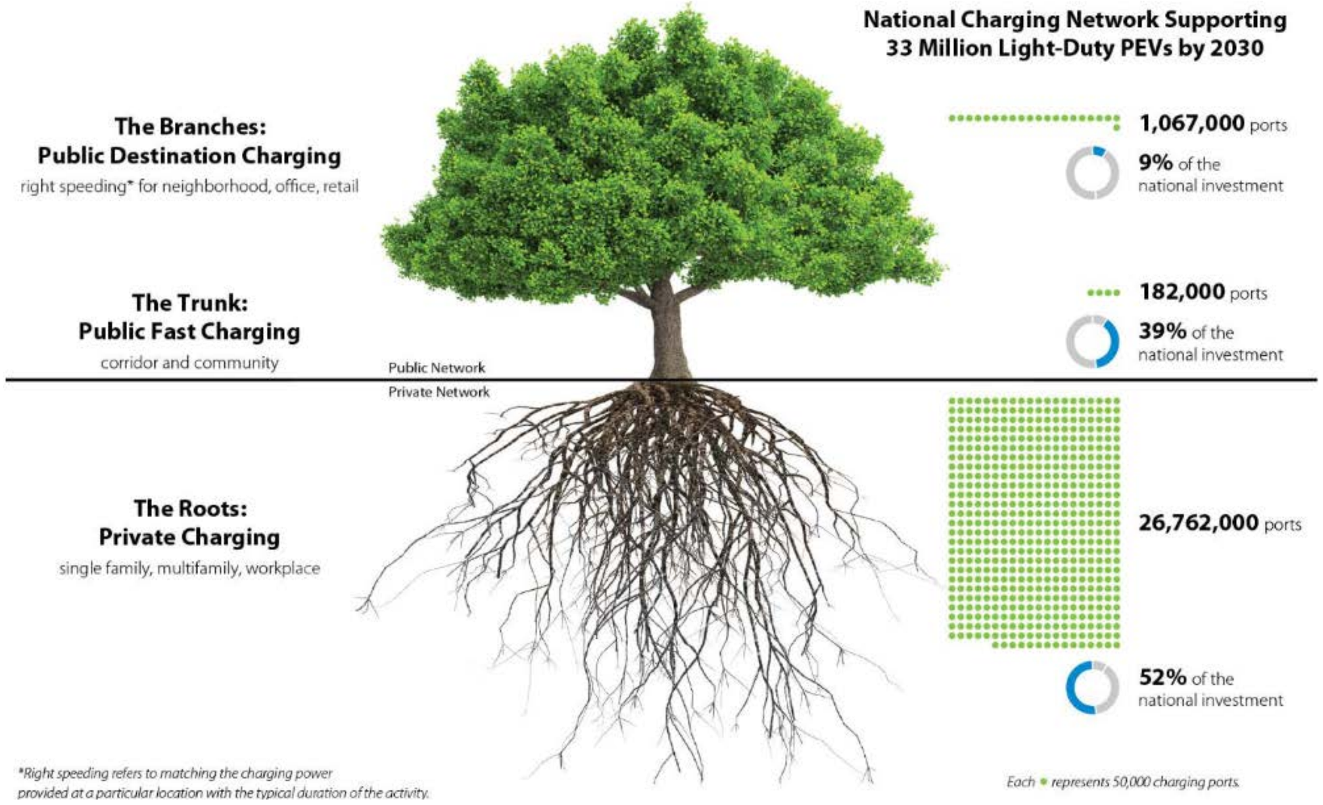
Building the 2030 National Charging Network

27 million new charging ports are required which has been estimate that a $53–$127-billion cumulative national charging infrastructure investment, including $31–$55 billion for publicly accessible charging infrastructure, is necessary to support charging infrastructure needs under the baseline scenario.



The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure; NREL https://www.nrel.gov/docs/fy23osti/85654.pdf

Consortium Objectives

- Develop charging technologies and standards needed to meet U.S. goals of **transitioning to a nationwide fleet of on-road vehicles powered by electricity**, bringing the transportation sector closer to a net-zero-emission future
- Bring together the **national laboratories' hardware and software expertise, capabilities, and facilities** related to EV charging, charge management, grid services, grid integration, and cyber-physical security.
- Enable **highly coordinated, targeted research** to be initiated and successfully conducted that is in step with rapid changes in the EV charging

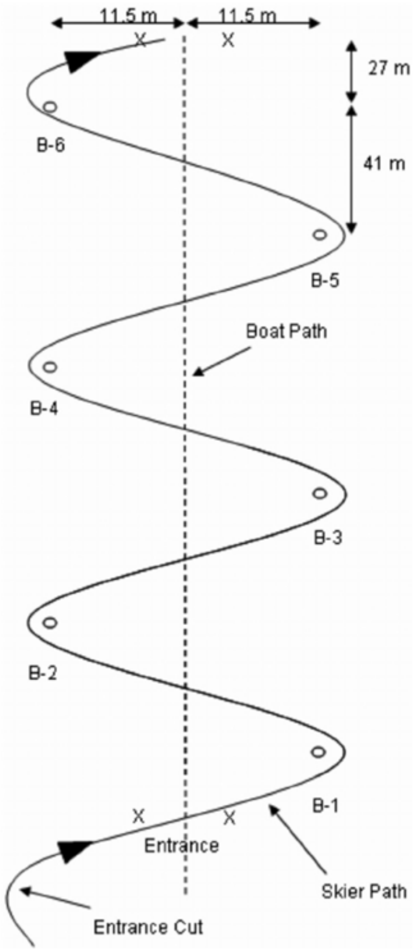
Installation of smart charging system at NREL's Flatirons Campus (Dennis Schroeder / NREL)

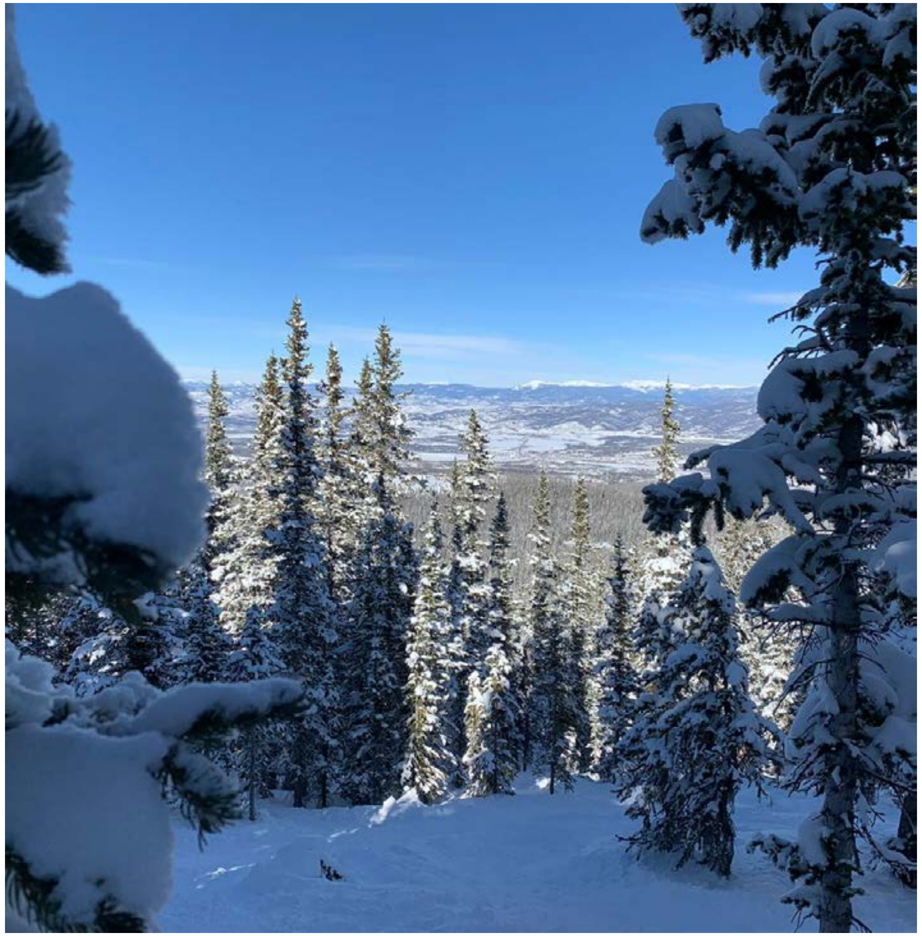
So why are we here today?

https://climberkyle.com/2023/02/21/how-to-find-good-tree-skiing/

Objective

So why are we here today?





- Visualize your line
- Make quick turns
- Keep your speed under control
- Wear a helmet and watch for tree wells

Adapted from https://www.rei.com/learn/expert-advice/how-to-ski-or-snowboard-in-trees.html and Bray-Miners, Jordan & Runciman, John & Monteith, Gabrielle & Groendyk, Nate. (2014). Biomechanics of slalom water skiing. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology. 229. 10.1177/1754337114547555.

EVs @ Scale and ChargeX Consortium

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CHARGEX
consortium

Establishing a secure and scalable infrastructure is necessary to support the transition to an electric fleet in 2030

– Optimizing charging to ensure demands placed on the grid by EVs consistently meet consumer expectations
– Enable greater safety, grid operation reliability, and consumer confidence.
– Formulating technologies, practices, and standards to enable high-power, low-cost, and ubiquitous charging options

Work together as EV industry stakeholders to measure and significantly improve public charging reliability and usability by <u>June 2025</u>

– **Define the Charging Experience:** define and publish KPIs, set targets, and measure performance
– **Triage Charging Reliability and Usability:** understand root causes and quickly identify solutions
– **Develop Solutions for Scaling Reliability:** design new diagnostics and tools to scale interoperability

Consortium Structure

Leadership Council

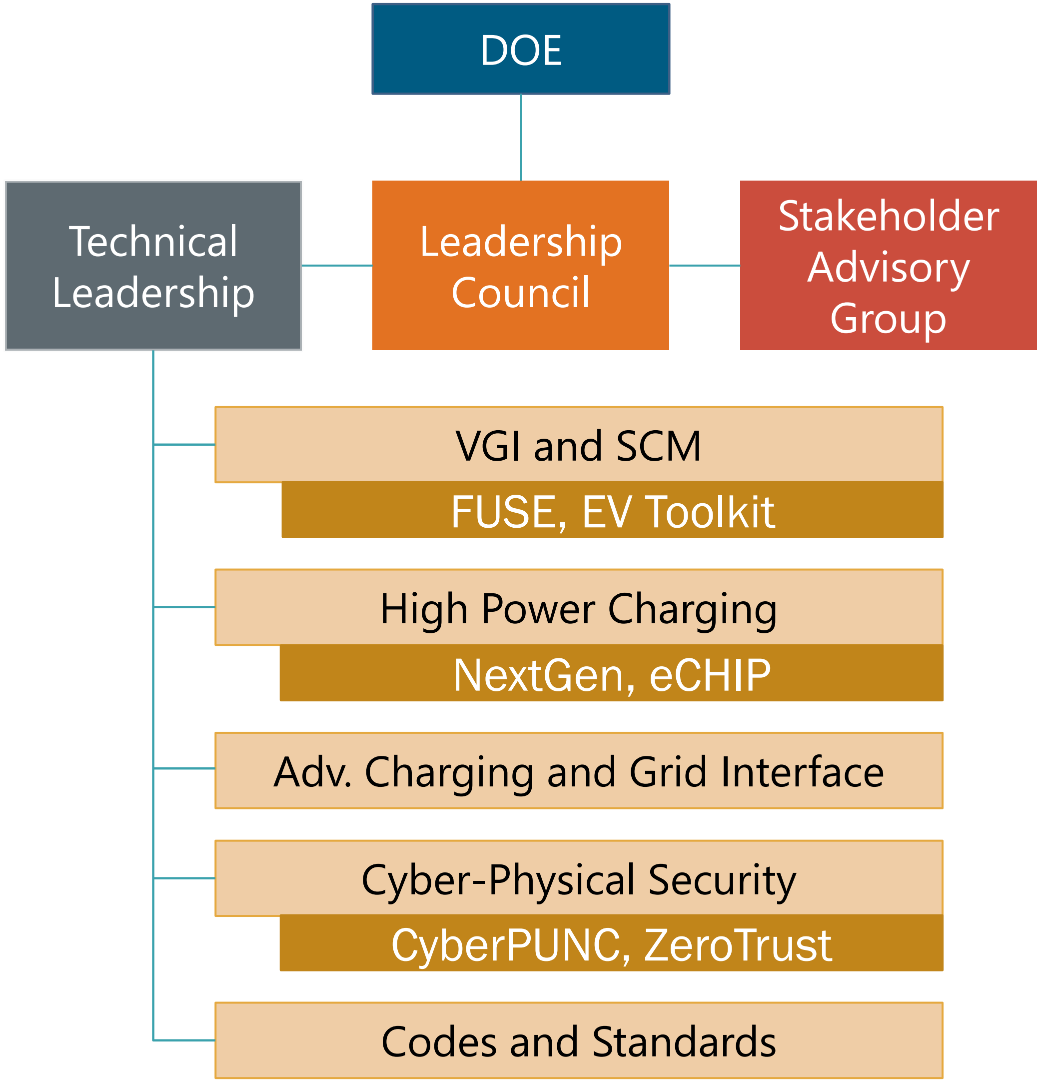
- Andrew Meintz (NREL, chair), Tim Pennington (INL, rotating co-chair), Don Stanton (ORNL), Summer Ferreira (SNL), Lori Ross (PNNL), Dan Dobrzynski (ANL), Bin Wang (LBNL)

Stakeholder Advisory Group

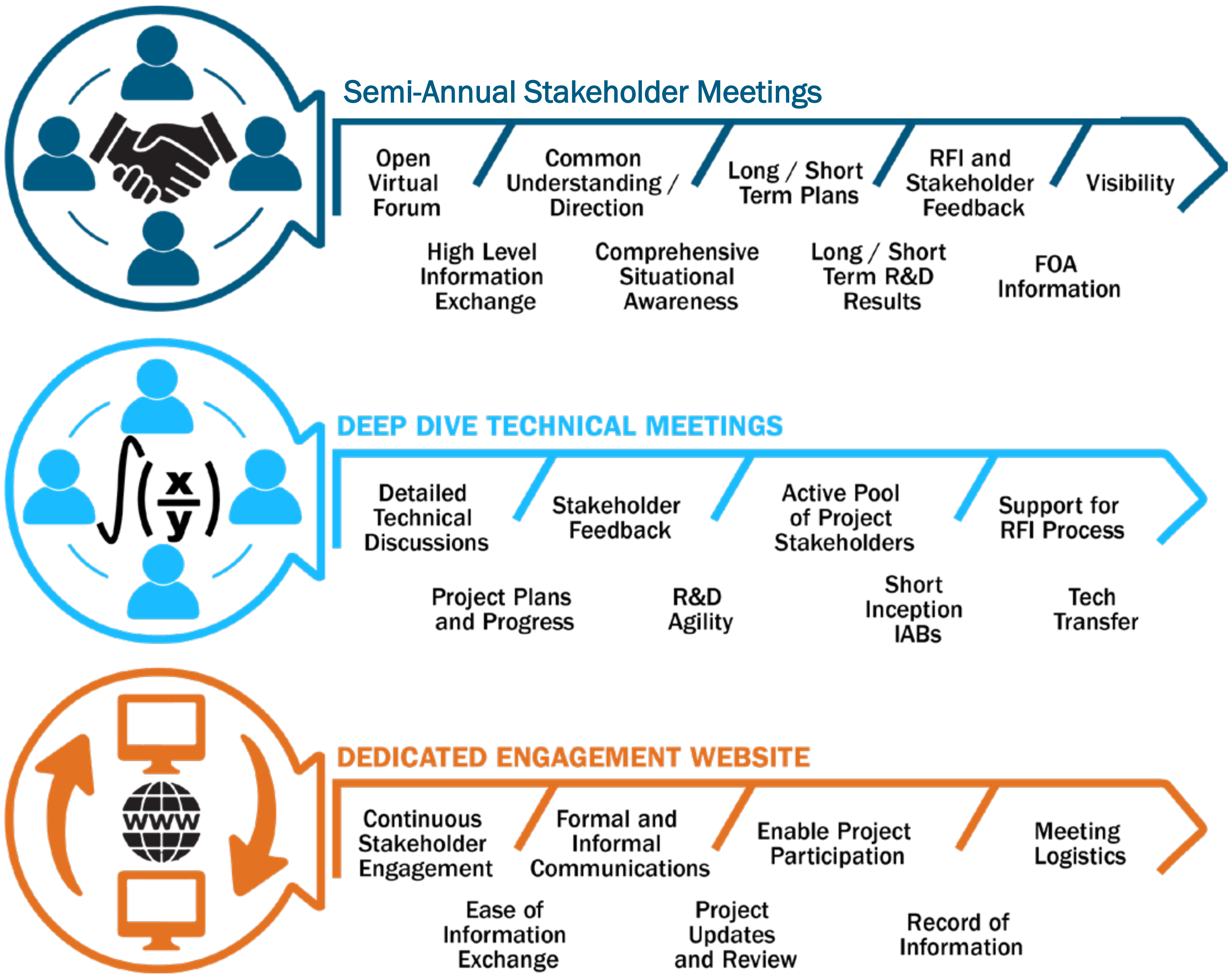
- Utilities, EVSE & Vehicle OEMs, CNOs, SDOs, Gov't, Infrastructure

Consortium Pillars and Technical Leadership

- Vehicle Grid Integration and Smart Charge Management (VGI/SCM): Jesse Bennett (NREL), Jason Harper (ANL)
- High Power Charging (HPC): John Kisacikoglu (NREL)
- Advanced Charging and Grid Interface Technologies (ACGIT): Madhu Chinthavali (ORNL)
- Cyber-Physical Security (CPS): Richard "Barney" Carlson (INL), Craig Rodine (SNL)
- Codes and Standards (CS): Ted Bohn (ANL)



EVs@Scale Lab Consortium Stakeholder Engagement and Outreach



Collaboration and Coordination

Stakeholder Advisory Group

- Utilities, EVSE & Vehicle OEMs, CNOs, SDOs, Gov't, Infrastructure

Direct interaction for each pillar projects

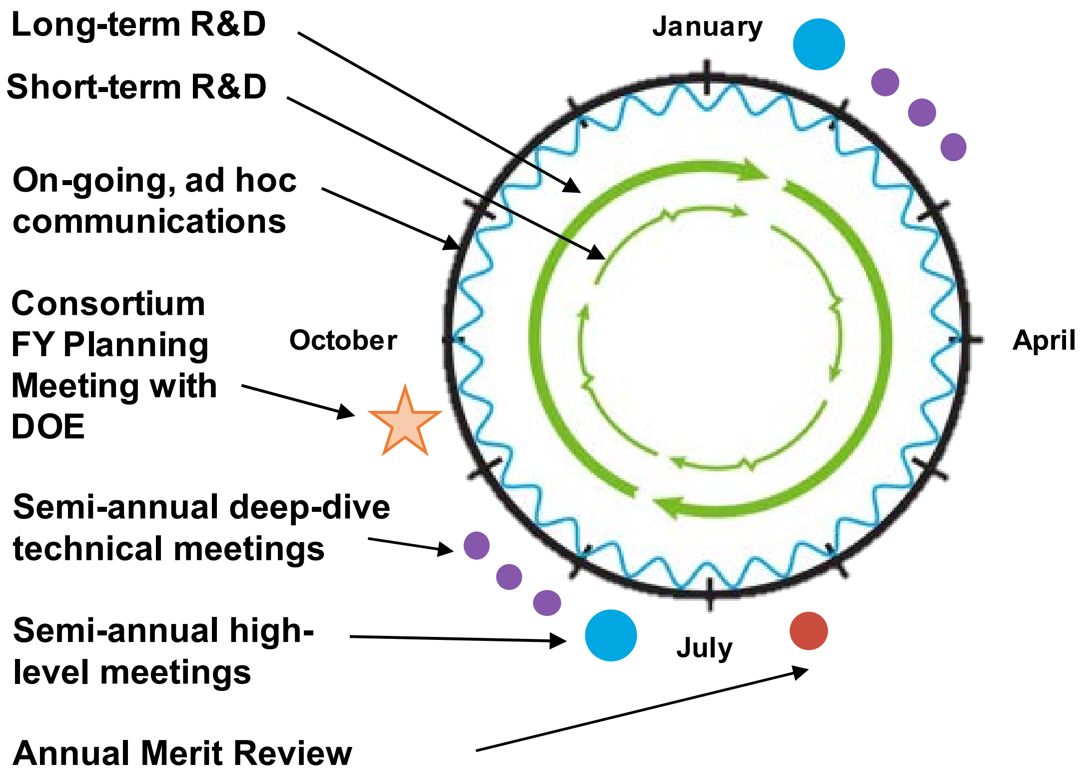
- Utilities, EVSE & Vehicle OEMs, CNOs, SDOs, Gov't, Infrastructure
- Webinars / Project discussions

Semi-annual high-level meetings

- Rotation among labs with discussion on all pillars

Semi-annual deep-dive technical meetings

- VGI/SCM, HPC & WPT, and CPS with C&S incorporated into all meetings

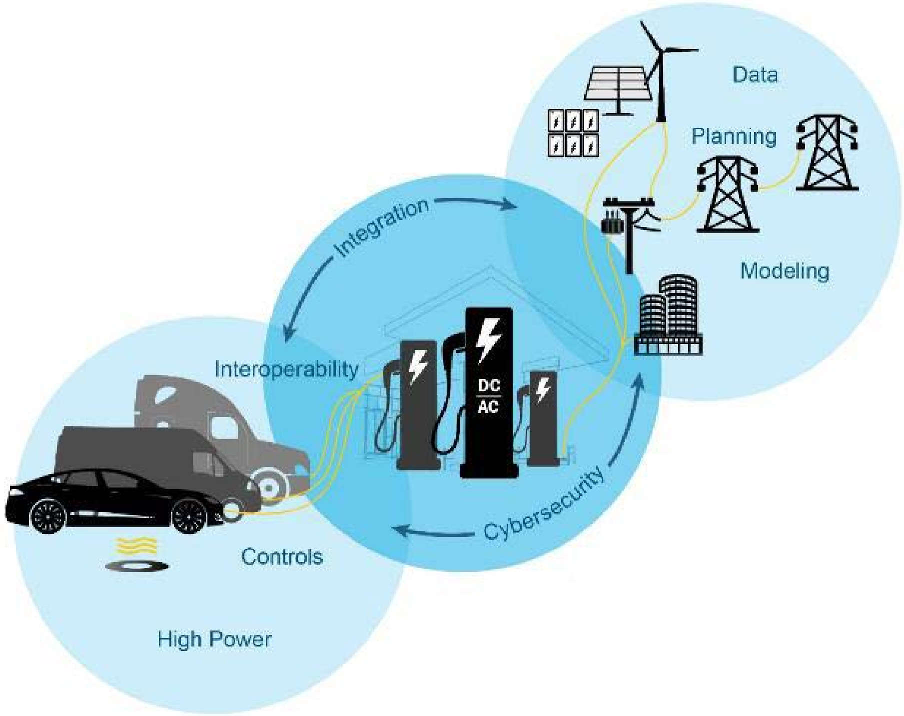


Two semi-annual high-level meetings were held in April 2023 and Sept 2024 with attendance reaching 100 stakeholders with several attending the follow-on deep dive discussions

Summary

The EVs@Scale Lab Consortium will

1. Address challenges, develop solutions, and enabling technologies for transportation electrification ecosystem **through national lab and industry collaboration**
2. Formulate and evaluate EV smart-charging strategies that consider travel patterns, charging needs, and fluctuating power generation loads
3. Overcome barriers to EVs@Scale and provide answers to fundamental questions with activities that
   - Assess potential **grid impacts and grid services**
   - **Develop and evaluate hardware and system** designs for high power and wireless charging systems
   - Create design guidelines and evaluate approaches to **secure charging infrastructure** and the grid
   - Support consensus-based **standards development** through evaluation and industry engagement



The EVs @ Scale Lab Consortium will consider these key components of the transportation electrification ecosystem

We need __your input today and tomorrow__ to tell us where we can improve on delivering these outcomes !

Upcoming Stakeholder Engagement Events

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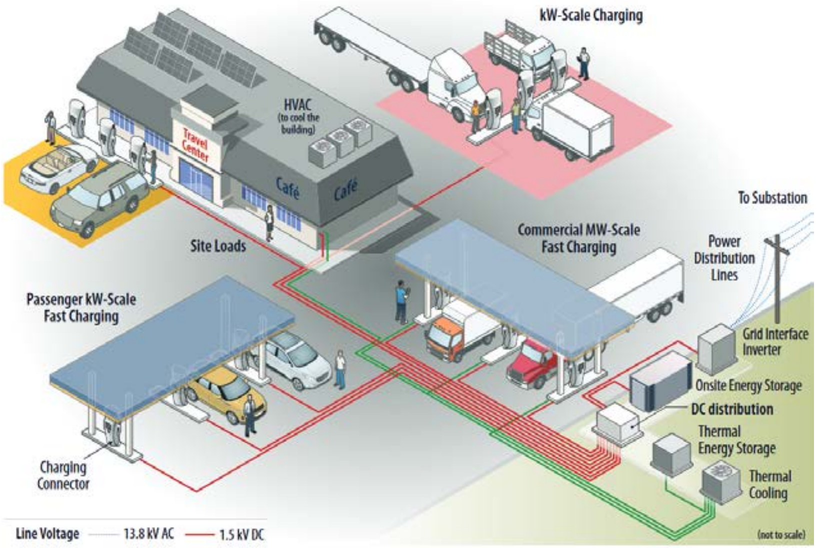
We have the following upcoming stakeholder engagement events planned and will send out invites to registrants of this event for the deep-dives next week.

- Deep Dive Meetings
  - Codes & Standards Pillar
    - Monday April 8th
  - Cyber-Physical Security Pillar
    - CyberPunc, and ZeroTrust Projects
    - Tuesday April 9th and Wednesday April 10th
  - SCM&VGI Pillar
    - FUSE Project
    - Thursday April 4th
  - High-Power Charging Pillar
    - NextGen Profiles and eCHIP Projects
    - Tuesday April 23rd
- Semi-Annual Meeting
  - INL will host in Idaho Falls, Idaho
  - September 25th and 26th

Conclusion

From the bunny hill of charging…



To the future of charging

Housekeeping for Today's Discussion

- **We are using PollEV to ask for your input**
  - Pillar Presentations
  - Panel Discussions
  - Roundtable Questions
- **Please be thinking during the discussions**
  - "Are the principal thrusts proposed within this pillar on target and appropriate for DOE to be pursuing?"
  - "Are there additional barriers / challenges within this pillar that DOE should be addressing?"

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High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP)

John Kisacikoglu, Ph.D.
Team Lead, EV Grid Integration
NREL

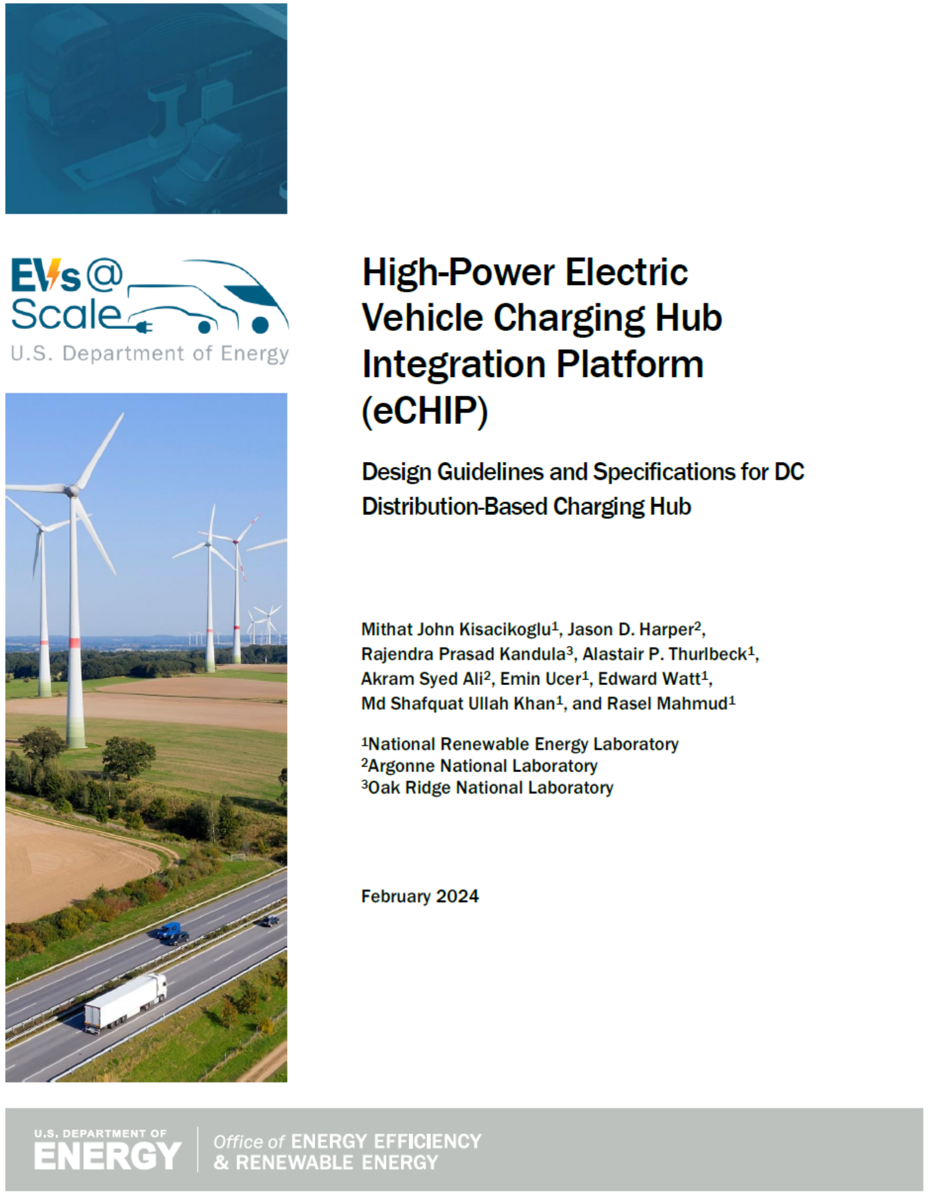
February 28, 2024

Outline

1. Project Overview
2. DC Charging Hub Overview and Current Status
3. Site Energy Management System (SEMS) Platform Development
4. DC Hub Charging Hub Hardware Development and Results
5. C-HIL Platform Real-Time Simulation Results
6. DC-DC Charger Power Electronics Development and Controller Integration
7. Conclusion, Next Steps and Timeline

First eCHIP Report Publication

- First eCHIP public report is published.
- Providing more in-depth technical information about summary of two-year progress.
- Complements content of this presentation.



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High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP)

Design Guidelines and Specifications for DC Distribution-Based Charging Hub

Mithat John Kisacikoglu[1], Jason D. Harper[2], Rajendra Prasad Kandula[3], Alastair P. Thurlbeck[1], Akram Syed Ali[2], Emin Ucer[1], Edward Watt[1], Md Shafquat Ullah Khan[1], and Rasel Mahmud[1]

[1]National Renewable Energy Laboratory
[2]Argonne National Laboratory
[3]Oak Ridge National Laboratory

February 2024

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High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP)

Objective: Develop plug-and-play solution allowing charging site to organically grow with additional chargers and DERs through predefined compatibility with standards that will ensure interoperability

Outcomes:

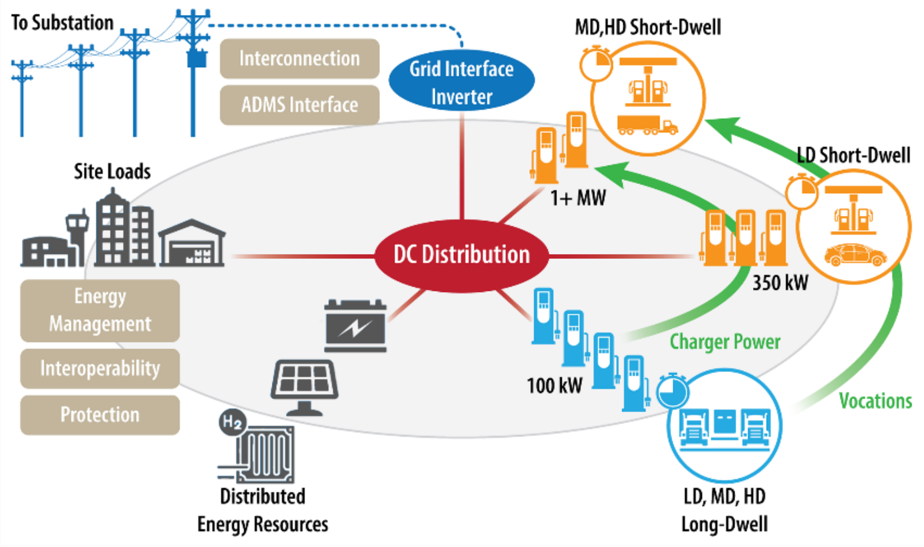
– Determine interoperable and scalable hardware, communication, and control architectures for high-power charging facilities
– Broadly identify limitations and gaps in DC distribution and protection systems that allow for modular HPC systems
– Develop and demonstrate solutions for efficient, low-cost, and high-power-density DC-DC for kW- and MW-scale charging

- John Kisacikoglu (PI)
- Derek Jackson
- Shafquat Khan
- Namrata Kogalur
- Vaibhav Pawaskar
- Alastair Thurlbeck
- Emin Ucer
- Ed Watt

- Jason Harper
- Akram Ali
- Bryan Nystrom

- Prasad Kandula
- Steven Campbell
- Madhu Chinthavali

NREL
Argonne NATIONAL LABORATORY
OAK RIDGE National Laboratory



Overview of DC Hub Approach

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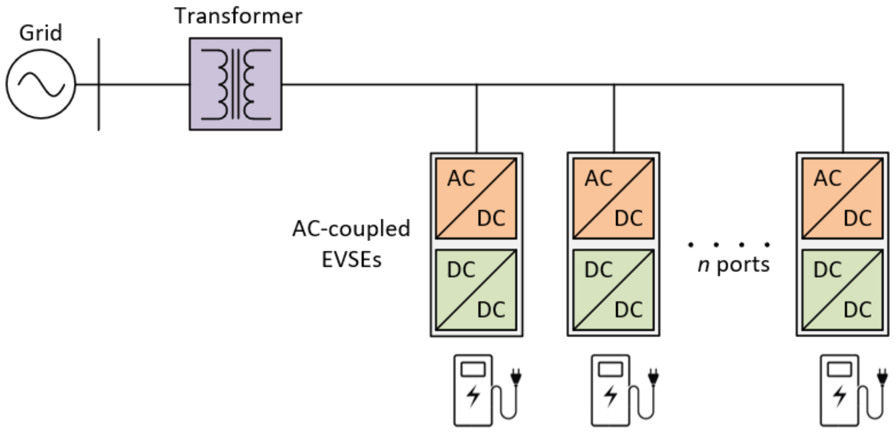
Parameter	AC Hub	DC Hub
Number of AC/DC converter modules	2X	X
Power distribution cable mass	2.5X	X
Higher efficiency operation	1.08MWh-2MWh of daily energy loss	1.01MWh-1.8 MWh of daily energy loss

DC Hub over AC hub: ~70-200kWh of daily energy savings

*For a station with 20 ports and 300 kW port capacity. More info:
[1] D. Jackson, E. Ucer, and J. Kisacikoglu, "A comparison of AC and DC distribution architectures for EV high power charging facilities," in preparation to be submitted to ECCE 2024.

Will be presented at HPC Technical Deep-Dive Meeting



AC-Hub (AC-coupled)

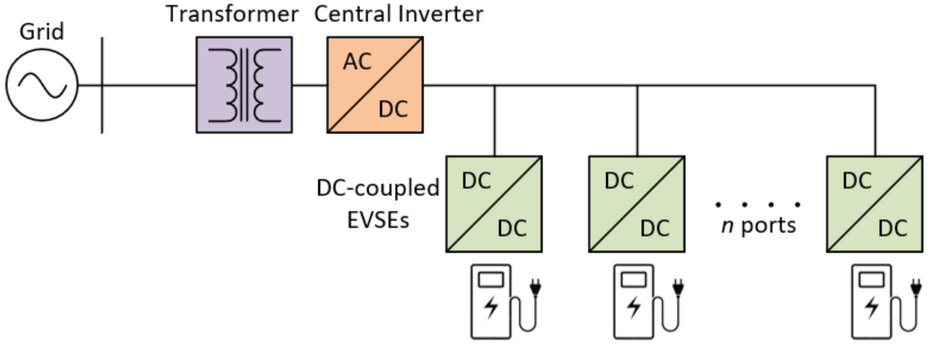
Advantages continued:

- Simplified controls (no AC sync., no Q-control)
- When PV and ESS integrates, above advantages will increase

Issues with DC Hub:

- More complex protection
- Product immaturity
- Lack of standardization for DC

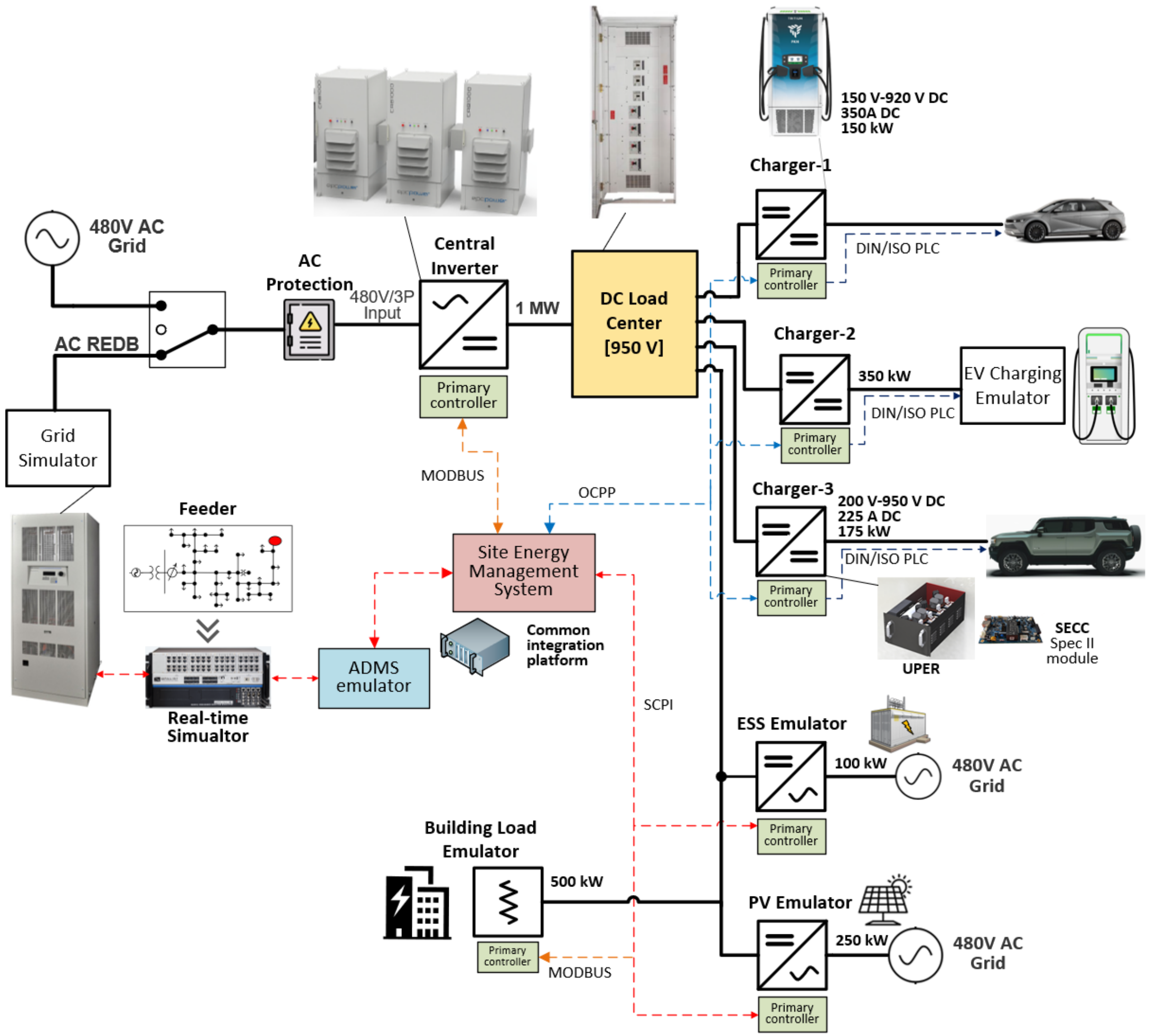
EVI-EnSite
https://www.nrel.gov/transportation/evi-ensite.html



DC-Hub (DC-coupled)

Proof of Concept DC Charging Hub Platform Overview

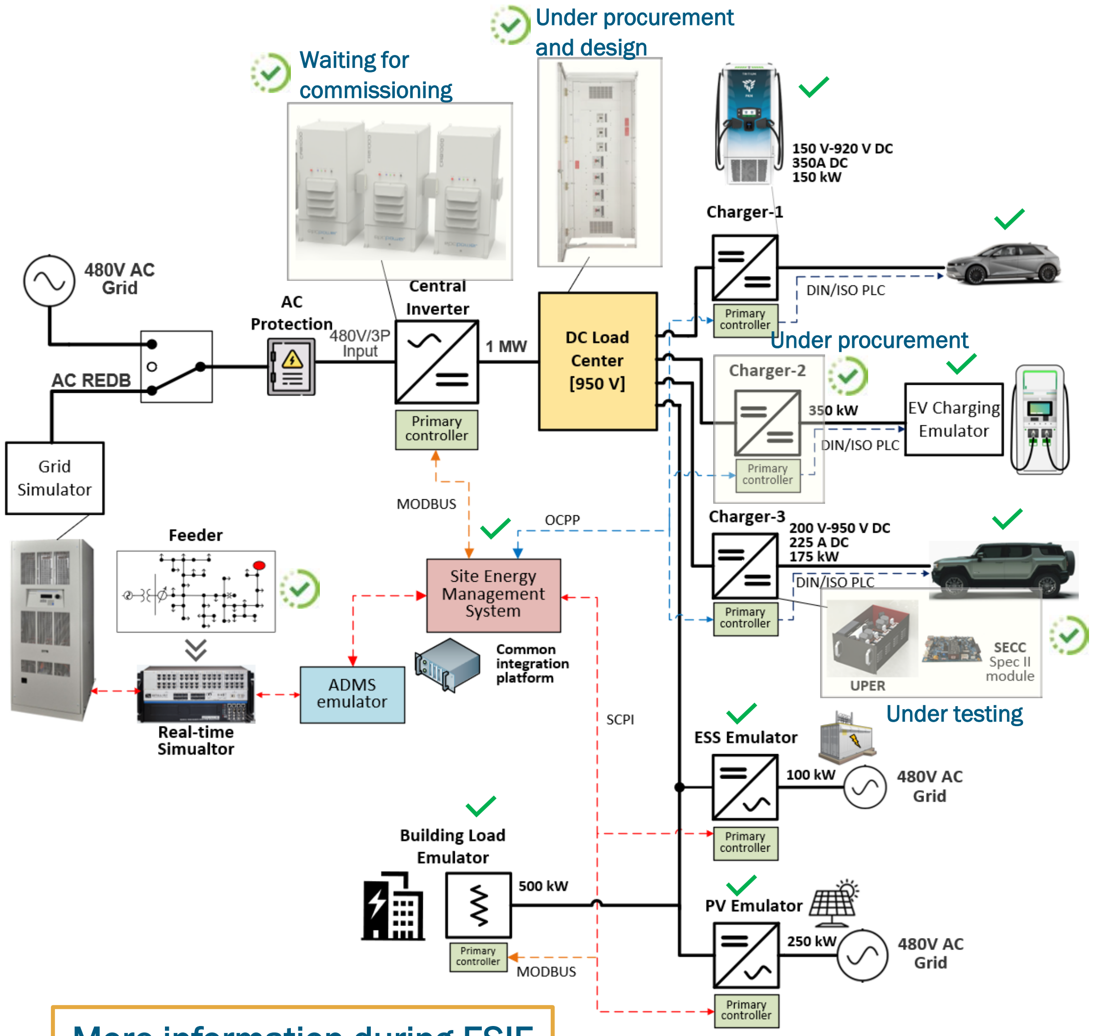
- Proof of concept test platform components
  - Grid-tie inverter
  - DC-distribution system
  - DC-DC charger
  - Real and emulated EVs
  - Battery ESS
  - PV emulation
  - Building load emulation
  - Open-source site energy management system (SEMS) platform
- DC hub platform explores:
  - <u>SEMS control strategies</u>
  - <u>Communications and interoperability</u>
  - <u>Bidirectional grid integration operation</u>



Proof of Concept DC Charging Hub Platform Overview, cont'd

Component Type	Component Name	Voltage Rating	Current/Power Rating
Inverter/Rectifier	Anderson AC2660P	265-1000 VDC	660 kW
Inverter/Rectifier	EPC Power CAB1000*	720-1250 VDC	1043 kW
DC Bus	DC REDB	1000 VDC	1600 A
DC Bus	DC Load Center*	2000 VDC	6000 A
DC-DC Charger	Tritium PKM150	Input: 950 VDC Output: 150-920 VDC	150 kW
DC-DC Charger	UPER*	Input: 900 VDC Output: 250-900 VDC	175 kW
EV-1	Hyundai Ioniq 5	800 VDC	235 kW
EV-2	GM Hummer EV	400/800 VDC (switchable)	350 kW
EV Emulator	CCB	1000 VDC	500 kW
EVSE / EV Emulation	OPAL RT 5700 and NHR 9300*	1200 VDC	100 kW
Energy Storage Syst. Emulation	OPAL RT 5700 and NHR 9300	1200 VDC	100 kW
PV Emulation	Magna-Power MTA1000-25	1000 VDC	250 kW
Building Load Emulation	Simplex Mars DC Load Bank	1000 VDC	500 kW

*Currently under development or installation



More information during ESIF tour today!

Site Energy Management System (SEMS)

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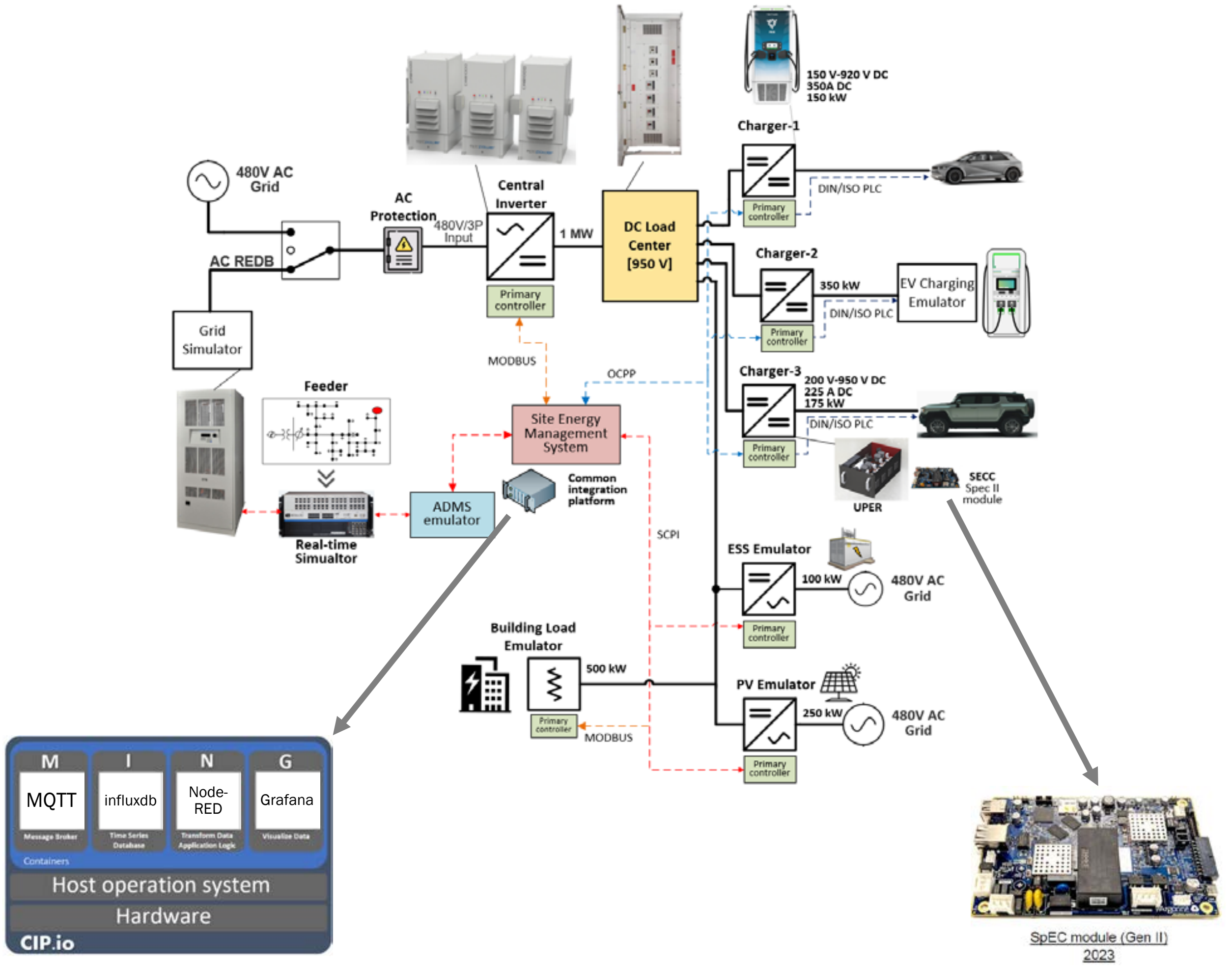
CIP.io – Common Integration Platform developed by Argonne is used for SEMS.

Highlights:

- DC-coupled chargers integrate into SEMS via **OCPP** and **MQTT**
- OCPP is used to handle monitoring and control of EV charging, while MQTT is used to implement non-standardized DC hub integration monitoring and control
- **SpEC module** will handle all SEMS communication for DC chargers and EV
- **Custom control applications are created in Node-RED, Python and C/C++**
- Discussing potential collaboration with Current/OS

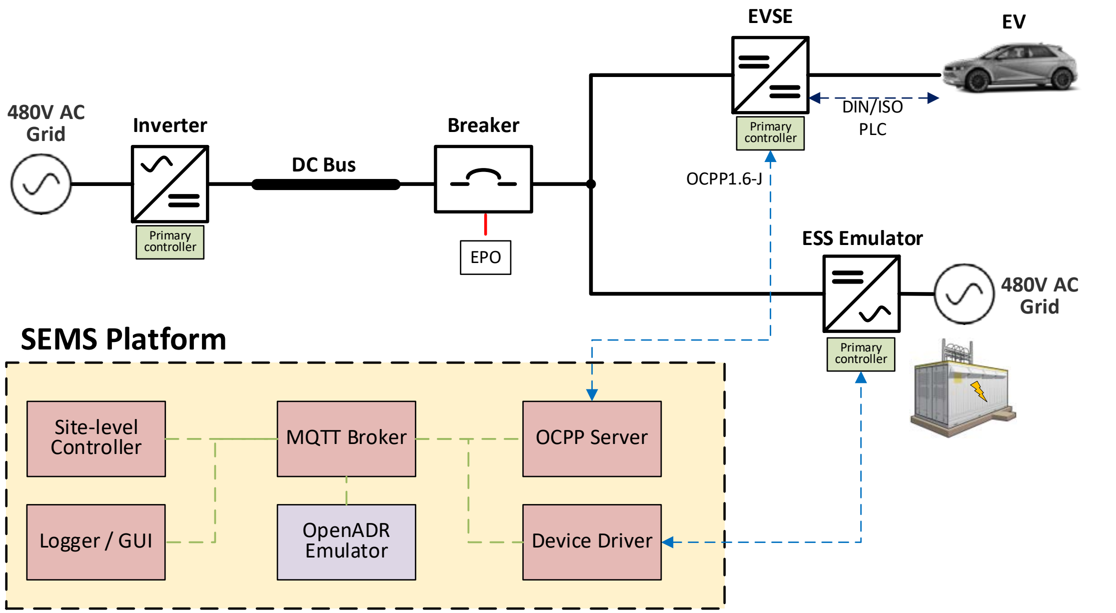


DC Hub with EV and Battery ESS Emulation

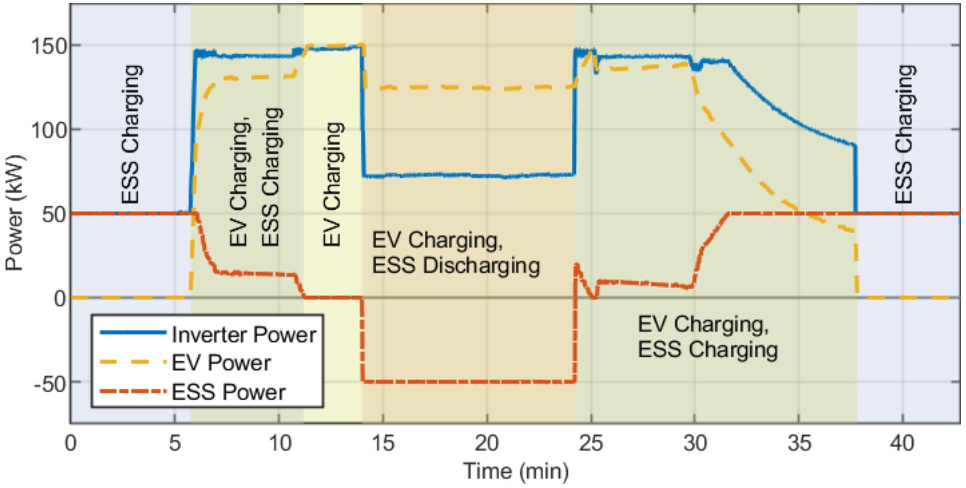
This use case demonstrates automated demand response capability of the DC hub platform using BESS support.

Highlights:

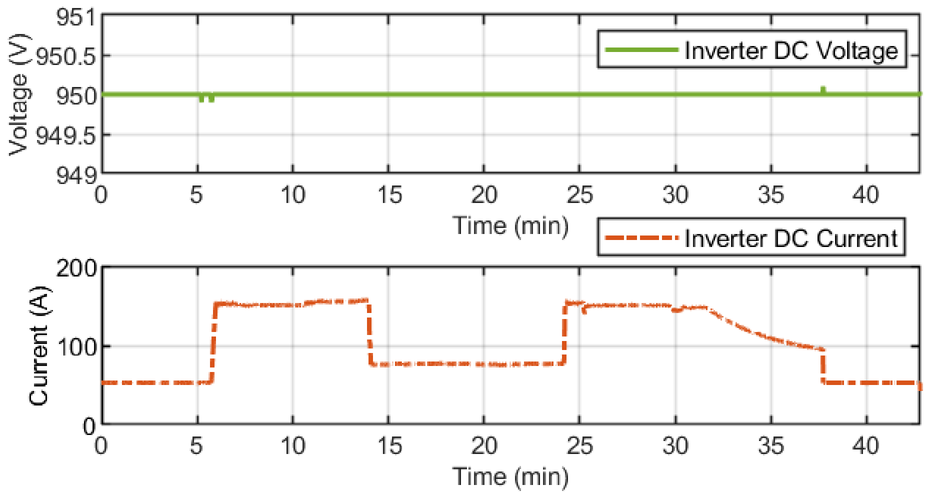
- During a demand response event, SEMS controller applies inverter power limit to meet specified load reduction.
- BESS discharges to DC hub to support EV charging as much as possible.
- If a lower charging power limit is still required, this is communicated by the SEMS to the EVSE via OCPP.



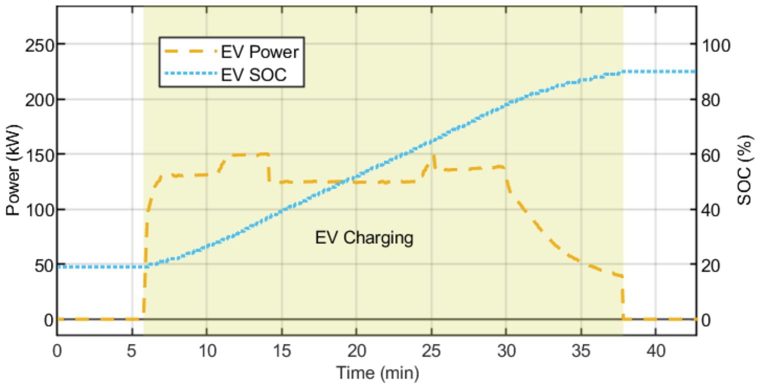
DC Hub with EV and Battery ESS Emulation, cnt'd



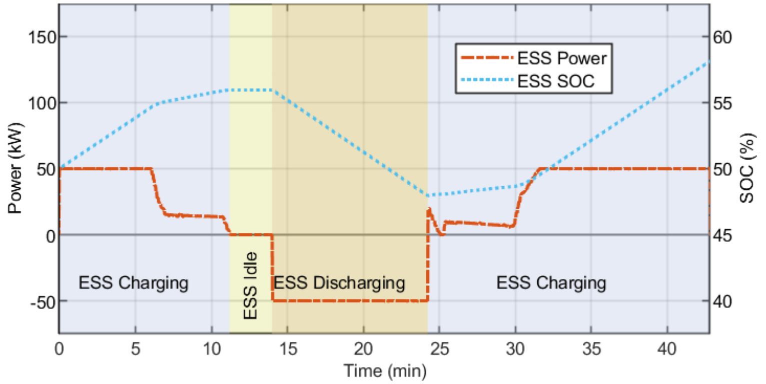
Power flow to/from DC hub components



Grid-tie inverter DC voltage and current



EV charging power and battery SOC



Battery ESS charging power and SOC

DC Hub with EV, Battery ESS, PV Generation, and Building Load Emulation

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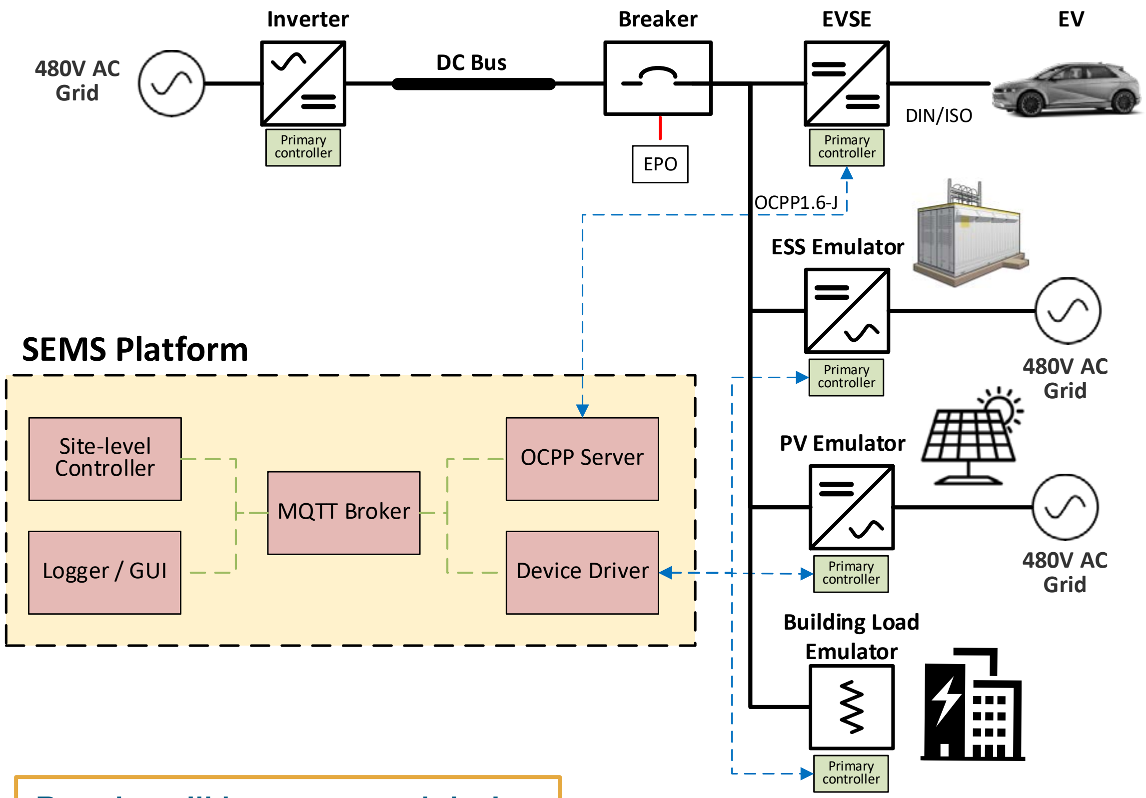
This use case demonstrates DC hub with EV, BESS, PV generation, and building load emulation

Highlights:

- BESS is emulated using a bidirectional DC-AC converter and real-time model running on OPAL-RT simulator.
- PV generation is emulated using a controlled DC source.
- Building load is emulated using a programmable resistive load bank.
- 1-second resolution PV power data is used to capture fast-timescale effects of PV generation variability.
- 1-second resolution building load data is used.
- SEMS dispatches ESS power in response to measured PV generation and DC hub loads (measured EV charging power and building load).
- PV generation is used within the hub to support EV charging or building loads. Any excess is used to recharge BESS or fed back to the grid if BESS is full. BESS is used to support high hub loads, reducing the maximum power demand from the grid.



Results will be presented during lab tour today!

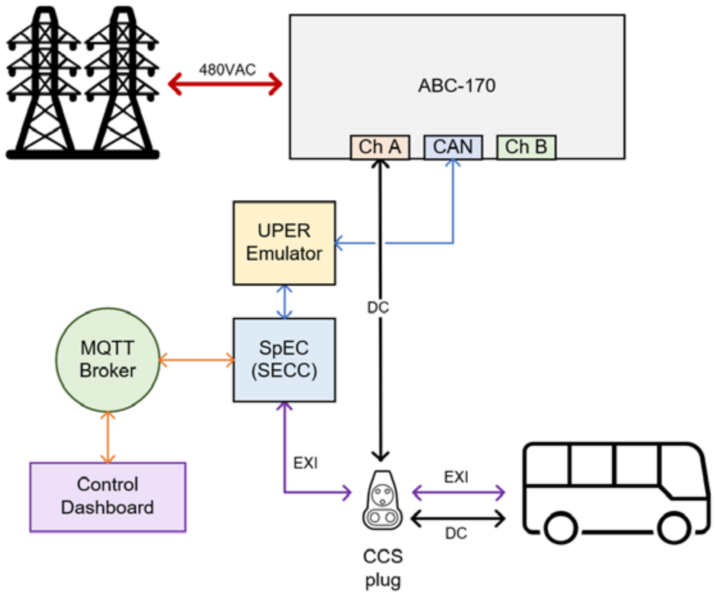
Results also available at report: High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP)—Design Guidelines and Specifications for DC Distribution-Based Charging Hub

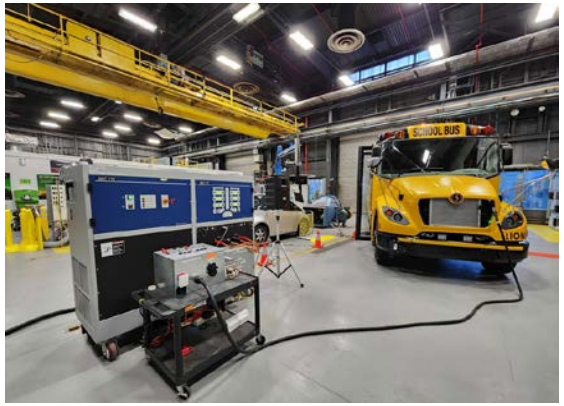
Bidirectional Power Transfer (BPT) w/ Lion Electric Bus

BPT has been achieved with ISO 15118-2.

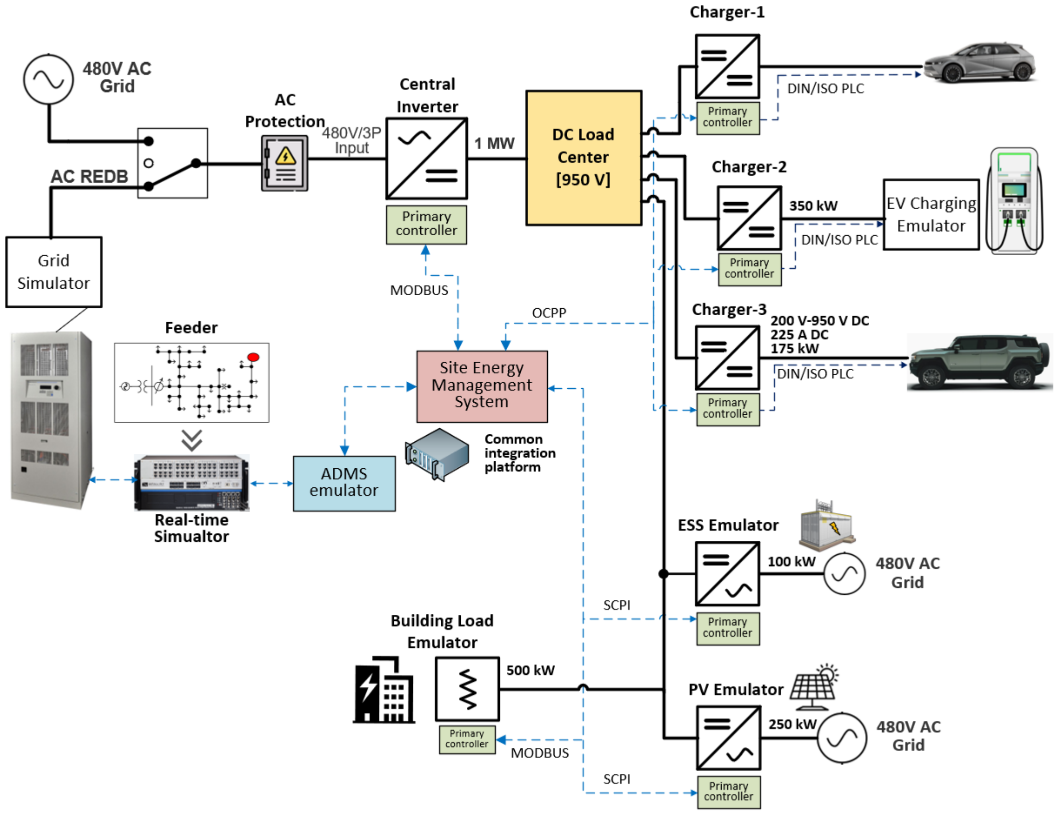
Highlights:

- SpEC module firmware has been updated with **ISO 15118-2** BPT message set
- *"Dynamic mode"* allows charge and discharge of EV on demand
- Successfully demonstrated SpEC + UPER emulator performing dynamic BPT charge/discharge session with **Lion Electric bus** (using ABC-170 for power delivery)
- Custom Node-RED dashboard for real-time dynamic monitoring and control
- **OCPP 1.6J** client implemented on SpEC module
- Using ANL's **Global MQTT broker** for messaging
- Currently working on implementing **ISO 15118-20** message set

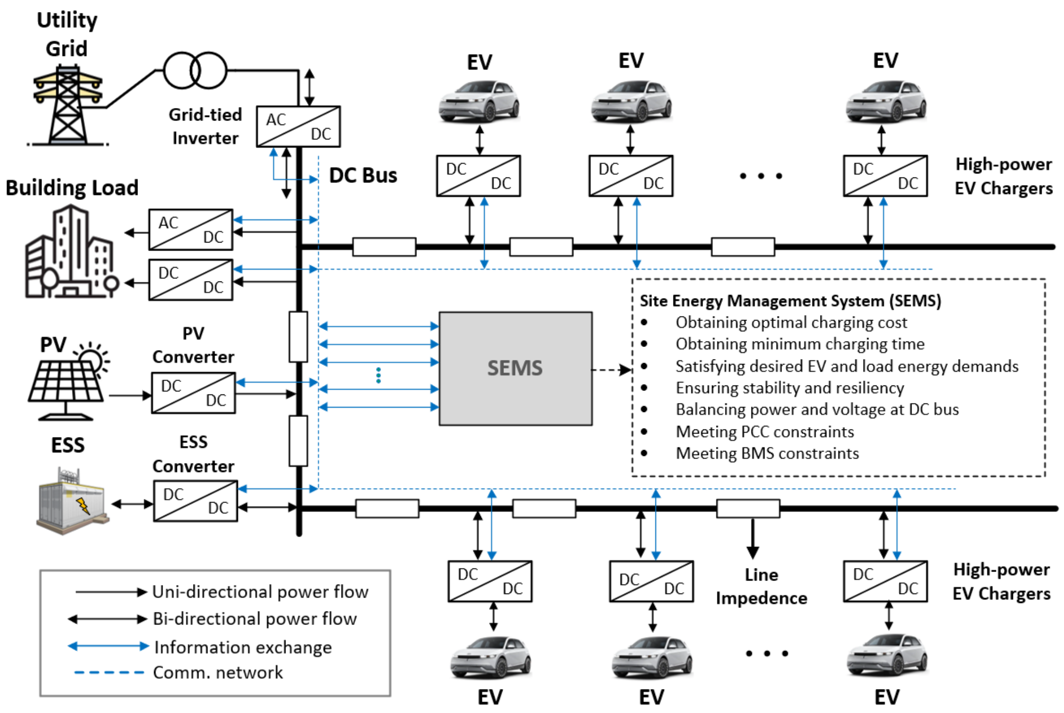




Scaling up DC Hub: Real Time Simulation (RTS) and Controller Hardware-in-the-loop (C-HIL)

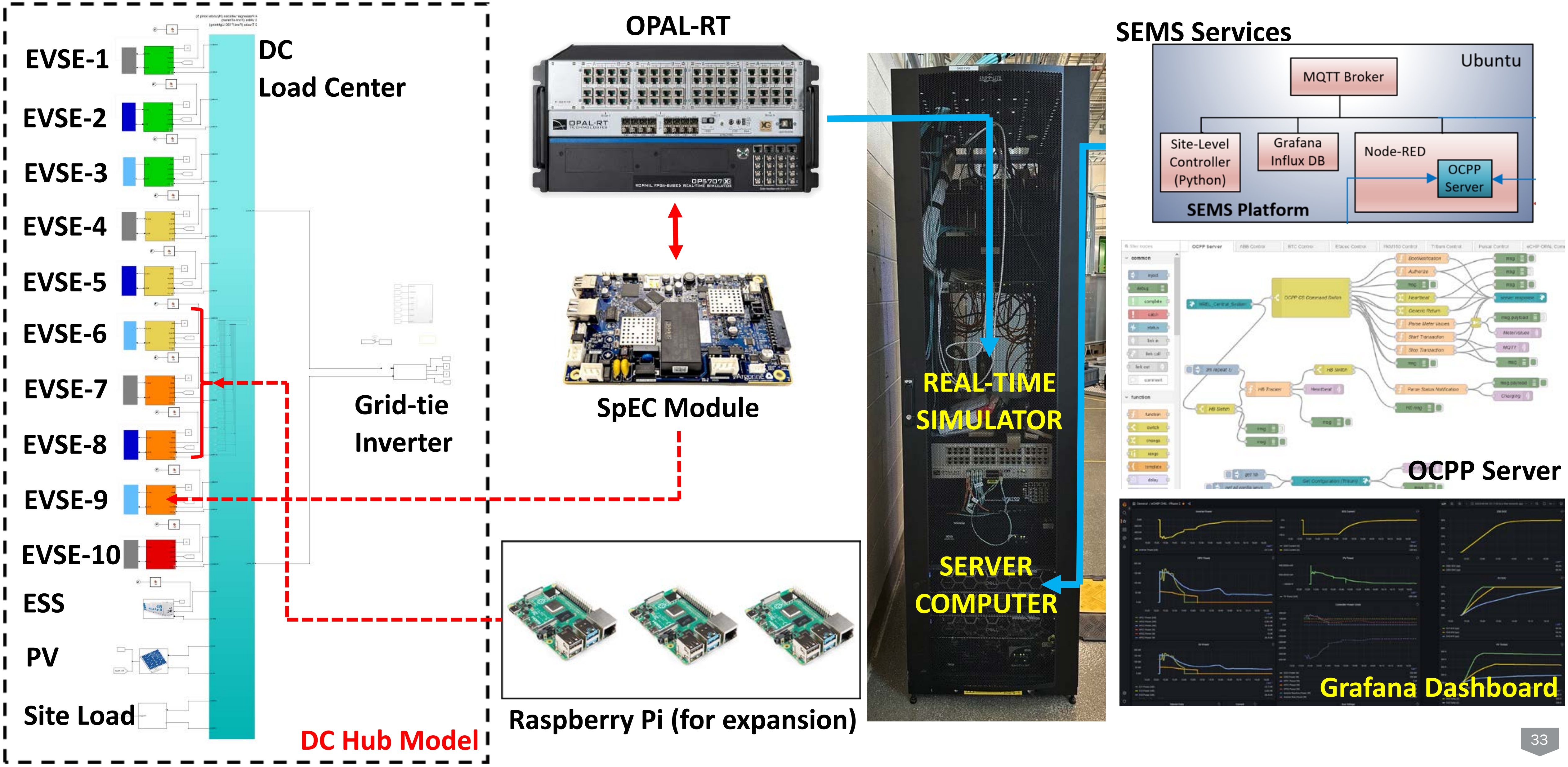


P-HIL Set-up



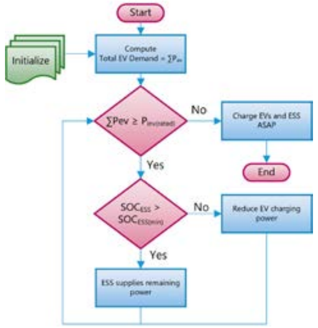
RTS Set-up

C-HIL Platform Development

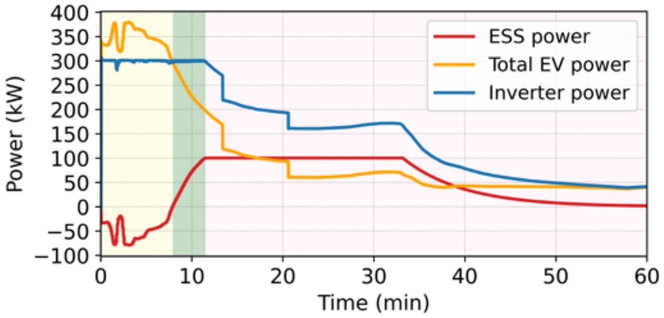


SEMS Controller Development

Rule-based

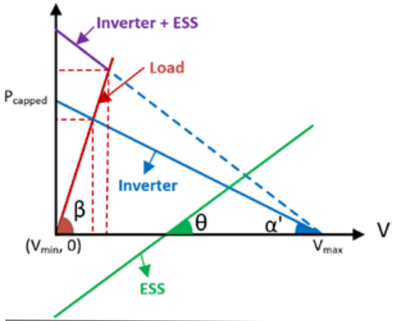


- Based on well-defined heuristics
- Easy to implement
- Centralized operation
- Requires real-time connectivity
- Moderate speed
- Sub-optimal

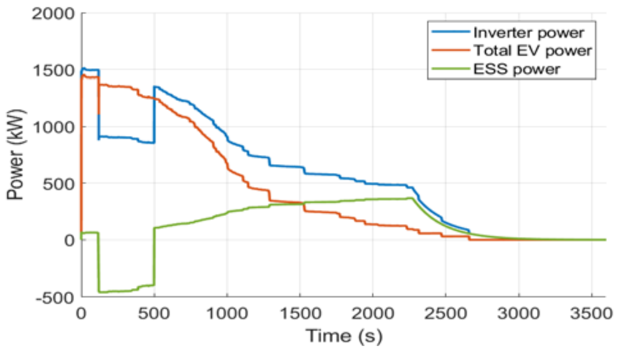


E. Ucer, A. Thurlbeck, E. Watt, Md. S. U. Khan, J. Kisacikoglu and A. Meintz, "Controller Hardware-in-the-loop Modeling and Operation of a High-power DC Charging Hub," IEEE ECCE, Nashville, TN, USA, 2023

Droop-based decentralized

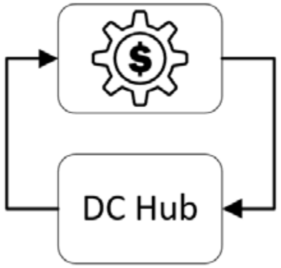


- Based on pre-defined P-V functions
- Decentralized and fast operation
- Autonomous power balance regulation
- Autonomous voltage regulation
- Single operating point based on droop coefficient
- Sub-optimal

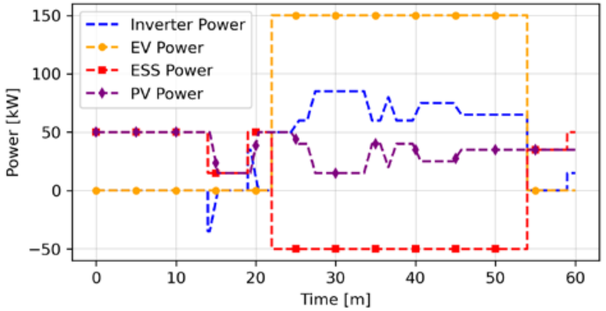


EVs@Scale HPC Pillar Technical Deep Dive Presentation, Nov 2023

Optimized



- Aims to optimize long term operations
- Centralized and slow operation
- Requires forecasting of load, generation and price
- Requires real-time connectivity
- Optimal

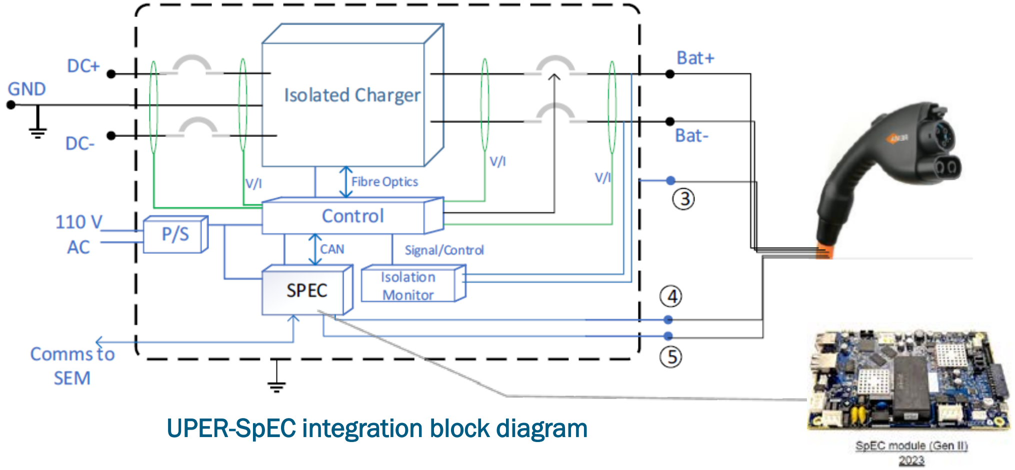


Universal Power Electronics Regulator (UPER)

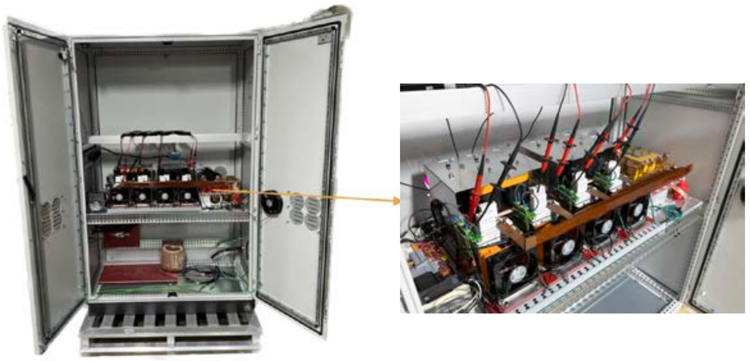
UPER is developed by ORNL and will integrate with Argonne-developed SpEC module.

UPER DC-DC Charger Specifications	
Output Power	175 kW per module
V_{in}	900 V ±5%
V_{out}	250-900 V with power derating
I_{max}	200 A
Dimensions (module)	24”h×36”w×25”d
Cooling	Forced Air
Power flow	Bidirectional

More info available on test results at report: [High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP)—Design Guidelines and Specifications for DC Distribution-Based Charging Hub]



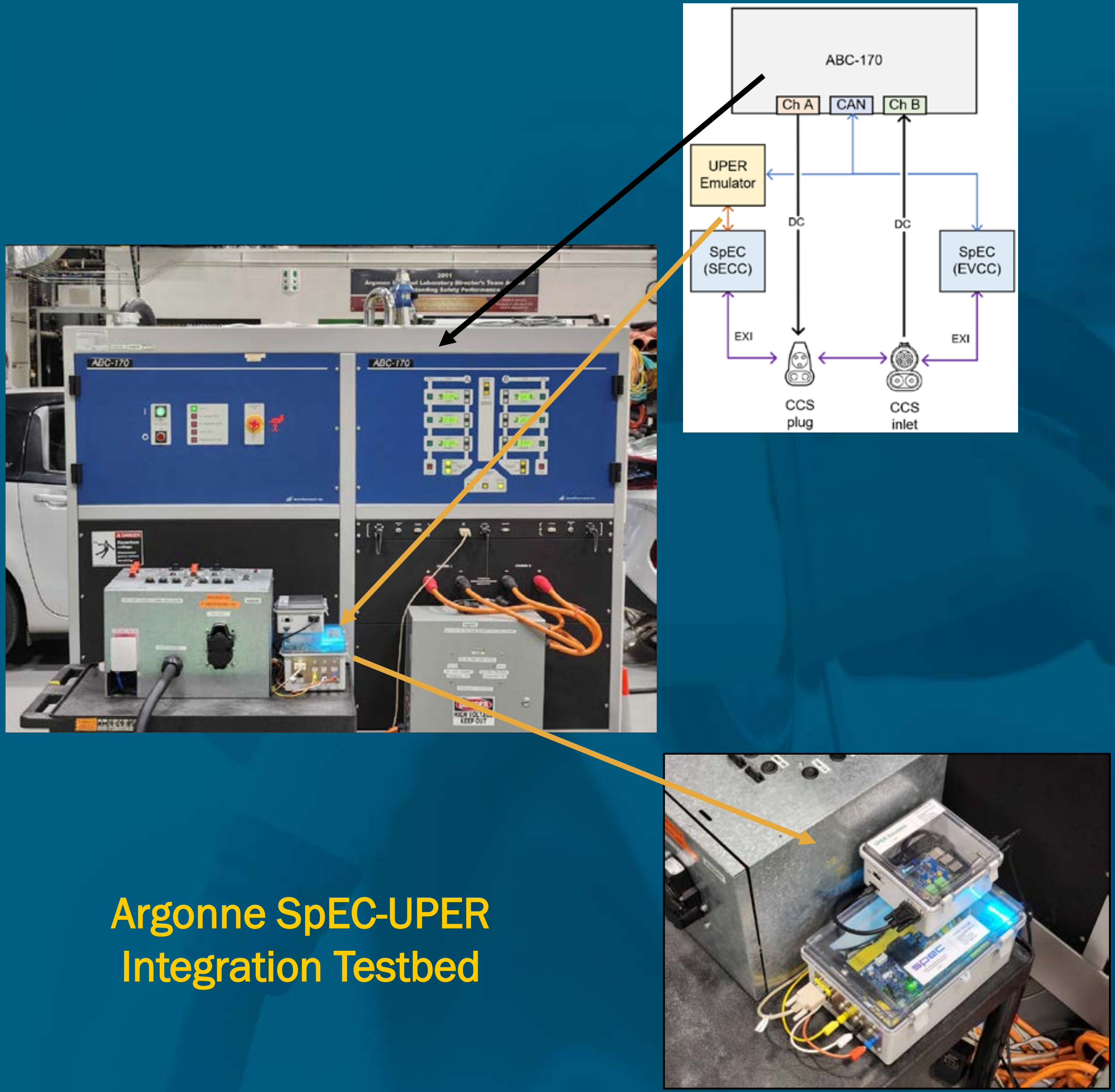
UPER-SpEC integration block diagram



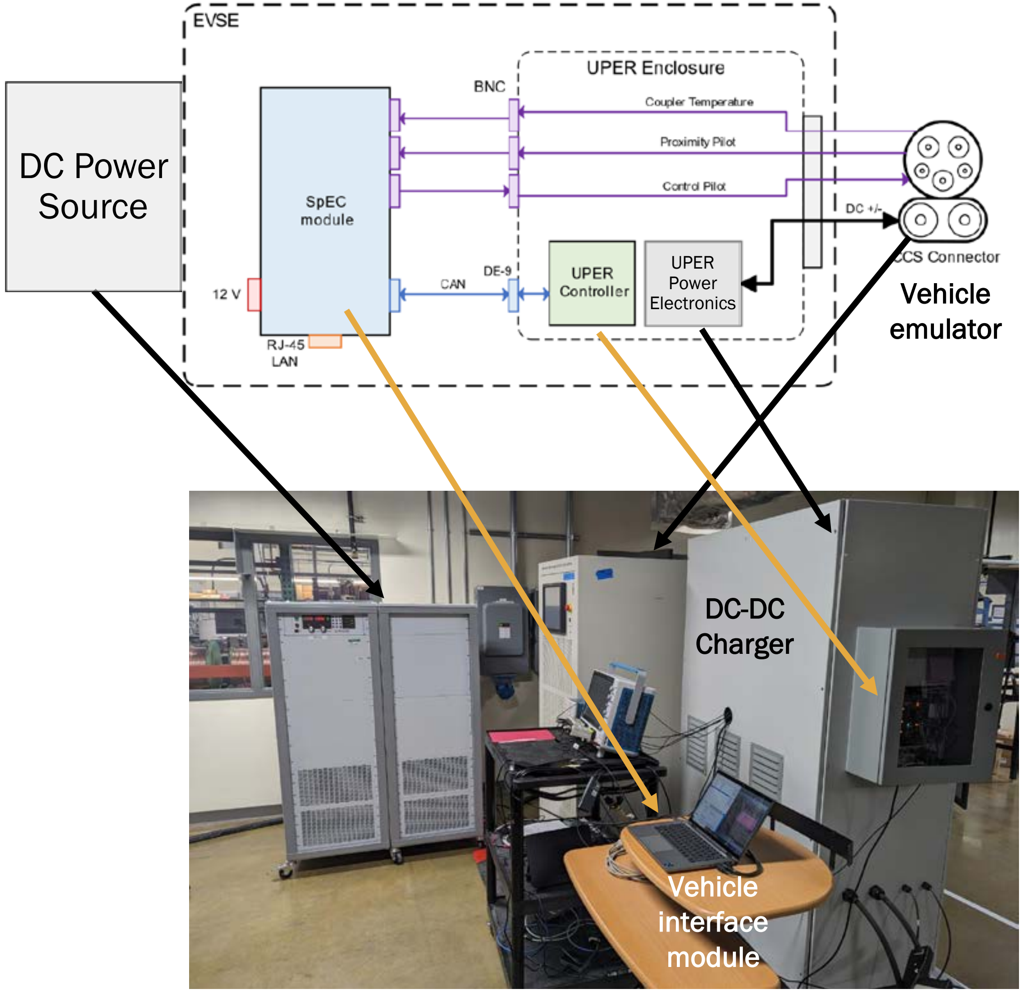
UPER 1000 V, 175 kW module

Rendering for UPER module scaled-up charger

UPER – SpEC Integration



Argonne SpEC-UPER Integration Testbed



ORNL UPER-SpEC Integration Testbed

High-Power MW Scale Charging Stations - Challenges and Barriers

Challenges / Barriers	eCHIP Project Solution
Interoperability of different hardware, communications, and controls.	eCHIP's DC hub test platform uses open-source SEMS platform to interface between hardware from multiple manufacturers using a variety of communication protocols. Any desired site control strategy can be deployed on the SEMS platform.
For a DC distributed charging hub, **DC protection** is more challenging and less mature than AC protection.	A DC load-center is currently being acquired which includes commercial DC protection devices for all connected hub components. Each connected DC-DC EVSE also includes galvanic isolation between input and output.
SEMS: Difficult to ensure **scalable**, reliable, fast, and optimized operation all at the same time → **Increasing data, computation and communication needs** with increased size and complexity.	High-fidelity real-time simulation capability within ARIES platform at NREL for easier scalability and high-speed communication. Deploying time-synchronized, distributed, modular data acquisition approach. Exploring PLCs and industrial computers for robust SEMS deployment.

Conclusion and Next Steps

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Conclusions and Demonstrated Benefits

- DC Hub P-HIL test platform combines an open-source SEMS platform with a DC-coupled hardware system.
- DC Hub can support automated demand response, enabled by the open-source SEMS platform. Integrated ESS can limit demand response event's impact on EV charging.
- DC Hub enables efficient integration of ESS, PV generation, and building loads. PV generation and ESS can reduce the peak grid power demand and reduce the charging system operating costs.
- Bidirectional power transfer is demonstrated for functionality and readiness.

Next steps

- Implementation of more advanced SEMS: optimized and hierarchical.
- Integration of UPER and SPEC modules within DC hub
- Scaling up C-HIL platform using larger RTS within ARIES.
- Continued focus on demonstration on various real-world use cases.

Thank You!

Join us for the

HPC Deep Dive on

Tuesday April 23, 2024

John.Kisacikoglu@nrel.gov

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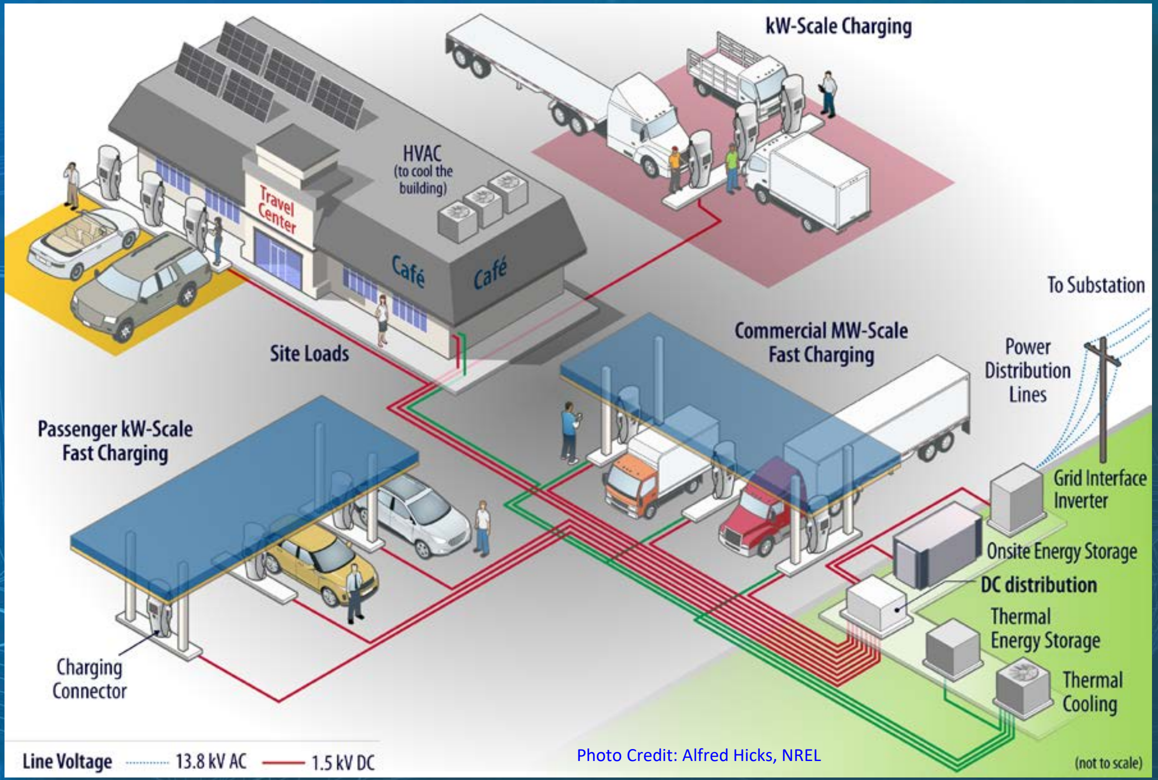

Photo Credit: Alfred Hicks, NREL

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Semi-Annual Meeting:

Next-Gen Charge Profiles

Sam Thurston

Feb 28th, 2024

Next-Gen Profiles Overview

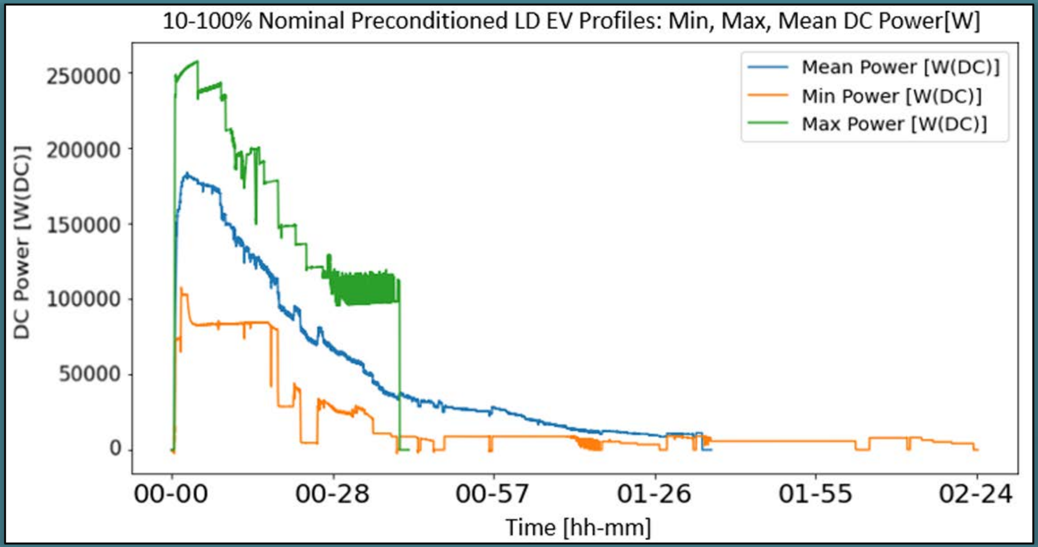
EVs@Scale Consortium > High Power Charging Pillar > Next-Gen Profiles

"To further understand the most recent technological capabilities of the electric mobility industry related to charging performance."

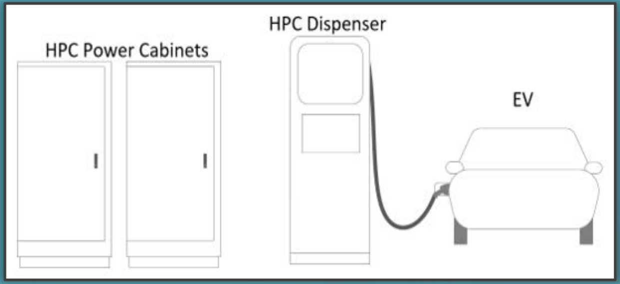
What to consider when assessing high power charging (>200kW):

- Nominal vs Off-Nominal conditions
- Conductive & Non-Conductive Equipment
- System responses to grid disturbances & charging management
- Unique & thoughtful methods of performance characterization

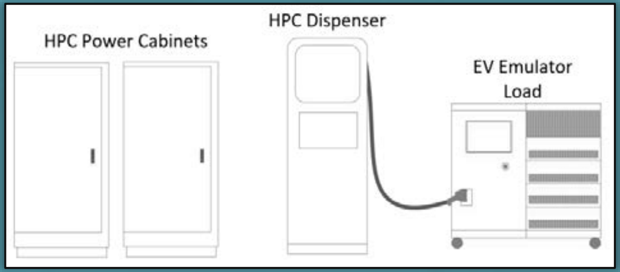
3 categories of HPC under investigation in Next-Gen Profiles:



1. EV Profile Capture

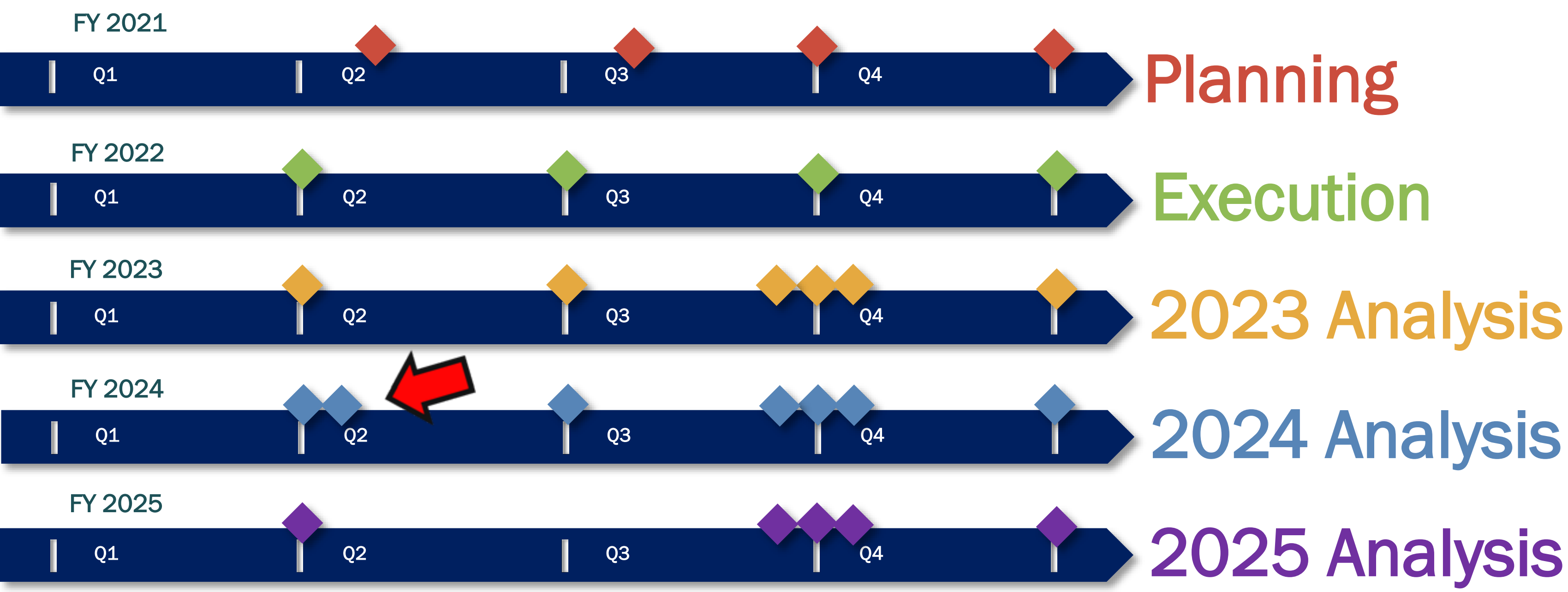


2. EVSE Characterization



3. Fleet Utilization

Project Timeline



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Completed
Ongoing
Future Work

Year 1 Milestones

- Solidify collaborator agreements
- Parameter definitions/draft procedure
- Procedure performance - refinement
- Finalized project procedures

Year 2 Milestones

- Fleet data collection review
- Capture conductive profile sets
- Complete EVSE characterization
- Capture non-conductive profiles sets

Year 3 Milestones

- Capture conductive profiles sets
- Finalize fleet data collection
- Complete R&D profile EVSE characterization
- Capture Boost Converter EV Profiles
- Gather fleet data
- Analysis, results, and reporting

Year 4 Milestones

- Refine & update testing procedures
- Acquire new test assets
- Integrate grid models with EV profiles
- Complete conductive profile sets capture
- Complete EVSE Characterization (LP V2X Included)
- Gather fleet data
- Amend reports

Year 5 Milestones

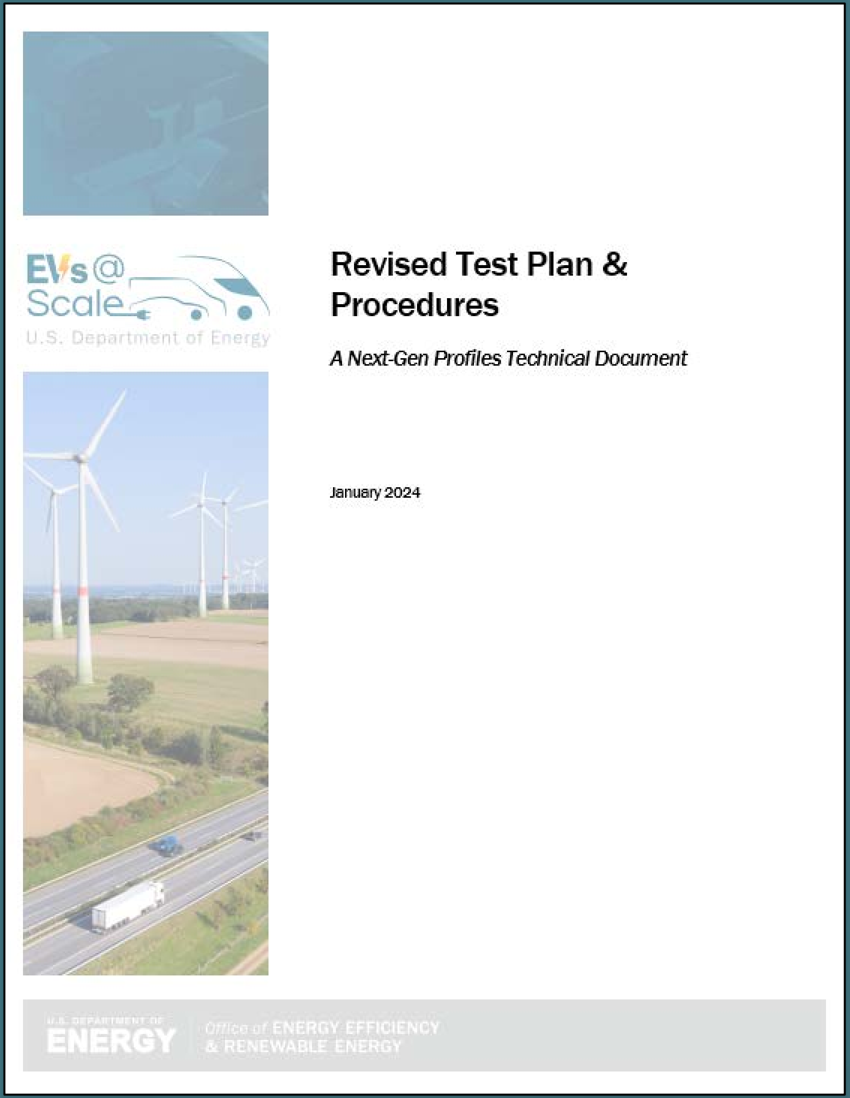
- Acquire new test assets
- Complete conductive profile sets capture
- Complete EVSE Characterization (HP V2X, NACS, MCS)
- Gather fleet data
- Amend reports

Procedures Revision 2024-2025

!! Feedback Period open until 04/01/2024 !!

- Last Revision was for 2021-2023
- This Revision will be for 2024-2025
- Major Updates:
  - EV Profile Capture:
    - Boost converter, EVSE power limited, Adapter test cases added & detailed
    - Vehicle Measurement locations update
    - Megawatt Charging Systems (MCS)
  - EVSE Characterization:
    - Vehicle-to-Grid (V2G) tests
  - Fleet Utilization:
    - Metrics list for Charging, Routing, Other
  - Data dissemination (3 types):
    - Public, project partner, proprietary results

EVs@Scale Next-Gen Profiles – Procedures Revision 2024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Revised Test Plan & Procedures

A Next-Gen Profiles Technical Document

January 2024

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

Reporting & Participation

!! Reports are EERE published available on DOE OSTI !!

EVs@Scale Next-Gen Profiles:

- *High-Level Analysis Report 2023*
- *EV Profile Capture Report 2023*
- *EVSE Characterization Report 2023*
- *Fleet Utilization Report 2023*

Participating OEMs:

- Receive 10Hz time-series profiles with meta-data for OEM sponsored assets
- Receive anonymized, lowered cadence time-series for non-sponsored assets
- Compare how your asset performs against other competing assets, while remaining anonymous
- Included in a large study characterizing EV charging during its most ever-changing period

EVs@Scale Next-Gen Profiles – Technical Reports 2023

Time-Series Anonymized Data (10Hz)

Charge Session Meta-Data

Vehicle Property		EVSE Property		Events	
Unique ID		Charger Model		Charge-Event #	
Vehicle Model		Station or EVSE ID		Station Plug	
Firmware Version				Odometer Reading	
				Plug-In Timestamp	
				Un-Plug Timestamp	
				Session Cost	
				Local OCPP Central Service	
				Curtailment Power [kW]	
				Curtailment Curent [A]	
				Curtailment Start Time	
				Curtailment End Time	

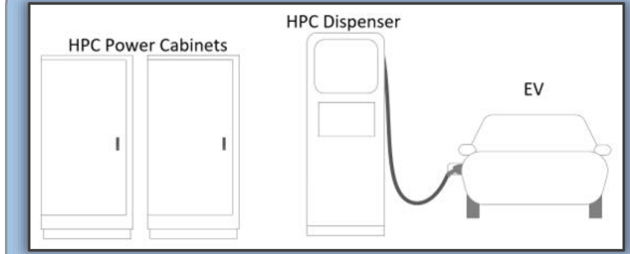
Time Series Charge Data

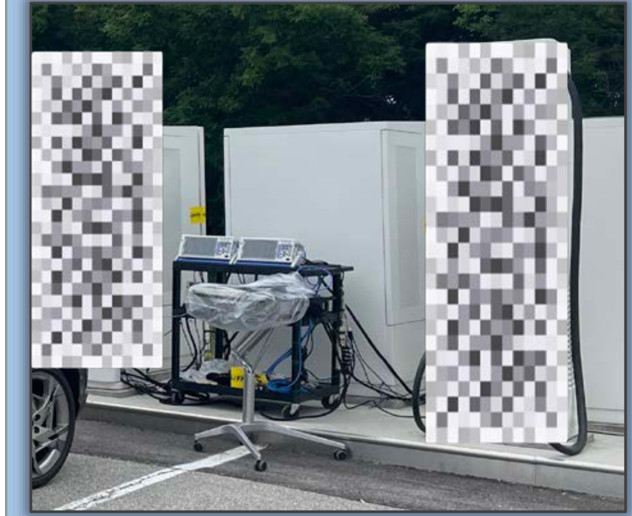
Time (10 Hz)		480VAC Cabinet 1 Phase A			
Date [YYYY-MM-DD]	Time [hh:mm:ss.0]	Voltage [V(RMS)]	Current [A(RMS)]	Frequency [Hz]	Real Power [W(RMS)]
2023-06-22	00:00:00.100000	275.21	2.87	60.02	3.20
2023-06-22	00:00:00.200000	275.22	2.88	60.02	4.30
2023-06-22	00:00:00.300000	275.20	2.87	60.02	3.50
2023-06-22	00:00:00.400000	275.15	2.86	60.02	3.90
2023-06-22	00:00:00.500000	275.16	2.88	60.02	3.90
2023-06-22	00:00:00.600000	275.15	2.88	60.02	3.70
2023-06-22	00:00:00.700000	275.28	2.87	60.02	3.90
2023-06-22	00:00:00.800000	275.39	2.85	60.02	3.70
2023-06-22	00:00:00.900000	275.47	2.86	60.02	3.40
2023-06-22	00:00:01.000000	275.49	2.87	60.02	3.70
2023-06-22	00:00:01.100000	275.49	2.88	60.02	3.80
2023-06-22	00:00:01.200000	275.46	2.86	60.02	3.70
2023-06-22	00:00:01.300000	275.46	2.86	60.02	3.90
2023-06-22	00:00:01.400000	275.44	2.86	60.02	3.90
2023-06-22	00:00:01.500000	275.42	2.87	60.02	3.80
2023-06-22	00:00:01.600000	275.43	2.88	60.02	4.20
2023-06-22	00:00:01.700000	275.43	2.87	60.02	3.40
2023-06-22	00:00:01.800000	275.42	2.87	60.02	3.70
2023-06-22	00:00:01.900000	275.43	2.86	60.02	3.80
2023-06-22	00:00:02.000000	275.43	2.88	60.02	3.60
2023-06-22	00:00:02.100000	275.44	2.88	60.02	4.00
2023-06-22	00:00:02.200000	275.46	2.87	60.02	3.60
2023-06-22	00:00:02.300000	275.48	2.86	60.02	3.70

EV Profile Capture:
Testing Procedures & Results

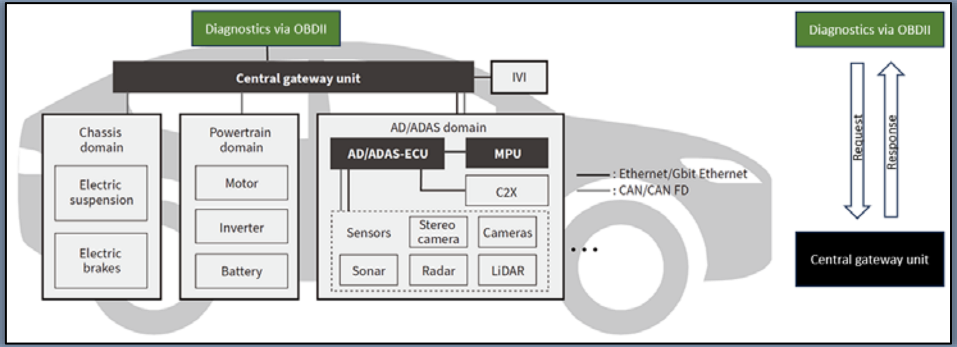
Overview: EV Profile Capture

- EV Assets: Production EVs, rated 150-400kW DC charging
- EVSE Assets: Production DCFC (500A, 1000VDC), typically dual cabinet topology, multiple handle types
- Nominal test conditions:
  - 10-100% EV state of charge (SOC)
  - Nominal (23°C/75°F) ambient temperature
  - EV pre-driven/preconditioned for 30-40min prior to plug-in
- Off-nominal test conditions:
  - 25-100%, 50-100% EV state of charge
  - Hot (40°C/100°F), Cold (-7°C/20°F) ambient temperature
  - EV temperature soaked for 4-hours, or pre-driven 30-40min
  - OCPP curtailed (65A for 2min)
  - Single power cabinet (EVSE Power Limited)
  - Boost converter utilized (800-volt EVs only)
  - WPT Profile Capture





EVSE Condition Categories		Condition Metric Requirement	Tolerance
EVSE Power Limited		No Limit, Dual Tower (Nominal)	–
		Limited, Single Tower	–
Boost Converters		Not Utilized (Nominal)	–
		Utilized	–
Outside Ambient Temperature		23°C (Nominal)	± 2°C
		40°C (Hot)	± 2°C
		-7°C (Cold)	± 2°C
Smart Charge Management Scheduled	Request	FALSE (Nominal)	–
		TxProfile	–
	Duration	No Limit (Nominal)	–
		2 Minutes	–
	Scheduling	No Request (Nominal)	–
		2 (min) After Charge Session Start	± 1 (min)
	Value	No Limit (Nominal)	–
		65A (AC Input Current)	–
WPT Alignment	X-Direction	<5% coil length offset (Nominal)	± 2%
		10% coil length offset	± 2%
		25% coil length offset	± 2%
		40% coil length offset	± 2%
	Y-Direction	<5% coil length offset (Nominal)	± 2%
		10% coil length offset	± 2%
		25% coil length offset	± 2%
		40% coil length offset	± 2%
	Z-Direction	Unloaded (Nominal)	± 2%



EV Profile Capture: Comparing EV Performance

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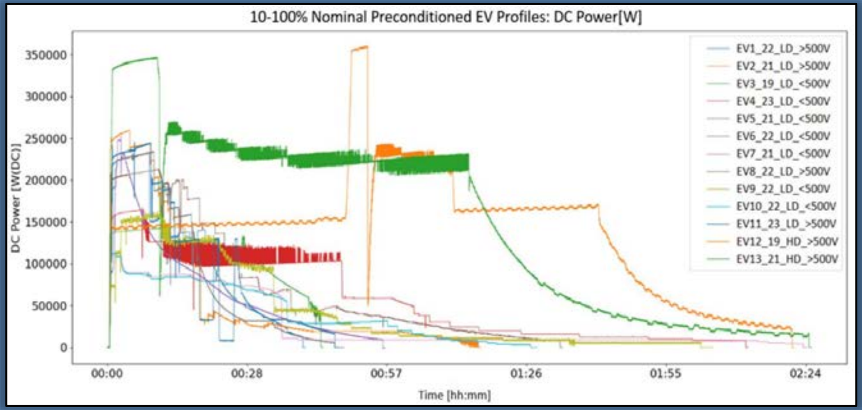
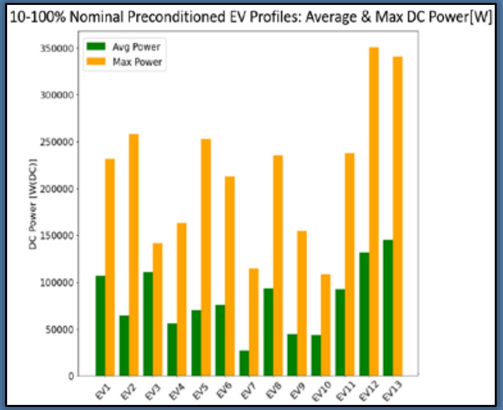
Goal: Capture the diversity of charge profiles under similar conditions through different means of performance metrics.

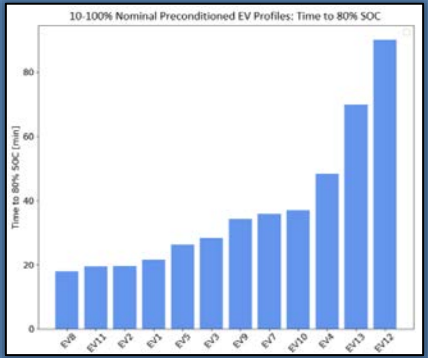
Findings:

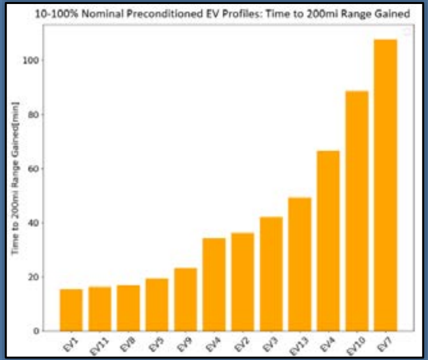
- DC Power profiles are unique
- Constant current vs constant voltage zones
- Ratio between peak power vs avg Power
- Different test goals yield different top performers for SOC, Range, Energy
  - Harmonization with standards for reports (SAE 2953/4)
- Graphical & tabular results

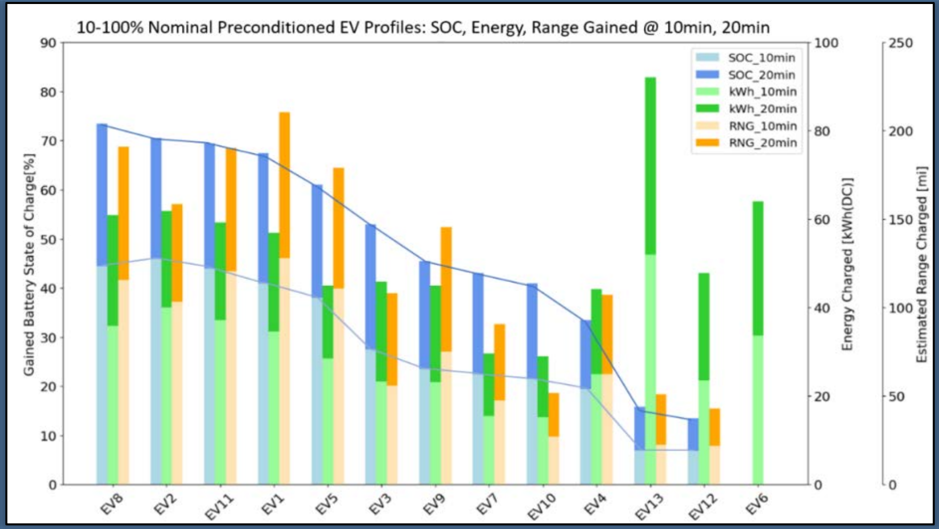
EV	Peak Power [kW]	Avg Power [kW]	Time Spent <100kW [min]	Time Spent 100-150kW [min]	Time Spent >150kW [min]	Total Charge Time [min]
EV1	200-250	~105	18.7	10.6	10.5	39.8
EV2	250-300	~65	58.1	3.5	14.3	75.9
EV3	100-150	~110	13.5	30.0	0.0	43.5
EV4	150-200	~55	87.0	37.2	6.9	131.1
EV5	200-250	~70	42.7	7.5	6.1	56.3
EV6	200-250	~75	66.5	8.4	18.0	92.9
EV7	100-150	~25	140.6	2.4	0.0	143.0
EV8	200-250	~95	28.1	1.9	16.4	46.4
EV9	150-200	~45	97.0	17.3	7.6	121.9
EV10	100-150	~45	84.5	2.3	0.0	86.8
EV11	200-250	~95	26.4	7.0	13.0	46.4
EV12	350-400	~130	34.9	45.1	60.7	140.7
EV13	300-350	~145	59.6	6.7	77.9	144.2









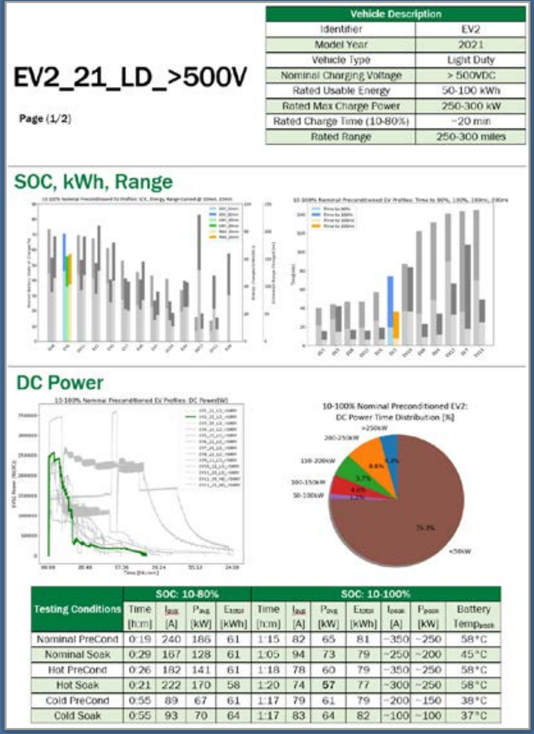


EV Profile Capture: EV Portfolios

Goal: Create detailed portfolios for each EV, highlighting multiple areas of performance graphically and tabularly.

Findings:

- Compares EV against all assets, shows unique performance highlights
- Provides performance variance when exploring boundary conditions for SOC, temperature, vehicle condition, EVSE limited, Adapter use, SCM, etc.
- Captures Next-Gen Profiles' full scale of profile capture testing
- Future analysis/portfolio expansion expected with project scope increase



EV2_21_LD_>500V

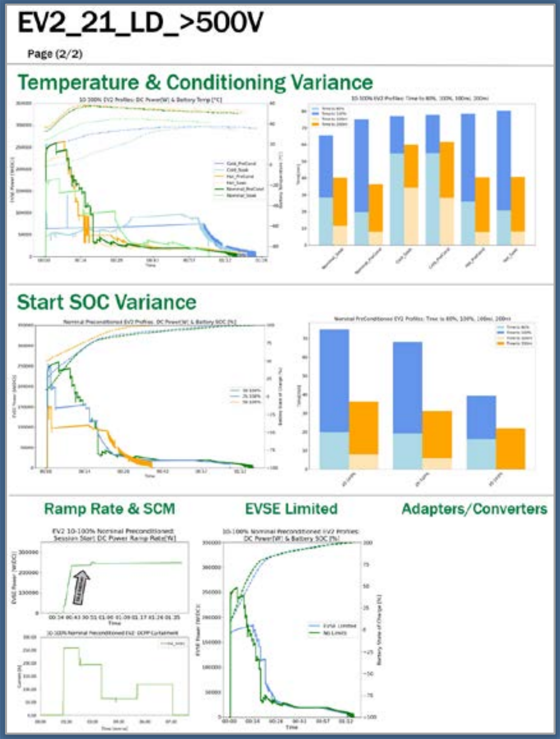
Page (1/2)

Vehicle Description	
Identifier	EV2
Model Year	2021
Vehicle Type	Light Duty
Nominal Charging Voltage	> 500VDC
Rated Usable Energy	50-100 kWh
Rated Max Charge Power	250-300 kW
Rated Charge Time (10-80%)	~20 min
Rated Range	250-300 miles

SOC, kWh, Range

DC Power

Testing Conditions	SOC: 10-80%				SOC: 10-100%						
	Time [h:m]	I_{avg} [A]	P_{avg} [kW]	E_{total} [kWh]	Time [h:m]	I_{avg} [A]	P_{avg} [kW]	E_{total} [kWh]	I_{peak} [A]	P_{peak} [kW]	Battery $Temp_{peak}$
Nominal PreCond	0:19	240	186	61	1:15	82	65	81	~350	~250	58°C
Nominal Soak	0:29	167	128	61	1:05	94	73	79	~250	~200	45°C
Hot PreCond	0:26	182	141	61	1:18	78	60	79	~350	~250	58°C
Hot Soak	0:21	222	170	58	1:20	74	57	77	~300	~250	58°C
Cold PreCond	0:55	89	67	61	1:17	79	61	79	~200	~150	38°C
Cold Soak	0:55	93	70	64	1:17	83	64	82	~100	~100	37°C



EV2_21_LD_>500V

Page (2/2)

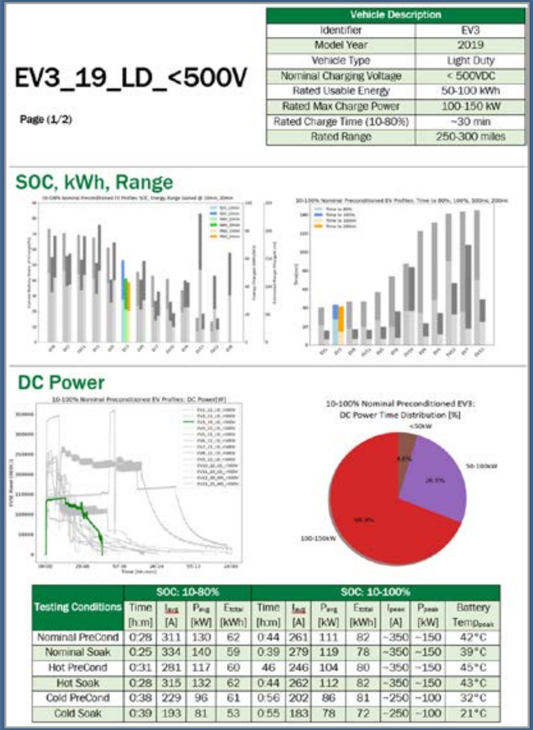
Temperature & Conditioning Variance

Start SOC Variance

Ramp Rate & SCM

EVSE Limited

Adapters/Converters



EV3_19_LD_<500V

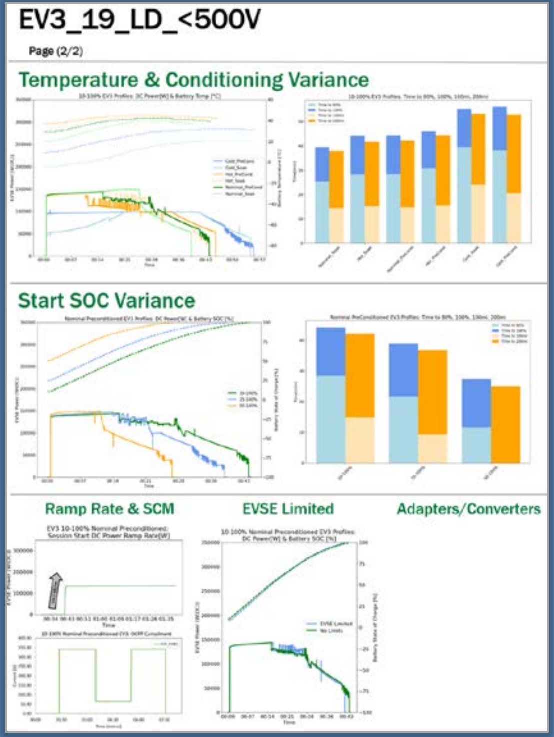
Page (1/2)

Vehicle Description	
Identifier	EV3
Model Year	2019
Vehicle Type	Light Duty
Nominal Charging Voltage	< 500VDC
Rated Usable Energy	50-100 kWh
Rated Max Charge Power	100-150 kW
Rated Charge Time (10-80%)	~30 min
Rated Range	250-300 miles

SOC, kWh, Range

DC Power

Testing Conditions	SOC: 10-80%				SOC: 10-100%						
	Time [h:m]	I_{avg} [A]	P_{avg} [kW]	E_{total} [kWh]	Time [h:m]	I_{avg} [A]	P_{avg} [kW]	E_{total} [kWh]	I_{peak} [A]	P_{peak} [kW]	Battery $Temp_{peak}$
Nominal PreCond	0:28	311	130	62	0:44	261	111	82	~350	~150	42°C
Nominal Soak	0:25	334	140	59	0:39	279	119	78	~350	~150	39°C
Hot PreCond	0:31	281	117	60	46	246	104	80	~350	~150	45°C
Hot Soak	0:28	315	132	62	0:44	262	112	82	~350	~150	43°C
Cold PreCond	0:38	229	96	61	0:56	202	86	81	~250	~100	32°C
Cold Soak	0:39	193	81	53	0:55	183	78	72	~250	~100	21°C



EV3_19_LD_<500V

Page (2/2)

Temperature & Conditioning Variance

Start SOC Variance

Ramp Rate & SCM

EVSE Limited

Adapters/Converters

EV Profile Capture: Grid Utilization

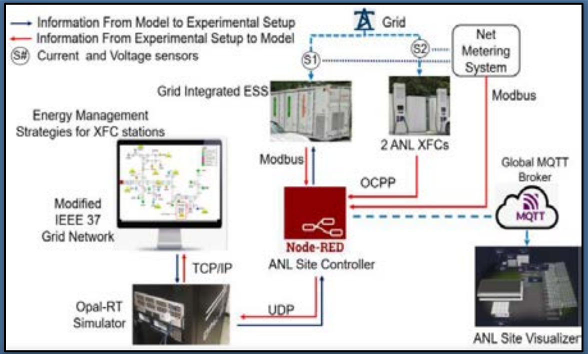
!! April Deep Dive on HPC Grid Model Integration !!

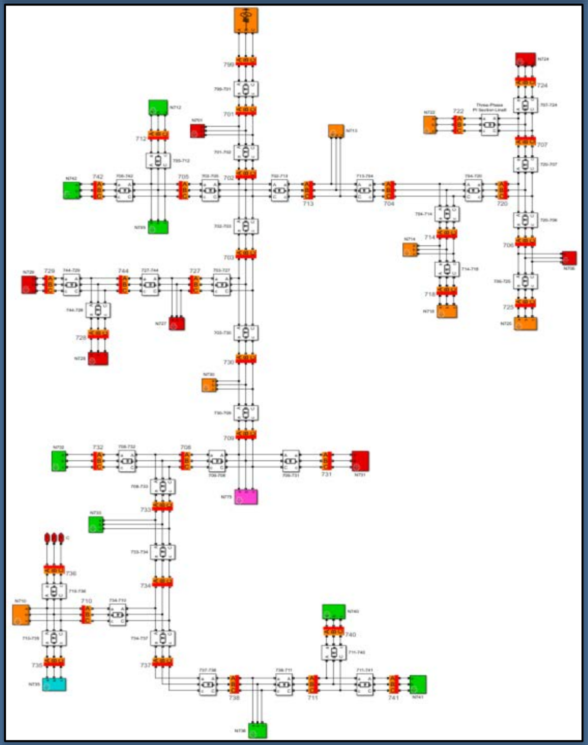
Goal: Integrate captured EV profiles captured into advanced grid modelling for utilization analysis

Findings:

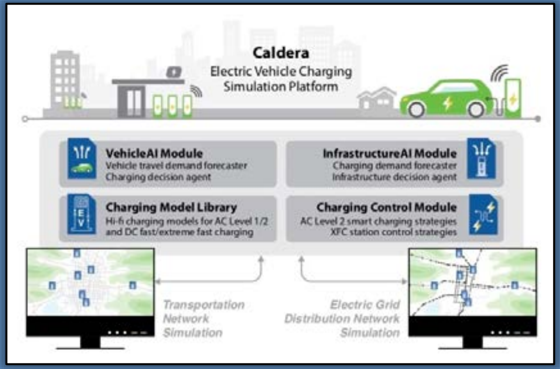
- Models:
  - ANL: IEEE HIL Grid Model
  - INL: Caldera Simulation Platform
  - NREL: EVI-X Modelling Suite
- Progress:
  - Integrated HPC profiles into models
  - Performed statistical analysis of real-world start/end SOC
  - Model & setup megawatt charging sites within model
  - Developed mixed-use (fleet/public) use case for simulations
  - Performing grid impact studies

ANL IEEE HIL Grid Model





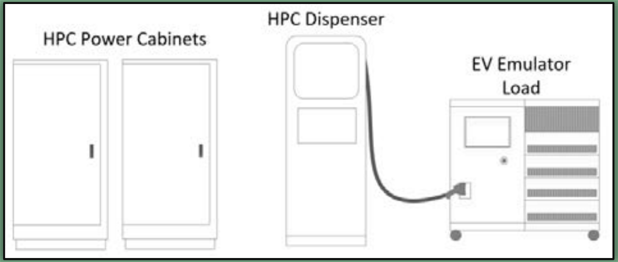
INL Caldera Models



NREL EVI-X Simulations

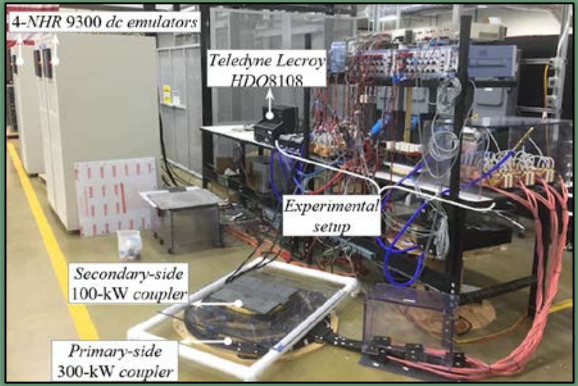
EVSE Characterization:
Testing Procedures & Results

EVSE Characterization: Overview



EVSE Condition Categories		Condition Metric Requirement	Tolerance
Outside Ambient Temperature		23°C (Nominal)	± 2°C
		40°C (Hot)	± 2°C
		-7°C (Cold)	± 2°C
Smart Charge Management Scheduled	Request	FALSE (Nominal)	–
		TxProfile	–
	Duration	No Limit (Nominal)	–
		2 Minutes	–
	Scheduling	No Request (Nominal)	–
		2 (min) After Charge Session Start	± 1 (min)
	Value	No Limit (Nominal)	–
		65A (AC Input Current)	–
WPT Alignment	X-Direction	<5% coil length offset (Nominal)	± 2%
		10% coil length offset	± 2%
		25% coil length offset	± 2%
		40% coil length offset	± 2%
	Y-Direction	<5% coil length offset (Nominal)	± 2%
		10% coil length offset	± 2%
		25% coil length offset	± 2%
		40% coil length offset	± 2%
	Z-Direction	Unloaded (Nominal)	± 2%
Grid Condition	Voltage	480VAC (Nominal)	± 2%
		528VAC, 110% Nominal (Swelled)	± 2%
		432VAC, 90% Nominal (Sagged)	± 2%
	Harmonics	No Harmonics (Nominal)	± 2%
		5% Voltage Distortion	± 2%
	Frequency	60Hz (Nominal)	± 2%
		61.2Hz (Increased)	± 2%
		58.8Hz (Decreased)	± 2%

Initial Power Transfer	Requested Power Transfer				
	Discharge 100%	Discharge 50%	0kW	Charge 50%	Charge 100%
Discharge 100%					X
Discharge 50%				X	
0kW	X				X
Charge 50%		X			
Charge 100%	X				



- <u>EV Assets:</u> EV Emulator (50-1000VDC), rated for 350kW
- <u>EVSE Assets:</u> Production DCFCs (500A, 1000VDC), typically dual cabinet topology.
- <u>Nominal test conditions:</u>
  - Voltage: 300V, 400V, 650V, 750V, 850V
  - Current: 50 to 500A, 10A increments
  - Nominal (23°C/75°F) ambient temperature
  - Grid supply: 480VAC, 60Hz, no harmonics
- <u>Off-Nominal test conditions:</u>
  - Hot (40°C/100°F), Cold (-7°C/20°F) ambient temperature
  - Grid supply: [538, 432]VAC, [58.8, 61.2]Hz, 5% harmonic distortion
  - SCM: 65A, 2min duration, *TxProfile, 2m*in into charge
- <u>Wireless Power Transfer:</u>
  - X-direction, Y-direction, Z-direction offsets.
- <u>Vehicle-to-Grid (V2G):</u>
  - 2024: Low power, test full capability
  - 2025: High power, test full capability

EVSE Characterization: Nominal Conductive & Non-Conductive

Goal: Characterize EVSE conductive charging performance and operation across a wide range of voltage and current test conditions

Findings:

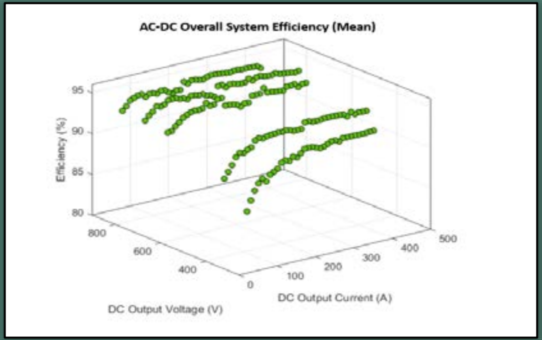
- 300V, 400V, 650V, 750V, 850V @ 10A increments [50, 500]A
- AC to DC Efficiency, Power Quality, Losses all have variation
- Losses due to cable, auxiliary loads, stand-by power

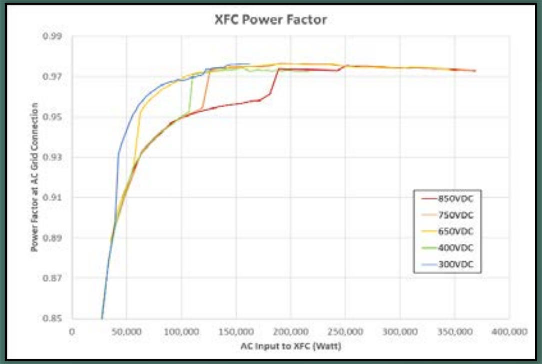
Goal: Characterize EVSE non-conductive performance and operation across a wide range of voltage and current test conditions

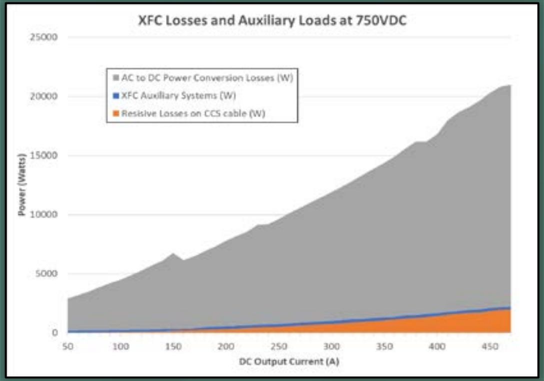
Findings:

- Resistive Loads: 93-94.1% efficiency, above 94% for 30-100kW
- Multiple voltage levels tested
- System Electric & Electromagnetic field emissions captured
- Further Non-Conductive Off-Nominal results in EVSE Characterization 2023 report

EVSE Nominal Conductive

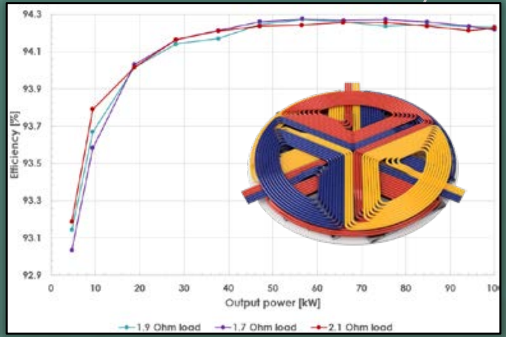




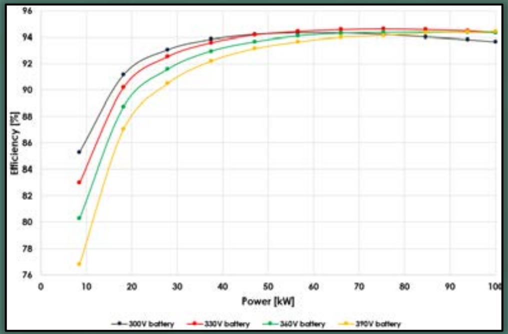


EVSE Nominal Non-Conductive

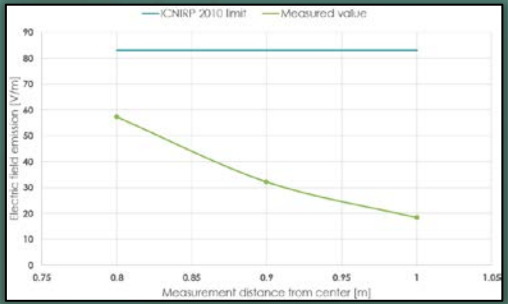
3 Resistive Loads: Efficiency



4 Battery Voltages: Efficiency



Electric Field Emission



EVSE Characterization: Conductive Off-Nominal & High Utilization

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EVSE Off-Nominal Testing

Voltage: [90%,110%] of nominal

Input AC Voltage Deviation Tests	Maximum DC Output Current	Minimum DC Output Current	Maximum DC output Current Ripple %
350 kW at 850 VDC	410.3 AMP	410.2 AMP	0.65%
150 AMP at 850 VDC	150.1 AMP	149.6 AMP	0.65%
500 AMP at 400 VDC	500.0 AMP	499.5 AMP	0.11%
150 AMP at 400 VDC	149.7 AMP	149.8 AMP	0.28%

Frequency: [58.8Hz, 62.1Hz]

Input AC Frequency Deviation Tests	Maximum DC Output Current	Minimum DC Output Current	Maximum DC output Current Ripple %
350 kW at 850 VDC	410.3 AMP	410.8 AMP	0.75%
150 AMP at 850 VDC	149.8 AMP	149.8 AMP	0.75%
500 AMP at 400 VDC	499.7 AMP	499.7 AMP	0.17%
150 AMP at 400 VDC	149.8 AMP	149.7 AMP	0.43%

Harmonics: 5% AC injection

Input AC Harmonics Injection Tests	Maximum DC Output Current	Minimum DC Output Current	Maximum DC Output Current Ripple %
350 kW at 850 VDC	405.3 AMP	409.7 AMP	14.2%
150 AMP at 850 VDC	149.8 AMP	149.8 AMP	4.32%
500 AMP at 400 VDC	500.0 AMP	499.9 AMP	0.48%
150 AMP at 400 VDC	149.8 AMP	149.7 AMP	0.49%

Goal: Characterize EVSE conductive charging performance during off-nominal conditions

Findings:

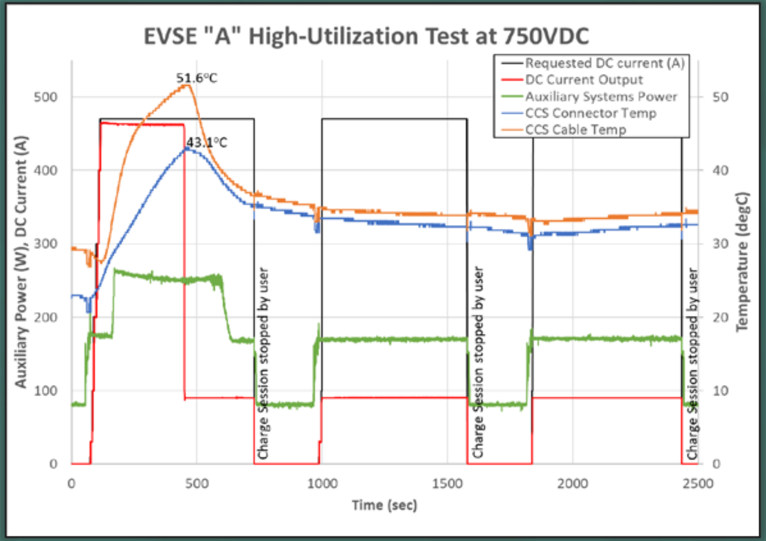
- DC Power transfer continues uninterrupted during all off-nominal, matching expected behavior
- Harmonics 850VDC saw higher variance than other cases

EVSE High Utilization Tests

Goal: Determine EVSE performance for consecutive 10min. full power charge sessions (i.e. Back-to-back)

Findings:

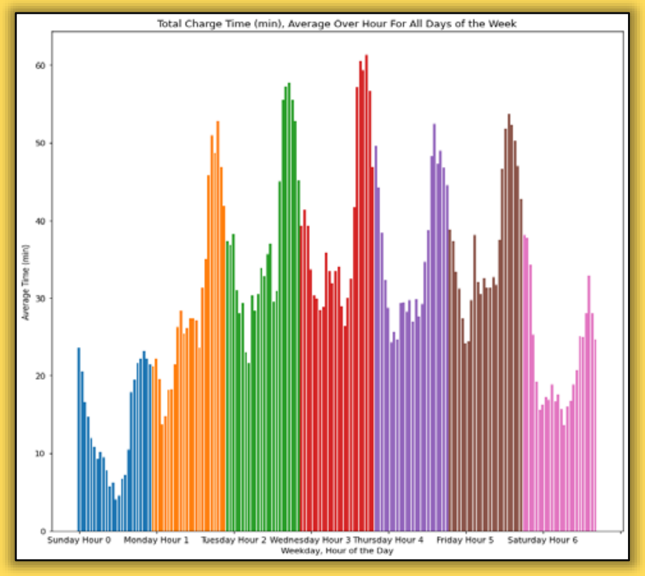
- Three 10-min charge sessions, 4-min rest between
- 500A requested, 465A delivered
- Cable thermal limit exceeded @ 6-min, limited current to 90A until reboot

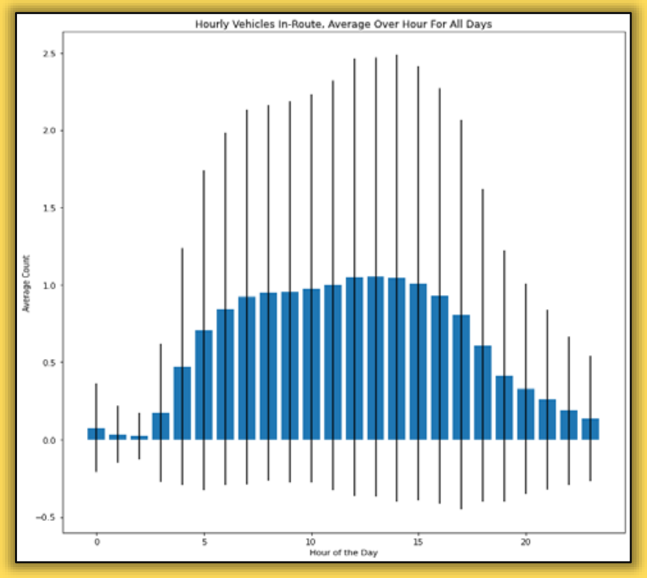


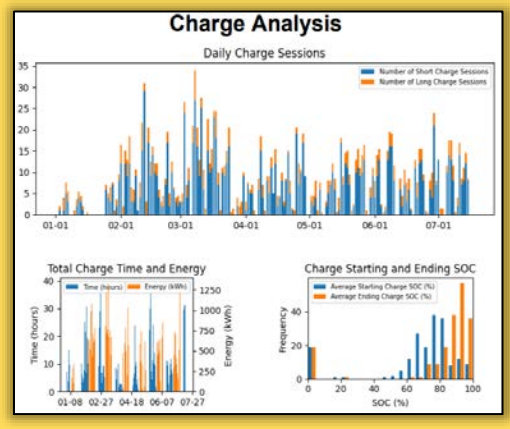
Fleet Utilization:
Testing Procedures & Results

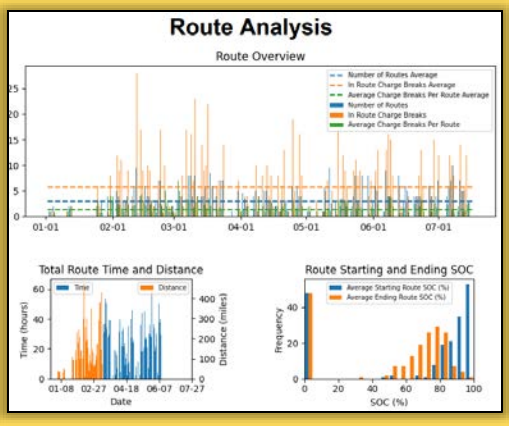
Overview: Fleet Utilization

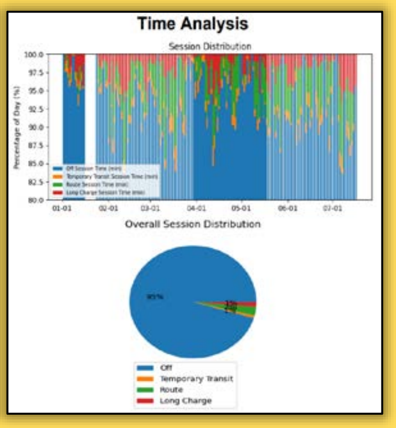
- <u>Assets:</u>
  - EV and/or EVSE Fleets
  - Conductive & Non-Conductive
  - Using data already collected from EV and/or EVSE
- <u>Types of Data:</u>
  - **Data Categories:** Charge, Route, Other
  - **Time-series data:** Hourly
  - **Graphical Data:**
    - Hourly, Daily, Weekly, Monthly, Annually.
    - Averages or totals
  - **Types of Analysis:**
    - Utilization Rates
    - Avg Start/End SOC
    - Average Power [kW]
    - Weekday usage rates [%], etc.
  - Reliant on OEM collaboration & access to data
  - Lab developed scripts are highly flexible, able to work with different formats & cadence
  - Gives insight on how EV profiles & EVSE characterization is applicable to a live case study











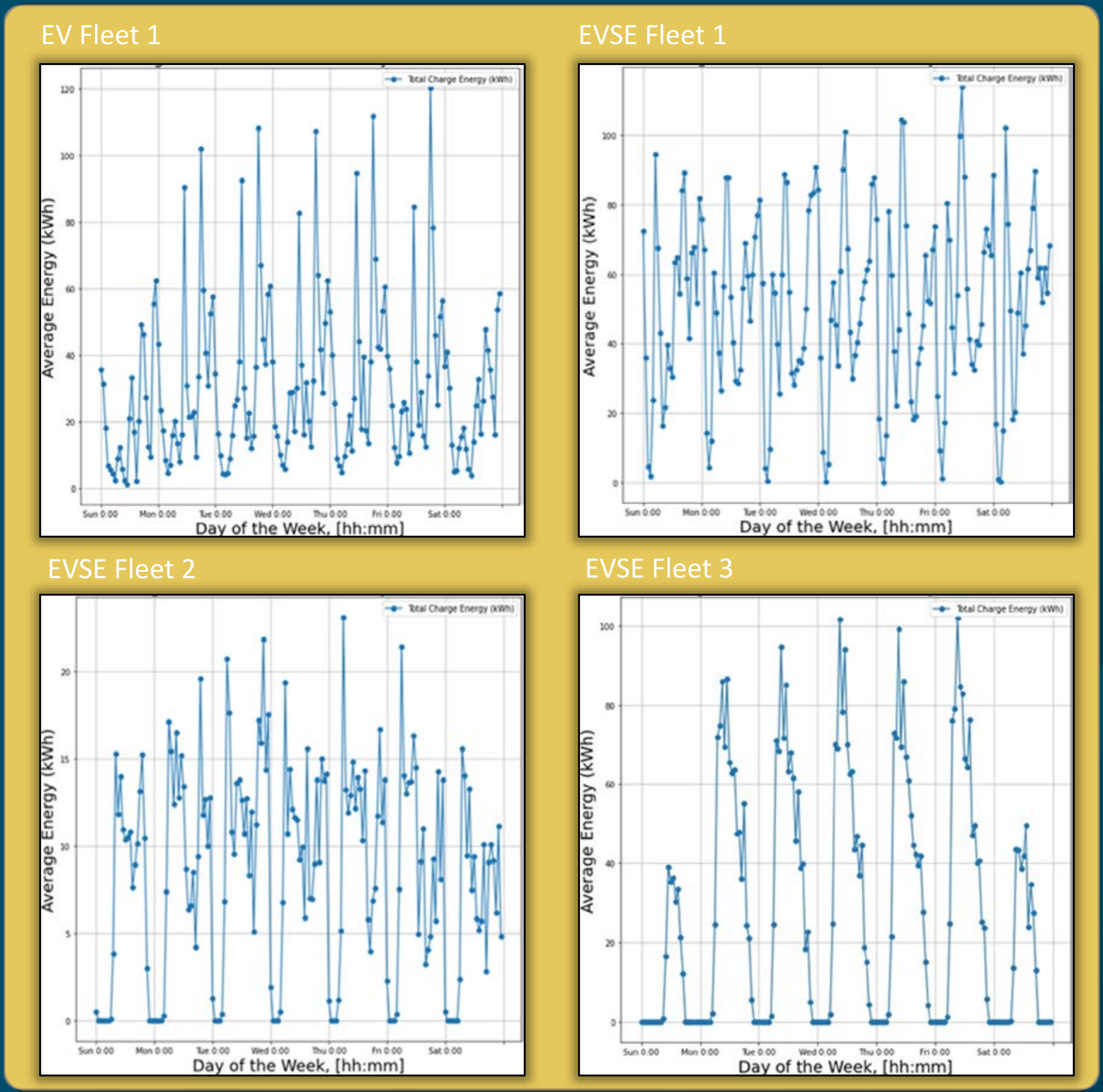
Fleet Utilization: Energy Usage Comparison

Goal: Average a year's worth of charging data to create a "typical week's usage" in terms of energy charged across all fleets

Findings:

- 1 EV fleet, 3 EVSE fleets
- Data gathered at 60 second cadence, rolled up to hourly for time-series data
- Hourly averages calculated for Sunday through Saturday
- Unique charging behaviors,
  - Low night-time charging utilization at night for EVSE Fleets 2 & 3
  - Higher utilization on weekdays than weekends
- Similar analysis performed for many other metrics
- Similar analysis performed for daily & yearly cadence

Averaged Total Energy Charged [kWh]



Conclusion

Final Touch Points

Thus far: Collected very insightful, thoroughly detailed data and analysis surrounding EV, EVSE, and Fleets

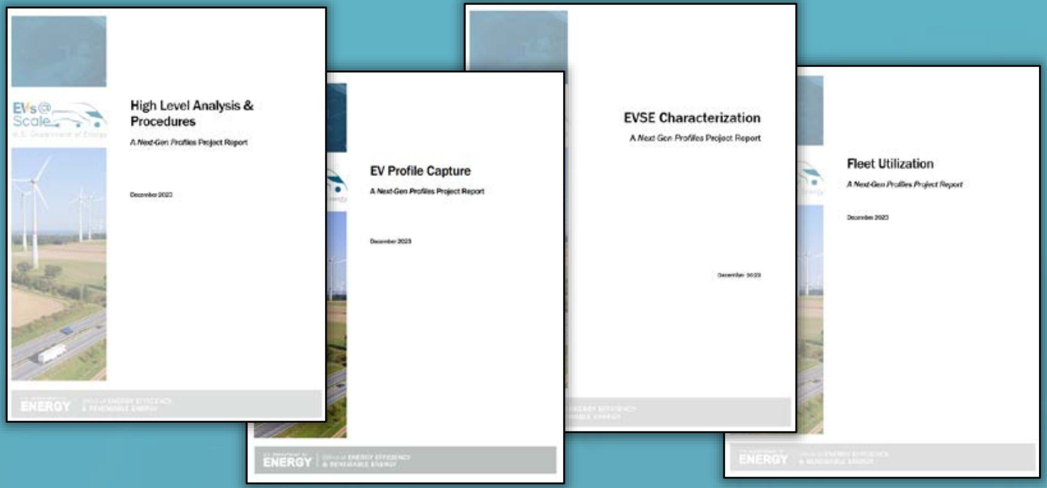
Moving forward: Looking to increase our scope, continue gathering data, receive feedback from industry on what is valuable to be gathered

- Performance, Exploring boundaries, Utilization rates

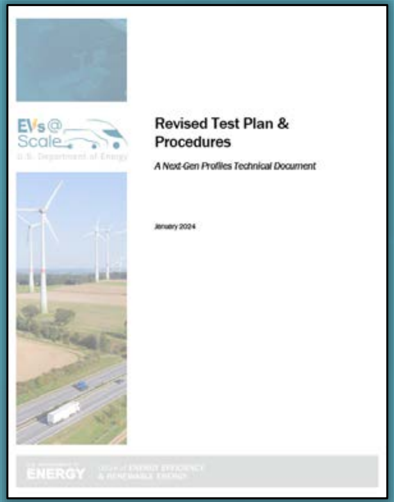
Right Now:

- Reports are EERE published, available on DOE OSTI
- Procedures Revision period open until 04/01/2024
- OEMs interested in participating in this study please reach out
  - Email: sthurston@anl.gov

EVs@Scale Next-Gen Profiles – Technical Reports 2023



Revised Procedures 2024



Thank You!

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Advanced Charging and Grid Interface Technologies Pillar

February Bi-Annual Meeting Stakeholders Meeting

Madhu Chinthavali

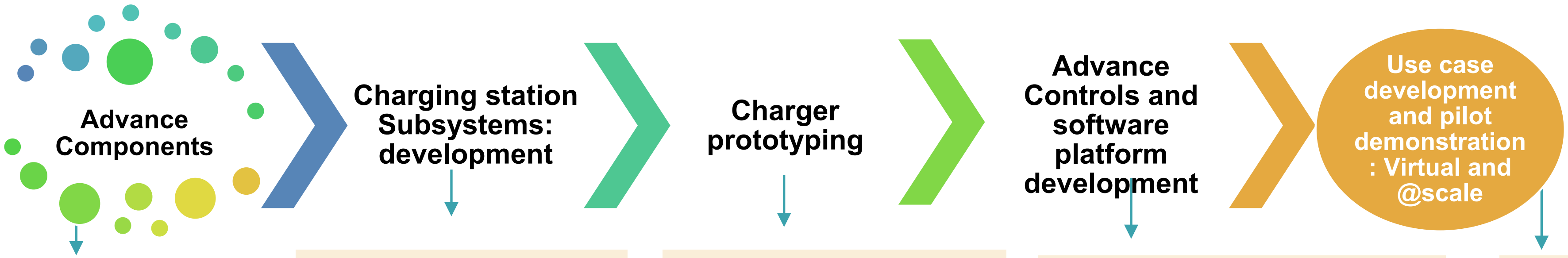
Prasad Kandula, Veda Galigekere, Michael Starke,Benny Varghese,Thomas Caroll
Don Stanton, Tim Pennington, Lori 'O' Neil

2/28/2024

Advanced Charging and Grid Interface Technologies Overview

Vision **:The Advanced Charging and Grid Integration Technologies (ACGIT) Pillar in an incubator of critical technologies with focus on basic R&D of high-risk, high-return technologies and systems to advance the resiliency of EV charging stations and equipment.**

Goal : The ACGIT Pillar centers on the proof-of-principle of advanced hardware components, subsystems, and systems, including scoping, benchmarking, and demonstration of advanced technology prototypes. Integrated virtual platforms and tools are utilized to evaluate prototypes with the technology readiness level (TRL) of selected technologies raised to 3-5.



- Identification of gaps in components : semiconductors, breakers, aux power systems
- Establish testing practices and protocols
- **Evaluating early-stage reliability of the subsystem components**
- Advanced magnetics with high insulation and low PD (partial discharge) while maintaining compact size/weight that will ensure reliable component life

- **Library of power stages:** Standardization techniques to achieve Plug-n-play
- **Communication and data interfaces for in-situ monitoring**
- **Diagnostics and Prognostics**

- **Novel topologies** that can achieve efficiency improvements, cost reduction or/and control simplifications
- Converter control architecture to handle multiple modules

- **Software architecture** and platforms for resource integration
- Real time management of resources beyond the chargers
- Multiple control schemes for multiple grid services for autonomous or coordinate secondary control

- **Use cases** for charging stations- large scale applications
- Real time, CHIL test beds for use case validation for future charging station architectures
- Evaluation of novel station architectures using @scale test beds

Synergistic cross cutting technology opportunities with other programs - OE,GMLC

ACGIT Outcomes : Charging Station Metrics

- **Resiliency for charging station is focused on customer (electric vehicle charging) outages (frequency and duration used in metric)**

- **Resilient mechanisms will simultaneously consider minimizing customer experience of outages or charging interruptions and maximizing customer service rates (charging experiences).**

Metric	Definition
Station Interruption frequency average	the average number of interruptions that a customer would experience versus a baseline
Station Interruption duration average	the average outage duration for each customer served versus a baseline
Station Interruption service recovery	the difference of energy delivered versus baseline

Advanced Charging and Grid Interface Technologies: Thrust Areas

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Address System Integration Challenges and Resiliency of EV ECOSYSTEM

Vehicle, Charger and Grid Interface Technologies

- ***Topologies : Advance component technologies*** *and controls for novel charging functionality*
- *High power* ***equipment prototyping*** *for heavy-duty vehicle and similar applications such as aircraft*
- *Flexible, modular, multiport Interface configurations for LD, MD, HD, off-road, and e-VTOL applications*

Resilient Charging and Resource Integration Platforms

- Autonomous controls for charger, Power quality issues
- *Energy storage, photovoltaic, and other technology integration solutions for* Application of V2X
- *Novel controls station level strategies.*
- ***Data Privacy and Ownership and DATA strategy***

Prognostics and Diagnostics and Advanced Algorithms

- AI/ML techniques for anomaly detection
- Subsystems and power stages diagnostics
- Subsystems and equipment prognostics
- Optimization for of operation-based controls for station

Networked Charging Station Architectures Infrastructure

- Novel energy infrastructure architectures
- *EV substation design and development for future large scale muti-vehicle stations*
- *Interface protection, safety and interoperability*
- Networked/coordinated station segments

Unique Capabilities Generated by Labs to Support

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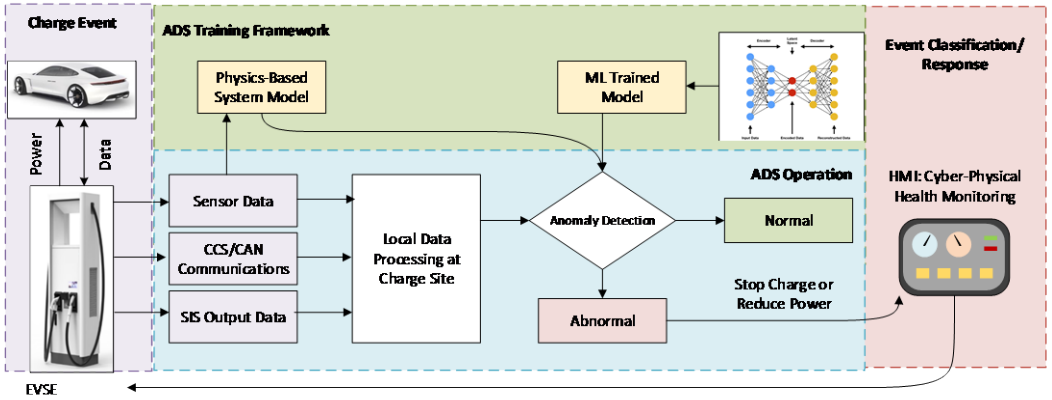
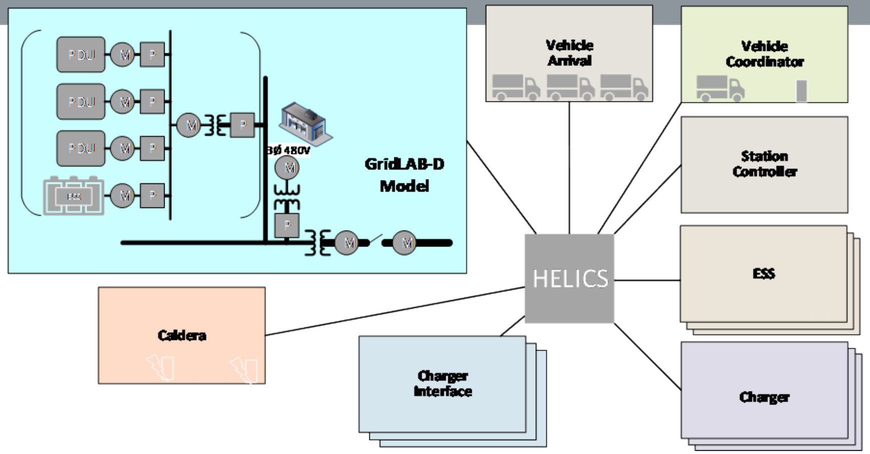
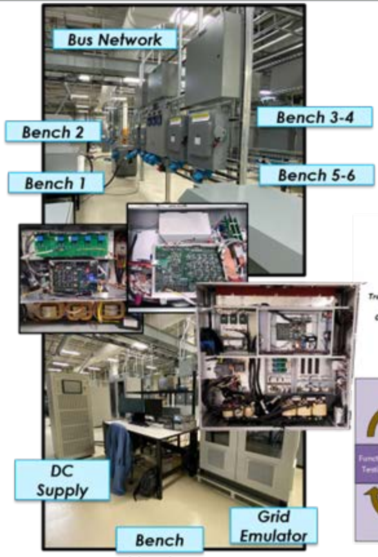




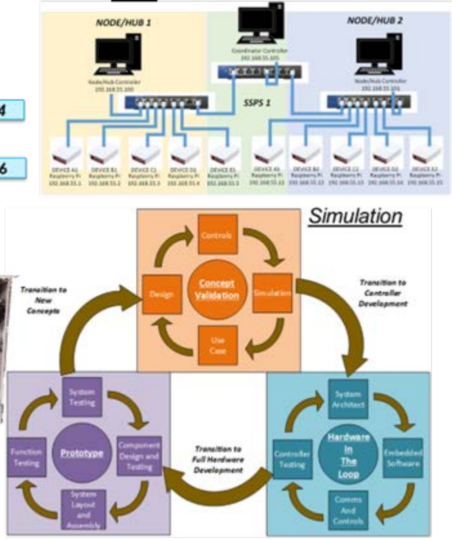
INL hardware and learning system for detection.

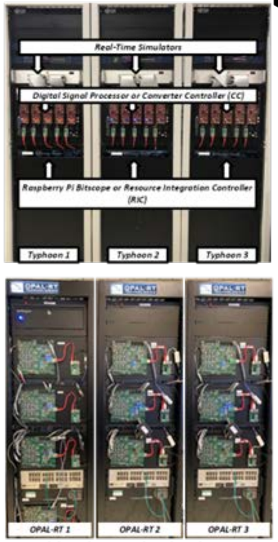
PNNL simulation system large scale modeling

Detect — *Analyze* — *Control* — *Restore*

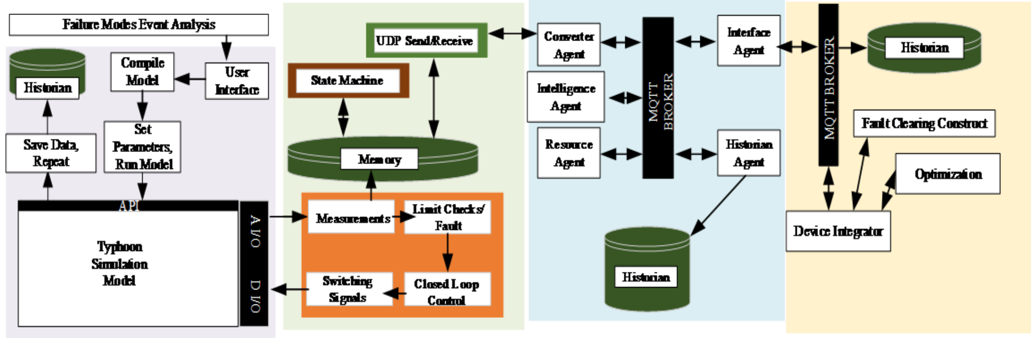


Hardware





Hardware in the loop



ORNL RT-simulation system for RT evaluation of control solutions and advanced technology prototypes

ACGIT Pillar Portfolio- FY24- 5 Projects – 3 Labs

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Vehicle, Charger and Grid Interface Technologies

- 1. Advanced Charging and grid interface(Grid Forming Charger): Demonstrate integrated charger (Grid to vehicle) with Advance Grid Controls - **ORNL - Prasad Kandula**
- 2. Optimized Flexible Multi-port Vehicle and Grid Interface Architecture- DC/HFAC/DC Universal EV Charger: -**Veda Galigekere- ORNL**

Resilient Charging Platforms

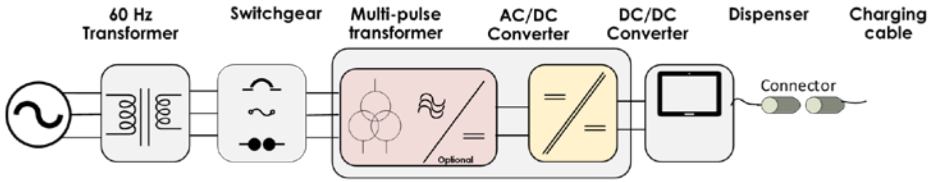
Prognostics and Diagnostics and Advanced Algorithms

Networked Charging Station Architectures

- 3. MCS Resiliency : Develop Real-time Simulation models and controls and demonstrate the MCS Resiliency Use Cases in real-time environment- **ORNL – Michael Starke**
- 4. MCS charger anomaly detection methods : **Benny Varghese: INL**
- 5. Charging station controls for MCS architectures : **Thomas Carroll– PNNL**

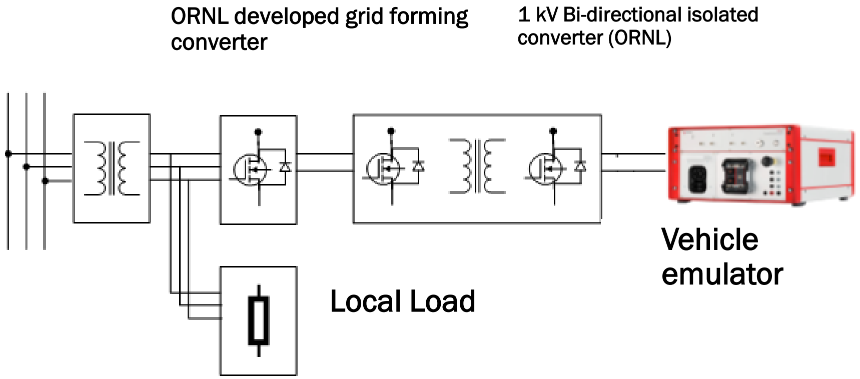
Project 1: Grid Forming Charger: Prasad Kandula

- **Objective:** is to develop a fully integrated charger/storage system with the grid interface converter enabling advanced functions such as operating as an islanded system, responding to grid transients
- **Gaps:** Fully integrated charger capable of providing grid support functions (respond to frequency variations etc) and ability to operate under islanded/grid connected modes.
- **Main challenges:**
  - Grid interface converter providing advanced functionality while considering DC side dynamics, transient free synchronization/islanding, supply for local unbalanced loads.
  - Coordination of multiple DC/DC converters and co-ordination of multiple grid forming converters to ensure oscillation free operation.
- **Projected Outcomes:** Use charging systems to improve Grid or local system resiliency



Vendor	Voltage class	Bi-directionality	HF Isolation	Power rating Block/full unit	Efficiency	Power density	Thermal Management
A	500 V DC	Claim- Not implemented	Yes	125/375 kW DC-DC 70 kW AC-DC			liquid
B	950 V DC	None	Yes	60/360 kW DC-DC	98% (AC-DC) 98.5 % (DC-DC)	92”x24”x40” (AC-DC) 79”x 22.5”x15.5” (DC-DC)	Air Cooled
C	920 V DC	None	No	175 kW/350 kW	94% (Grid - Car)	46”x 30”x 30”	Air Cooled
D	920 V DC	None	Yes	100 kW/1 MW	94% (Grid - Car)		Air cooled

Phase 1: Demonstrate complete integrated charger (Grid to vehicle) with Advance Grid Controls : Grid Forming Charger



Project 2. HF AC and DC Link Based Charger Architecture : Veda Galigekere

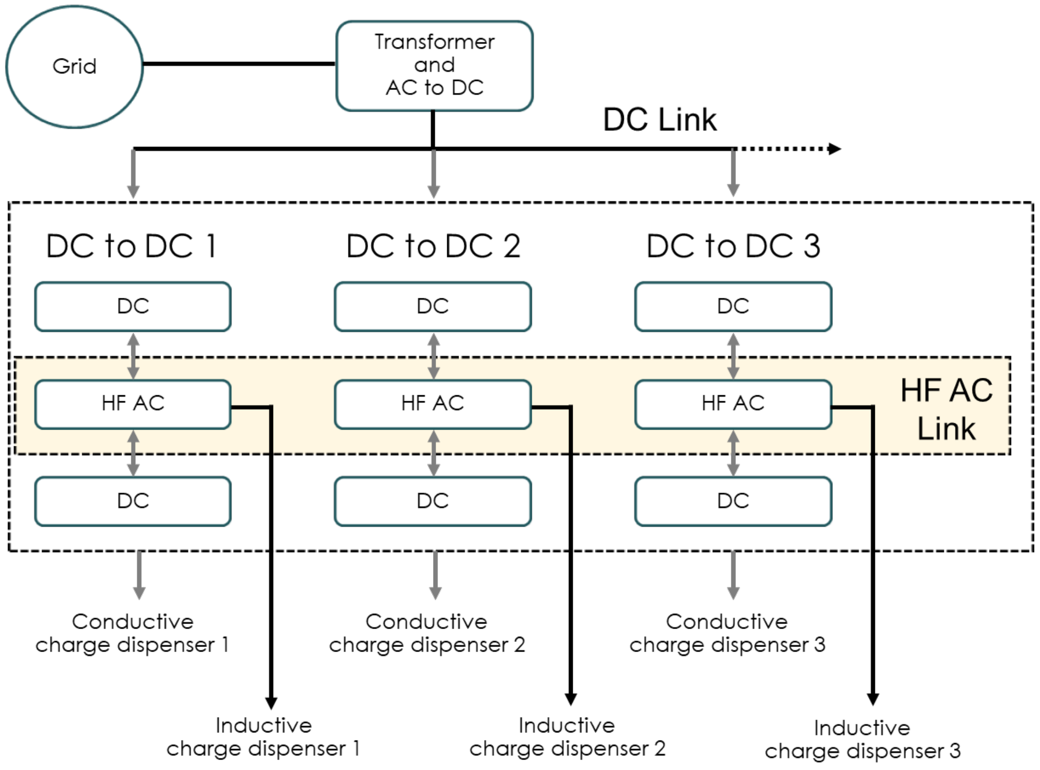
Objective: To develop and validate a universal power electronics architecture with high-frequency AC link to enable interoperability and increased utilization of grid and vehicle interface technology with optimized footprint and cost

Gaps:

- **Interoperable:** can supply high power conductive or inductive charge dispensers
- **Increased utilization:** increase utilization of charger and throughput of vehicles served
- **Flexible**: can modulate voltage and power at individual charge dispensers
- **Compact:** optimally shared PE architecture with HF AC link
- **Reliability**: increased reliability with modular restructuring of architecture

Outcomes: Modular, Scalable, and Interoperable

- Power can be tapped at DC and HF AC points
- Suitable for conductive and inductive charge dispensers
- Increased utilization, interoperability, and flexibility



HF AC Link Based EV Charging Architecture:100 kW interoperable HF DC/AC/DC EV charging system

Project 3: Megawatt Scale Charging Resiliency
Michael Starke

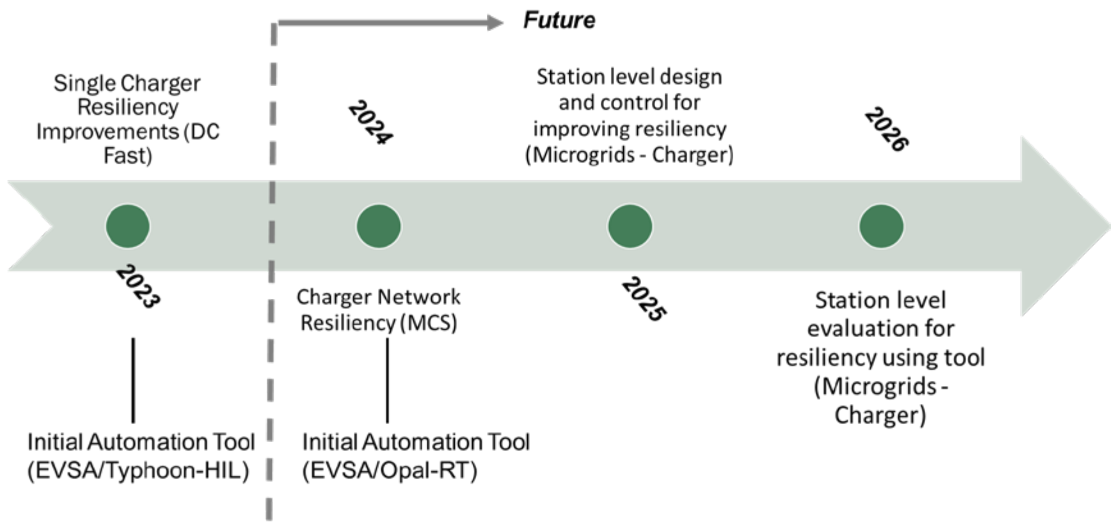
Objective: Develop resiliency improving approaches for heavy duty (HD) class EV charging systems.

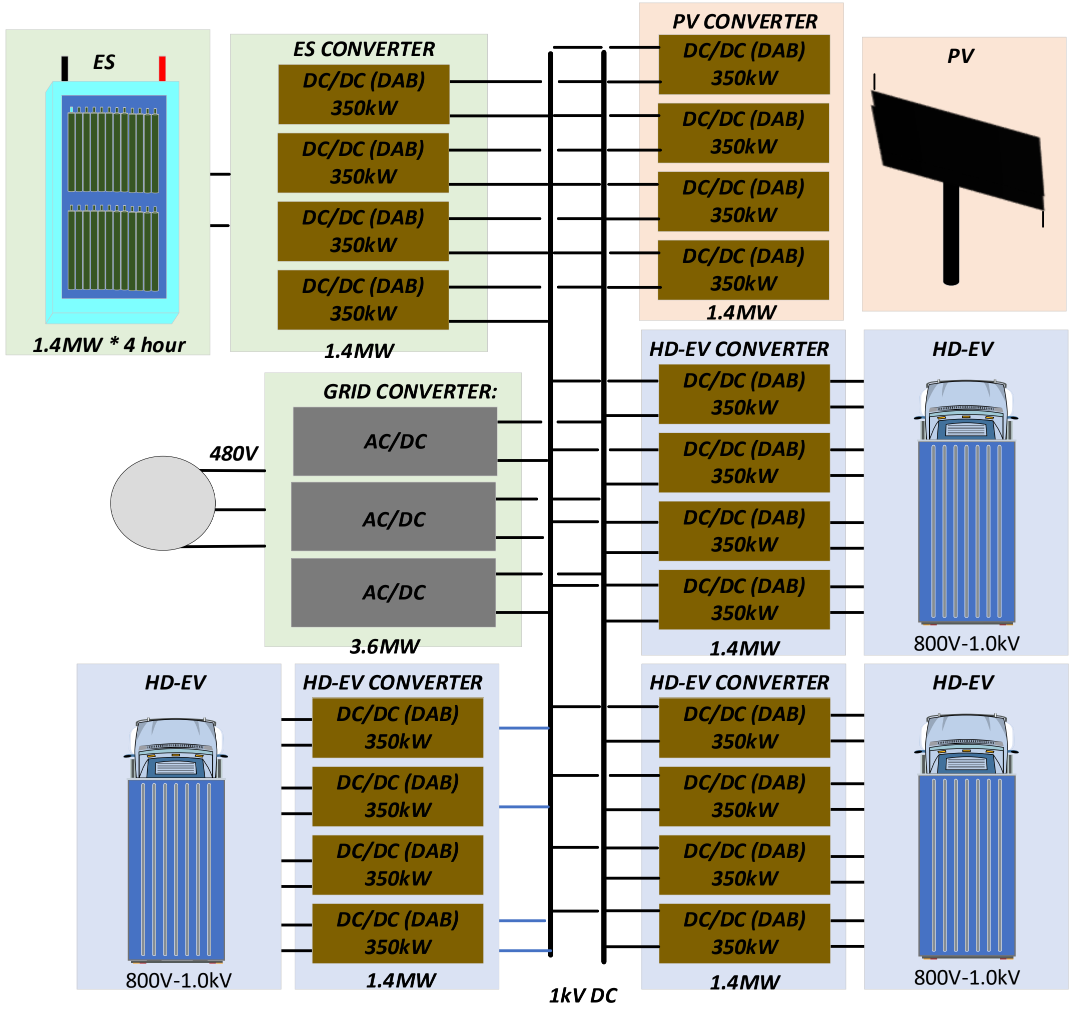
Gaps: Resiliency methods and evaluation tools for supporting MCS architectures

Challenges:

- MCS architectures and topologies are in still in development with resiliency often not considered.
- Many different resiliency improving options to consider.
- Modeling should be able to adopt new architectures and topologies quickly and evaluate them with real-time solutions efficiently.

Outcomes: Resiliency improving techniques developed and proven in real-time simulation environment

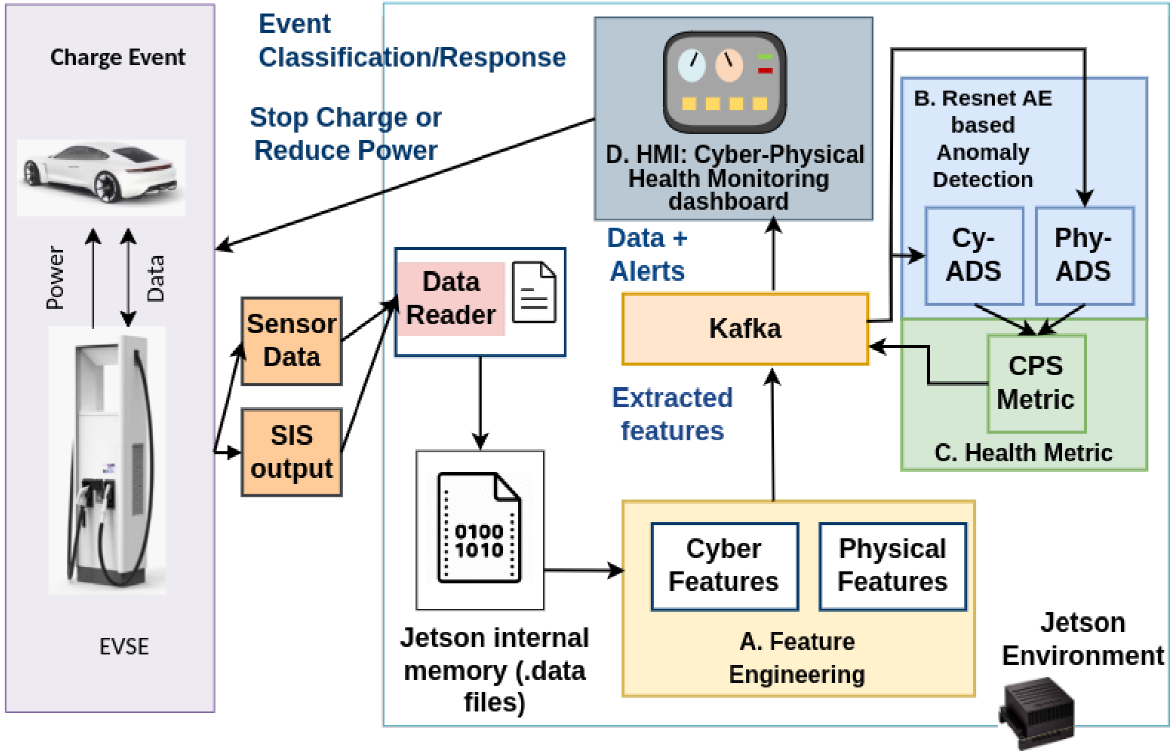




Proposed HD-EV MC System

Project 4 : MCS charger anomaly detection methods and framework
Benny Varghese: INL

- **Objective:** To improve resilience of EV charging infrastructure with a focus on Megawatt Charging Systems (MCS), leveraging prior work on DC fast charging (DCFC) and extreme fast charging (XFC) technologies.
- **Industry gaps:** Lack of MCS charging infrastructure deployment or hardware test-bed environment
- **Main challenge:** Identifying additional challenges MCS introduces to charging and energy infrastructure resilience
- **Projected outcomes:** Understanding the MCS specific resilience requirements and developing detection methods to identify anomalous behavior in advance



Previous Outcomes (E-VISION)

- Anomaly detection system frameworks explored to detect cyber and/or physical anomalies in EVSEs and EV charging stations based on the following data streams:
  - Physical sensor measurement data from the EVSE – voltage, current, temperature etc.
  - Input CAN communication to the EVSEs
  - OCPP communication between CSO and EVSEs
- Includes physics based and machine learning models for anomaly detection
- Tested and implemented a Safety Instrumented System (SIS) to respond to anomalous situations during an EV charging event
- SIS further developed into Cerberus (patent pending)

Project 5: Charging station controls for MCS architectures
Thomas Carroll

- **Objective:** Identify and evaluate architectures, controls, and strategies for resilient and secure MCS depots

- **Gaps:**
  - Lack of research pertaining to grid compatibility and resiliency for MCS depots;
  - Little on the development and effectiveness of control measures and response strategies

- **Approach: Using simulation to:**
  - Characterize and prioritize adverse grid impacts
  - Study architectures and controls to address adverse grid impacts and operations concerns

- **Outcomes:**
  - Improved understanding of adverse grid impacts
  - Resilient MCS depots that operate under varied grid conditions

Thank You

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Codes and Standards Support

Theodore Bohn
Argonne National Laboratory

February 28th, 2024

Outline

- Initiative Overview
- Codes and standards activity priorities enabling EVs at Scale
- ‘Divide and Conquer’ approach by lab teams to cover multiple standards areas
- Standards areas covered by each participating laboratory
- Focus areas and progress in standards development in FY2024
- Summary of FY24 deliverables/milestones
- Conclusion and Next Steps

Codes and Standards Support Initiative Overview

Objective: Codes & standards support priorities focus on development of the most critical standards for EVs at Scale, i.e., high power DC charging, storage (microgrid, DERMS) integrated with DC charging, vehicle-grid integration, high power scalable/interoperable wireless charging, vehicle-oriented system standards and energy services to support transparent optimized costs/delivery.

Outcomes:

- Complete drafts of SAE J3400 NACS, J3271 Megawatt Charging System (MCS), AIR7357 TIRs
- Develop and demonstrate a reference implementation of J3271 MCS EVCC/SECC controller
- Develop phase two of Open API Energy Services Interface (ESI) implementation
- Complete a study w/summary reports in support of identified high importance standards
- Active participation in SDO standards meetings/committees to close gaps in EVs@S standards

Argonne National Laboratory
- Theodore Bohn
- Mike Duoba
- Keith Hardy
- Jason Harper
- Dan Dobrzynski

Idaho National Laboratory
- Richard Carlson
- Anudeep Medam
- Tim Pennington
- Benny Vargheese

NREL National Renewable Energy Laboratory
- Yashodhan Agalgaonkar
- Jesse Bennett
- John Kisacikoglu
- Jonathan Martin
- Andrew Meintz
- Vivek Singh
- Isaac Tolbert
- Ed Watt

Oak Ridge National Laboratory
- Veda Galigekere
- Omer Onar

Pacific Northwest National Laboratory
- Brian Dindlebeck
- Lori O'Neil
- Richard Pratt

Codes and Standards Activity Priorities Enabling EVs at Scale

Constant Evolution: The group of lab team members focus is on stds **most** relevant to EVs at Scale

Priority Areas: *(it is now year ~2.5 of 5 year EVs@Scale)*

- EVs at Scale standards support focus is mostly on scaling charging capabilities. I.e. how to serve more vehicles in more locations without exceeding resource limits, for a spectrum of vehicle sizes/classes (from light to medium to heavy duty; commercial and passenger cars)
  Charging rates from 30A to 3000A for conductive/wireless methods, AC or DC, µgrid, etc

- Electric power delivery oriented standards areas; V2G, local DER, integrated storage, system controls including the Energy Services Interface method of bi-directional information exchange leading to contract based optimization of resources, DC as a Service, communication protocols

- Vehicle Oriented **System Standards** (including non-road, electric aircraft) that include on-vehicle systems (power take-off, refrigeration units, battery management, battery safety, etc.),

- High Power Scalable/Interoperable Wireless Charging (SAE, J2954-1/2/3) (up to 1MW)

‘Divide and Conquer’ Diverse Coverage of Standards by Lab Teams

5 Lab Teams in FY2024 Covering ‘Top 10’ Standards Areas:

National Lab participants each proposed support/development within the ‘top ten’ areas for EVs@S

General Standards task areas (shorthand summary)

- **NREL** focus on MCS coupler testing, system architectures/impacts study, J3400, P2030.13
- **ORNL** focused on wireless (WPT) topics for standards; new topics in FY25
- **INL** on WPT, P2030.13 (grid side of charging)
- **PNNL** on heavy vehicle charging stds, P2030.13
- **ANL** on ‘umbrella’ (chair of multiple stds groups) coverage of ongoing W&M stds, ANSI meter stds, IEEE P2030 series (.5, .11, .13, etc), NACS, MCS ‘everything’, emphasis on communication and reliability, (summary chart of active EV charging/safety standards; testing/data in support of standards)

Snapshot of Standards Engagement/Progress in 2024; Next steps

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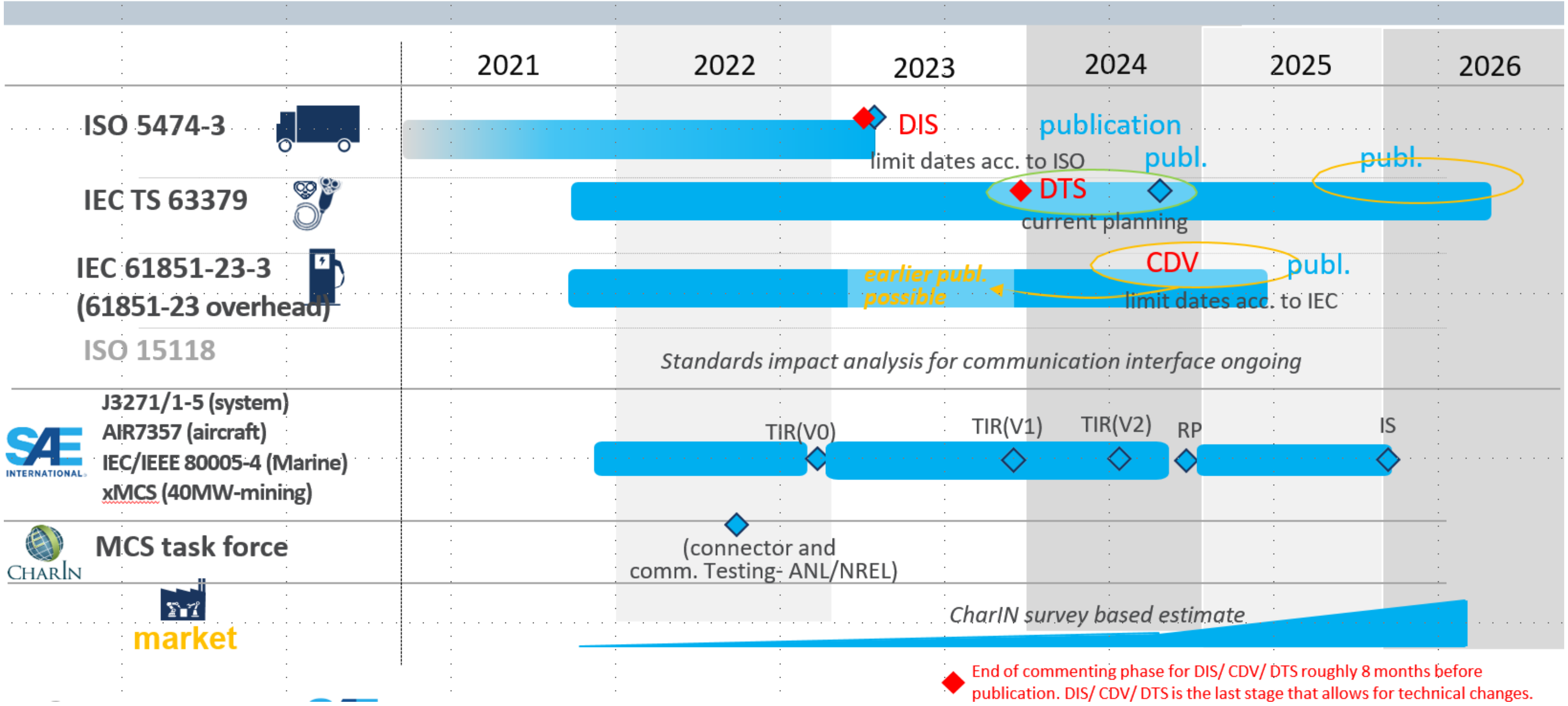
Status excerpts on active standards committees support by topic 4E resources, via labs/contractors

- **EVSP EV Standards Roadmap;** Year of effort/work groups, published June 2023; FY24 quarterly update maintenance
- **IEEE P2030.13 DCaaS Functional Specification for charging system feed;** published/for sale; version 2 proposed
- **SAE J3400 NACS;** Committee launched August 2023, pubished Dec 2023, RP version published in June 2024?
  J3400/1 CCS-NACS Adapter safety; Launched Dec 2023, TIR Expected June 2024; discussing testing procedures
- **MW Level stds (J3271, AIR7357, IEC80005-4, xMCS/mining);** J3271 TIR-v1 released, xMCS(40MW) weekly meetings
- **Energy Services Exchange (ESX) implementation;** based on P2030.13, Phase 2 under way (OpenADR3.0), website up
- **Weights and Measures;** Meter drift study, GUI for off-the-shelf HB44 test tool; HB105 transfer standard guide
- **'Other' SAE/IEEE standards on interoperability, reliability, safety, recycling, etc:** moving forward/expanding scope
- **Mike Duoba EV Variability study/project(s)** expanded study is planned {SAE J1634, J1711, J2908, etc}
- **Wireless Power Stds**; J2954/1 light duty published; J2954/2 Heavy Duty TIR released, J2954/3 dynamic charging

Harmonization of High Power Charging SDO Committees/Standards

Working together as a global team: National Lab participants in these and other standards areas need to have consensus between overlapping standards. There is not one 'global' Standards Defining Organization' so all the SDOs have to harmonize standards as a foundation for global interop.



SAE J3400…Everything, Everywhere, all the time; J3400/1 Adapter Safety

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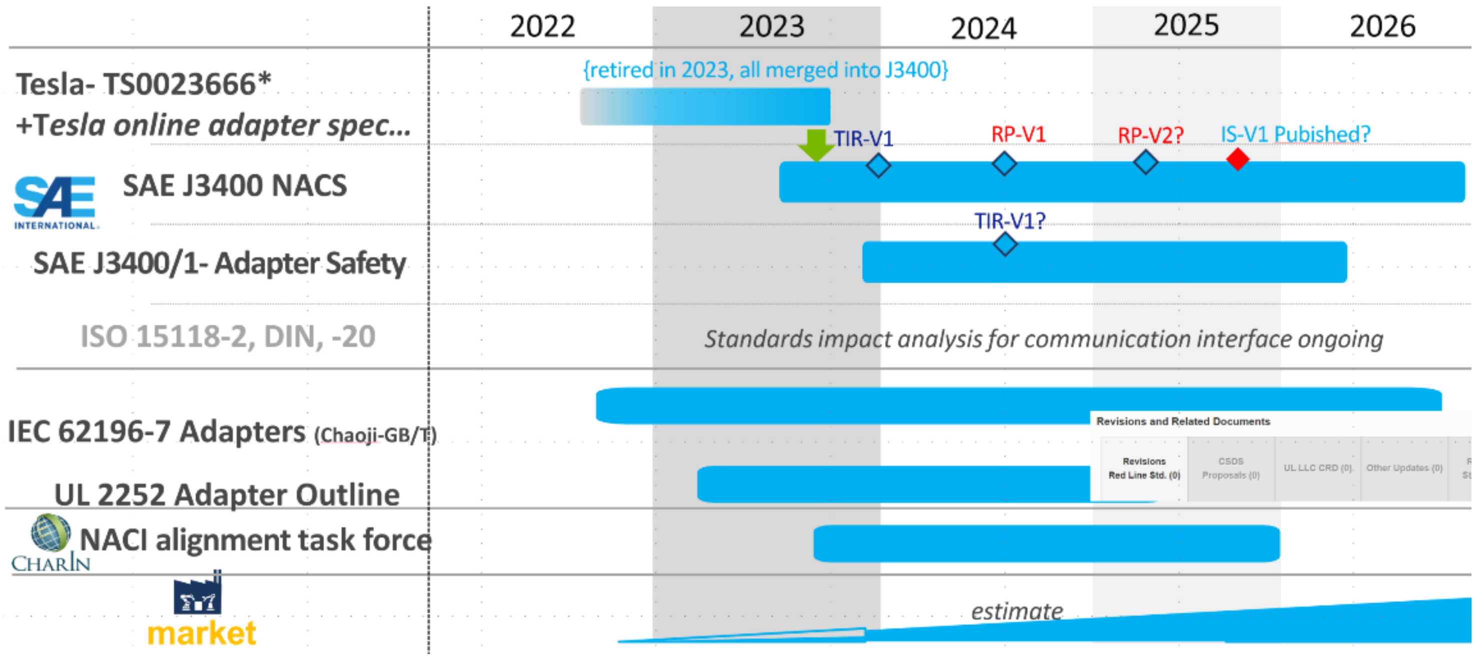
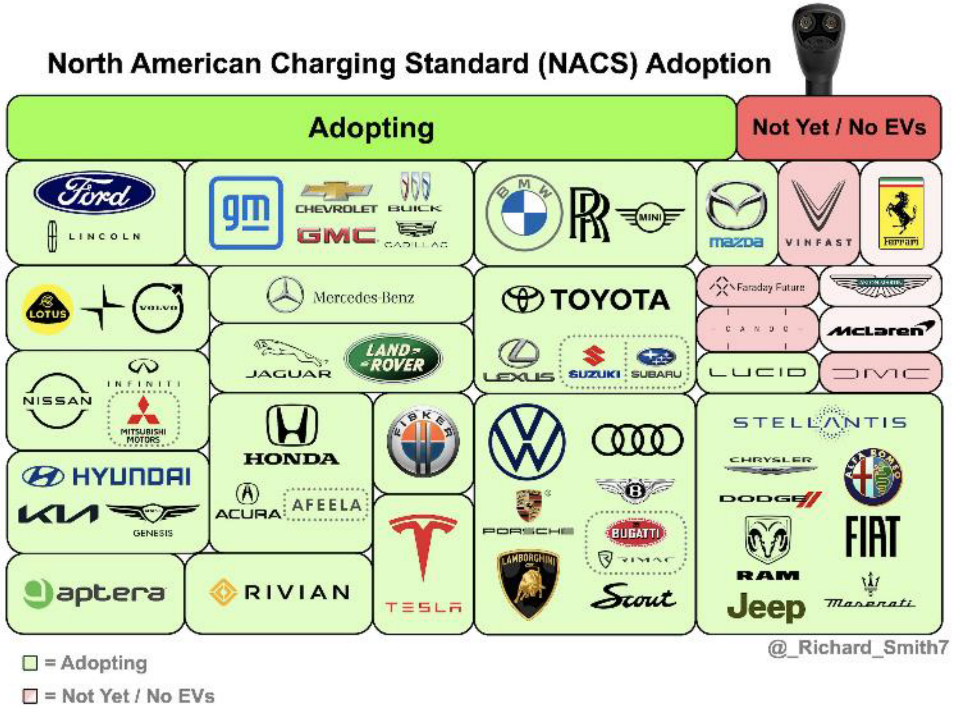
(1 minute Summary):

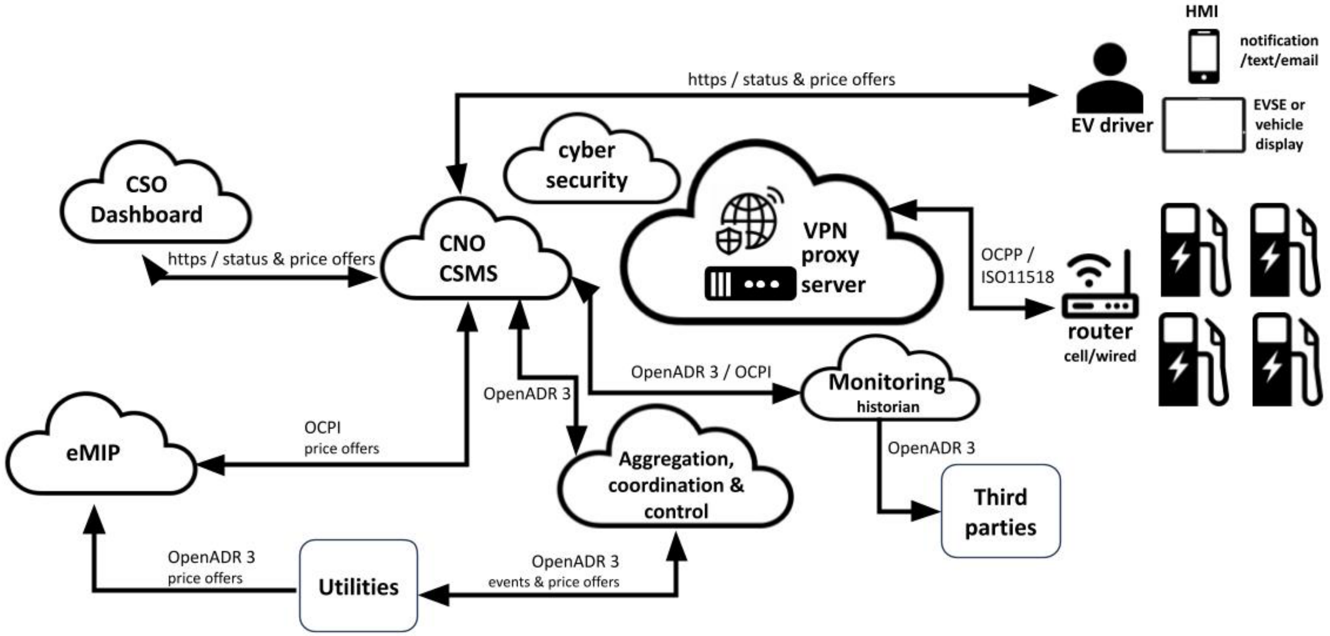
- J3400 NACS Launched June 2023, TIR published December 2023; goal is RP published June 2024
- J3400/1 Adapter Safety launched December 2023; bi-weekly meetings; harmonized w/UL2252
- ANL paper on J3400 published at WCX (April 2024); EV Adoption tracker list 78 entities; 28 OEMs
  NREL FMEA/adapter testing inside ChargeX Task group 2



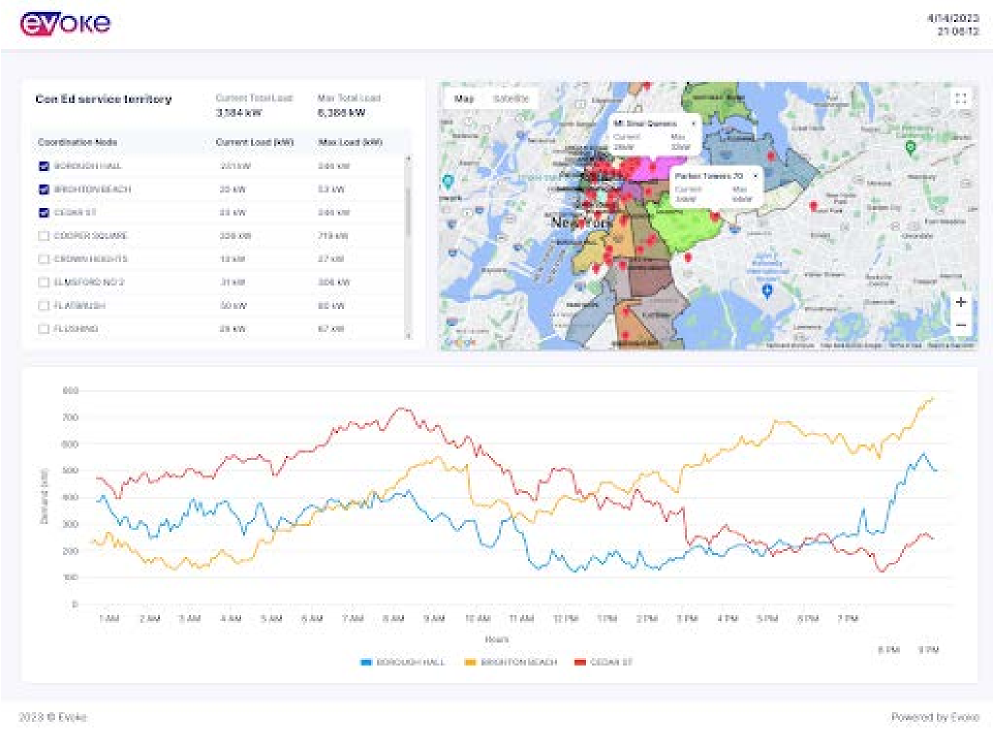


EVoke-ANL Energy Services Exchange Project Phase 2, Website Launched

- ESX Recent Progress
  - Easy to remember website has been launched; https://esx.energy/ Features and demonstraction description; 'Join Us' tab
  - Phase 2 of the project moving along; implementing features (VTN, public API, OpenADR3.0,..) described at last EVs@S meeting
  - Key ESX features include: Real-Time Management; Standardized Information; Integration and Coordination



ESX Architecture



Demonstration at Scale: New York City

SAE Light Duty Vehicle Performance and Economy Measure (LDVPEM) Committee

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SAE INTERNATIONAL

- **Membership of 111 participants**
- **Chassis dynamometer-based efficiency test documents**
  - J2263 and J2264 coastdown/road load
  - J1711 HEV/PHEV and J1634 BEV test procedure
  - (no j-doc number yet) Environmental Testing for On-Road Vehicle Which Use Automation Systems task force
- **Other Testing Documents**
  - Battery SOC and SOH
  - Drive Quality (drive metrics during dyno test)
  - Some road testing (acceleration, on-road fuel economy, etc)

Current Focus:
SAE J1634 – Latest revision April 2021

SAE INTERNATIONAL

SURFACE VEHICLE RECOMMENDED PRACTICE	J1634™	APR2021
	Issued 1993-05 Revised 2021-04 Superseding J1634 JUL2017	
(R) Battery Electric Vehicle Energy Consumption and Range Test Procedure		

RATIONALE

Battery electric vehicle (BEV) technology has continued to progress since SAE J1634 was revised to include the multi-cycle test (MCT). BEV driving ranges and capabilities continue to increase along with the addition of many new BEV models in the marketplace, further taxing lab testing.

In order to reduce lab test burden, a short multi-cycle test (SMCT) is introduced to allow longer range BEVs to perform a fixed distance test in approximately 50% of the dynamometer time of an MCT test, while achieving comparable range and energy consumption results. This method utilizes an off-board discharge process to determine remaining energy in the battery pack.

A short multi-cycle test plus steady state (SMCT+) is also introduced to provide driver flexibility for longer range BEVs to perform testing for range, energy consumption, and five-cycle test data simultaneously without the need for additional off-board discharge equipment.

Single-cycle test (SCT), MCT, SMCT, SMCT+, and BEV five-cycle testing (Appendix B) have also been amended to allow thermal conditioning prior to driving, a desired customer feature in today's BEV marketplace to improve vehicle range.

FOREWORD

Historically, the determination of range and energy consumption for battery electric vehicles (BEV) has relied on the SCT methodology. The SCT requires that a vehicle be repeatedly driven over the same speed versus time profile (i.e., drive cycle) until the vehicle's battery energy is completely exhausted. The long and indeterminate nature of the SCT places significant logistical strains on test facilities, a situation that will worsen as battery technology advancements enable even greater range capability. It is also possible that additional test cycles—beyond the currently required UDDS ("city") and HFEDS ("highway") cycles—will be necessary in order to better characterize the effects of temperature and accessory loads on range performance, making the SCT paradigm even less practical. For these reasons, a multi-cycle test (MCT) procedure was been developed.

Investigating Variances of J1634 Procedures

- Testing cycles at different:
  - **SOC states**
  - Thermal states
- → **Mostly similar results**

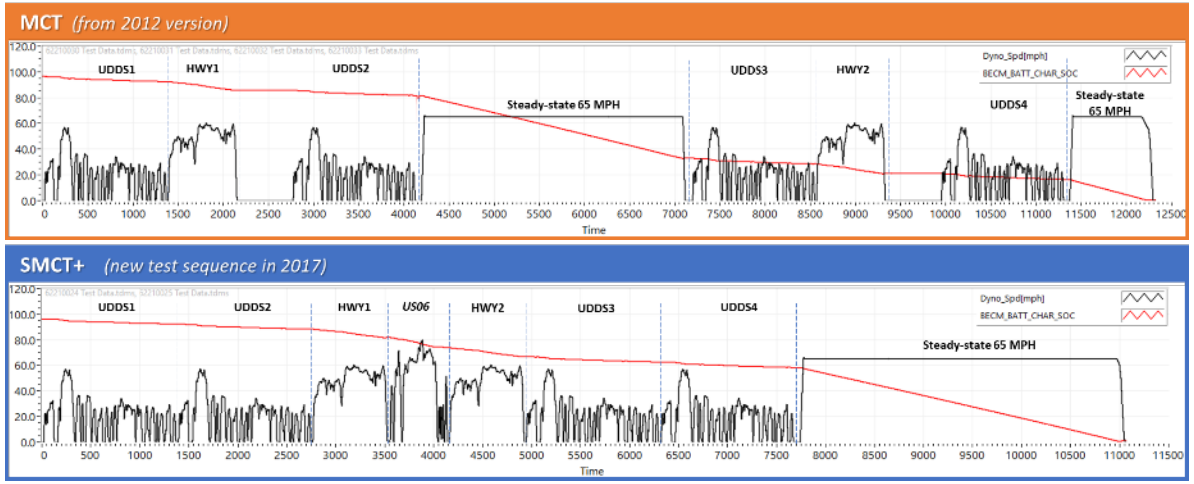
Reoccurring Differences:

A: Cycles at lower SOC, increased efficiency

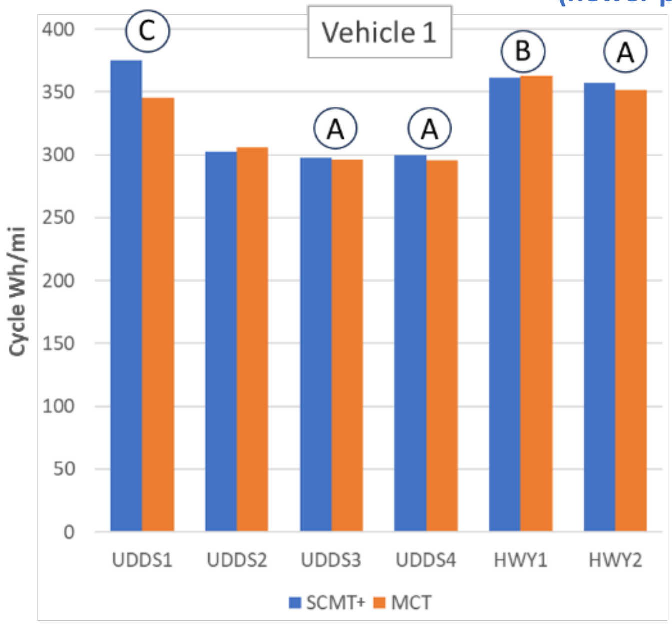
B: 1st HWY in SMCT slightly better because higher warmup state

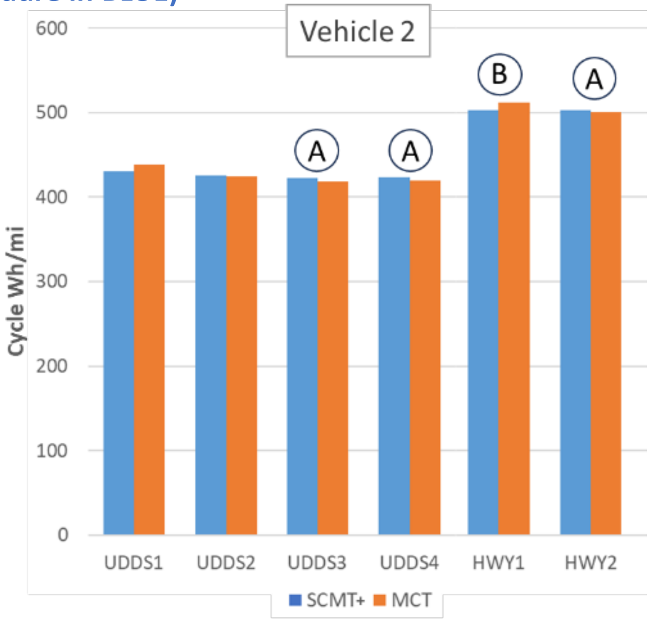
New Issue:

C: Why such a large discrepancy in first cycle (MCT and SMCT should be same here)



(newer procedure in BLUE)





Support of NIST HB44-3.40/Weights & Measures Activities

- **Inter-Lab-Comparison (ILC) program:** Collaborating with NMI/EU Colleagues on round-robin testing of a 30kW DC EVSE; compare dispensed energy test results between ISO17025 traceable labs (Type 2, 400vac/50Hz EVSE obstacles; requires use of AC grid emulator; type 2 fixture) ANL is the only (known) US participant.

- **NIST SP2022-4 Document:** Development of HB105 traceability requirements for a transfer standard (reference fixture). Goal is a validated 100ppm accuracy 'system' based on off-the-shelf (non-proprietary) components with ISO17025 traceability. (ANL is supporting NIST research staff by collaborating on past testing experience

- **AC-DC Meter Drift Study:** In Support of NIST HB44-3.40 Reinspection Period 25 total test articles(7+9+9); two tests on each per month 600 tests over 12 months
- Report released at 6 month and 12 month test results; extended past 12 months?
- Monthly AC EVSE and bench meter testing ongoing, DC vehicle-as-load testing overhead is an issue (renting EV, draining battery is not really feasible time use)
- Cold weather impacts on EVSEs not an issue; on batteries of laptop/phone impacted

Cold Weather Field Testing is 'Interesting' -16F Test Equipment Issues

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- January field testing 'opportunities'; power instruments benefit heat from test load dissipated (7kW) heat
- Observation that laptop and phone battery were unexpected shutdown problem with metal case sucking out heat

Step 1: Dig out EVSE…

Mobile Test rig in vehicle;
1000W inverter for instruments (under hood)

Zimmer power meter display- 6 digit resolution

5x power meters this day; studying instrument variability and resolution impacts on measurement differences; note heater inside

PNNL C&S Pillar Updates

- **J3271 – Megawatt Charging System for Electric Vehicles**
  - 10BASE-T1S is the official PHY Layer as chosen via IEC 61851-23-3/TC 69
  - Officially TIR since October 2023
  - Investigating Bilingual CANFD coexistence
  - Future work
    - 10BASE-T1S Testing
    - CANFD coexistence testing
- **Other C&S Support**
  - NISTIR 8473 - Cybersecurity Framework Profile for Electric Vehicle Extreme Fast Charging Infrastructure
    - Published 10/2023
  - CharIN EVSE Threat Model published

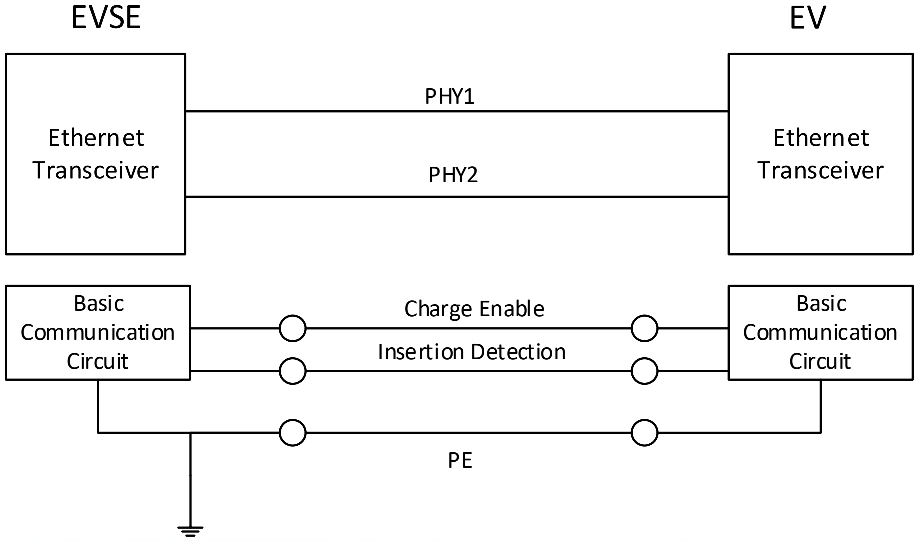
J3271 MCS Communication Controller Progress (Tesla, Delaware, ABB, ANL)

Tesla CAN prototypes-old

U-Delaware controller CAN w/Ethernet tunnel

Modified ANL SpEC (CCS) module

Eval board used in ABB module testing



3000A of power converters-> to dispenser w/CAN dispatch control

Dispenser with 3x MCS cables (~800A each); SECC controller inside

3x (Rema, T.E., Amphenol) 1800A MCS inlets on metal box w/ EVCC and bus bars (3000A)

MTU Pettibone Cary-All vehicle level testing; 3000A Load bank based vehicle emulator (@BTCP)

OSI layer for ISO 15118-20			
7	Application	ISO 15118-20	Application layer messages (V2G Message) SDP (SECC Discovery Protocol)
6	Presentation		EXI (Efficient XML Interchange)
5	Session		V2GTP (Vehicle-to-Grid Transfer Protocol)
4	Transport		TCP (Transmission Control Protocol)
3	Network		IP, DHCP
2	Data link	ISO 15118-3	10BASE-T1S IEEE 802.3cg
1	Physical		

INL- Codes and Standards Update – SAE J2954 and IEEE 2030.13

- **SAE J2954/2 released, and J2954/3 work in progress**
  - Update reflects heavy duty electrification charging needs
  - New power transfer levels and air gaps for heavy duty electric vehicles
  - Addresses static WPT requirements, J2954/3 to address dynamic wireless power transfer (DWPT)
  - No bidirectional power transfer
  - Recommends methods for evaluating safe operating electromagnetic emissions
  - Differential Inductive Positioning System (DIPS) chosen as alignment methodology for the light duty J2954 standard
  - Enables automated parking and charging for autonomous vehicles
  - Uses low-frequency, low-intensity magnetic fields from multiple coils on the GA to determine alignment

- **P2030.13 DC as a Service guidance; published, version 2 planned (overlap w/MV fed system stds)**
  - Provides guideline for development of functional specification for fast charging station management and control systems
  - Includes integration of local energy sources, including renewables such as solar PV generation and battery energy storage systems
  - Includes energy management and grid interaction functions

NREL Hosted MCS Connectors Testing Event 4 Summary

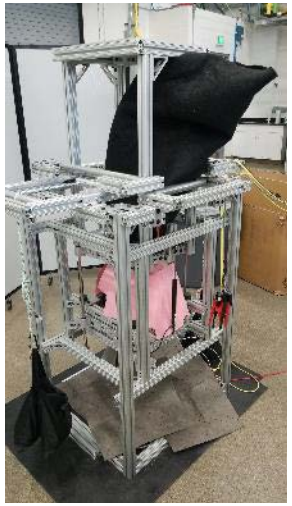
4th MCS evaluation event at NREL, consisting of 3 main evaluation categories of components from 4 hardware providers:

- Interoperability Evaluation:
  - 350A, 1000A, 3000A steady-state evaluations, with misalignment force evaluation
  - Performed at 25C ambient temperature
  - "Round robin" testing of prototype production-intent connectors and inlets
- Reference Device Evaluation
  - 1500A and 3000A reference inlet designs evaluated at rated current
  - Performed at 25C and 40C ambient temperature
  - Reference inlet prototype designs paired with prototype production-intent connectors
- Mechanical Evaluation:
  - Insertion force
  - Withdrawal force
  - Touch safety

Summary of Events 1-4:

- Event 1 (2020)
  - Fit and Ergonomics Evaluations
  - Thermal Interoperability Evaluation
- Event 2 (2021)
  - Thermal Interoperability Evaluation
- Event 3 (2022)
  - Thermal Interoperability Evaluation
- Event 4 (2023)
  - Thermal Interoperability Evaluation
  - Reference Device Evaluation
  - Fit Evaluations/Mechanical Evaluation

MCS 1500A Reference Inlet



FY2024 Milestones/Deliverables

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Milestones (shorthand)

- Report on conceptual/functional requirements for P2030.13 w/simulations
- MCS physical layer communication robustness test plan; test results (J3271/2)
- SAE J3400 NACS TIR published; RP draft version launched/evolving; J3400/1…
- IEEE P2030.13-J3271/4 based 'PowerBroker' Energy Services Exchange (ESX) implementation as an Application Programming Interface (API) (phase 1) complete

Deliverables (shorthand)

- Quarterly/annual progress reports
- MCS coupler thermal-mechanical testing results report
- (critical input to…) peer review draft of SAE J3271 (part 1-5) MCS TIR
- (critical input to…) final draft of IEEE P2030.13 Functional specs
- Monthly MW+ Charging industry engagement webinar based forum for input

Conclusion and Next Steps

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Review

- Initiative Overview
- Standards Support Areas
- Significant areas of standards development activities
- Implementation/validation of technology-requirements as part of standards

Next steps

- Continued monthly MW+ Charging Industry Engagement interactions/feedback
- Continued weekly SAE J3271(AIR7357) meetings toward TIR v2 , RP document by end of 2024
- Continued monthly standards work group participation; drafting standards, etc
- Expand into Medium Voltage fed charging systems; standards, testing, best practices (new ad hoc group met this week)
- Engagement in Interoperability (Testival) events; Lincoln Electric hosted- Cleveland OH, June 11-14 2024

- Codes and Standards Deep Dive web based meeting **APRIL 8th**
  Contact: Tbohn@anl.gov, Codes and Standards Pillar Lead

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Vehicle Grid Integration / Smart Charge Management use cases, implementation, and data gaps

Michael Kintner-Meyer

Scope of Session

- <u>Audience</u>: OEMs, Charging Network Providers, Utilities (few), aggregators, technology companies, EPA, DOE
- 4-5 questions designed for table discussions
  - <u>Question1:</u> on use-cases: give them table of use-case parameters:
    - Is the table complete? (if not, please add parameters/characteristics)
    - Please prioritize the key parameters of use-cases.
      - 1 through 5 with 1 being the most important one.
  - <u>Question 2:</u> for field demonstrations of managed charging, what are the right set of metrics to measure success?
    - Examples: a) participation rate in program, b) ability to provide grid services, c) reduce peak demand, e) reduce time to energize charging station
    - Write down metrics that are measurable (think of physical or economic units)
    - Please prioritize them (1-5, with 1 being the highest priority)
  - <u>Question 3</u>: How can we streamline the service/interconnection request?
    - What are the barriers. Please characterize them as to how they impede the process
    - What are potential solutions/processes to expedite energization of charging station?
    - Are the results dependent on use-cases and size of installation?

Scope of Session

- <u>Question 4:</u> discussion on cost allocation. Who bears the cost for service requests that require infrastructure upgrade. Equitable cost allocation
  - Do feeder upgrade cost limit future adoption EV and build-out of infrastructure
  - How do you assure that distribution infrastructure is future-proof and done equitably.
  - How do you factor in the needs of future capacity of feeders for additional electrification.
- <u>Question 5</u>: open ended.
  - When do utilities need to know for distribution system planning process
  - When do fleets know when they transition to EVs
  - How do effectively ’marry’ the two to improve the planning process to reduce the soft cost. Who would be the best entity to support a more coordinated build-out of grid and charging infrastructure.

Use-Case Parameters

DC Charging		public Highway
		public non-highway
		private depot
AC L2		DEPOT
		retail/destination
		workplace
		multi-family housing
		curbside
		single-family home
geography		dense-urban
		sub-urban
		rural
		underserved communities
ownership		privately owned
		Fleet (owned)
		Fleet (leased/rented)
vehicle segment		LDV (BEV/PHEV)
		MDV
		HDV
normal driving distance		short <100 mi
		100 <regional<300
		long >300
utility type		IOU
		MUNI
		PUD
		COOP
		vertically integrated
		non-vertically integrated
Communication options	decentralized	Telematics
		Coms to EVSE-EVs
		AMI meter
		OBD dongles
	centralized/aggregated	Telematics
		AMI meter
		OBD dongles
		Coms to EVSE-EVs
Interoperability testing		IEC 15118
		openFMB
		openADR
		OCPP/OCPI
Data security testing		Transaction data, charging data

	Provision of grid services	Peak load management
		Ancillary services
		Emergency services
		Local volt-var control
	Incentives for activie load management	Static rates with/without demand charge
		TOU
		rates embedded in home/building rates
		Dynamic pricing
		DR program participation
		Grid service program
		Participation and market size
	Who decides to control	fleet manager/aggregator
		individual EV operator/owner
Overarching motivation for SCM	EV owner	charging bill reduction
		additional revenue streams
		backup services
	utility	improved load forecasting
		better asset utilization and deferred grid upgrades
		renewables integration
		reliability/resilience improvements
	ISO/RTO	reliability/resilience improvements
Customer Participation	market segmentations	customer sementations (cohorts)
	sign-up incentives to	free charger
		gift card
	longitudinal characteristics	drop-out rate
		performance as funtion of time

EVs @ Scale

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Flexible charging to Unify the grid and transportation Sectors for EVs at scale (FUSE)

Jesse Bennett

February 28, 2024

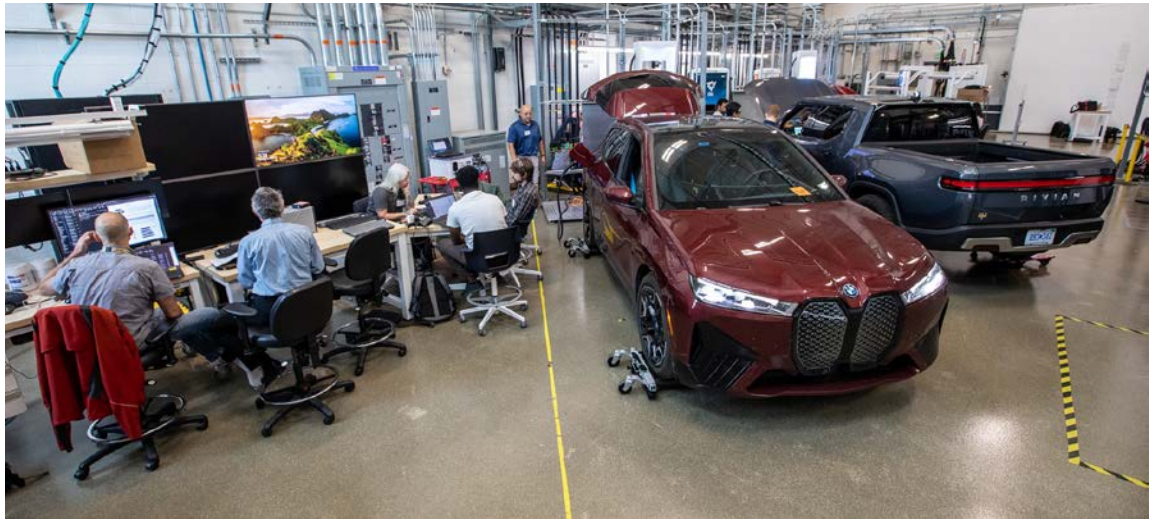
EVs@Scale FUSE - Overview

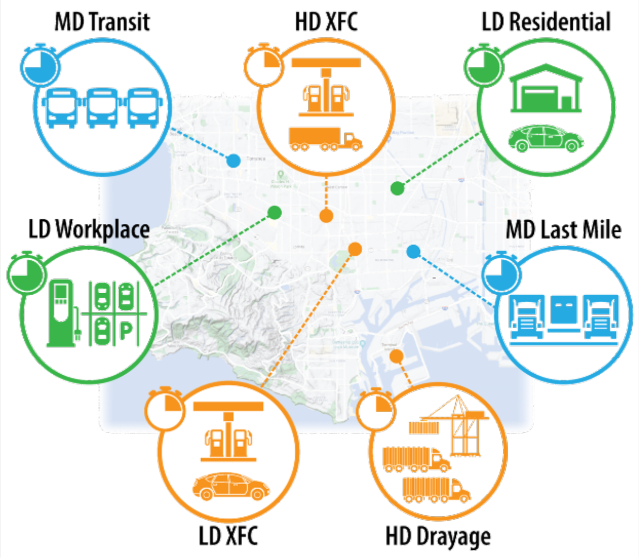
Objective:

- Develop an adaptive ecosystem of smart charge management (SCM) and vehicle grid integration (VGI) strategies and tools relevant to assess and reduce barriers to electrification throughout a wide geographic area and across numerous vocations

Outcomes:

- **Broadly identify limitations and gaps** in the existing VGI and SCM strategies to strategically shift PEV charging in time across a wide range of conditions
- **Develop enabling technologies** and demonstrate VGI approaches to reduce grid impacts throughout the entirety of the **LD, MD, and HD on-road electric fleet** while accounting for vehicle operational and energy requirements.
- **Determine SCM and VGI benefits** for consumers and utilities for EVs@Scale across the range of conditions (geographies and seasons) found in the US





EVs@Scale FUSE - Team and Partners

EVs@Scale U.S. Department of Energy

Team:

- National Renewable Energy Laboratory (NREL)
  - Vehicle Charging, Grid Impact Analysis, SCM/VGI Development and Demonstration
- Argonne National Laboratory (ANL)
  - SCM/VGI Development and Demonstration
- Idaho National Laboratory (INL)
  - Vehicle Charging Analysis, SCM/VGI Development
- Sandia National Laboratories (Sandia)
  - Grid impact Analysis

Industry Partners/Data Sources:

- Electric Distribution Utilities
  - Dominion Energy (100+ distribution feeder models throughout VA)
- Vehicle Travel Data
  - Wejo (~400 million LDV trips in VA for Sept. ‘21 and Feb. ’22)
  - GeoTab (Altitude API Access MD/HD vehicle operations)

NREL Transforming ENERGY

Jesse Bennett
Matt Bruchon
Shibani Ghosh
Yi He
Zhaocai Liu
Nadia Panossian
Priti Paudyal
Emin Ucer
Wenbo Wang
Mingzhi Zhang

INL Idaho National Laboratory

Manoj Sundarrajan
Jean Chu
Tim Pennington
Steven Schmidt

Argonne NATIONAL LABORATORY

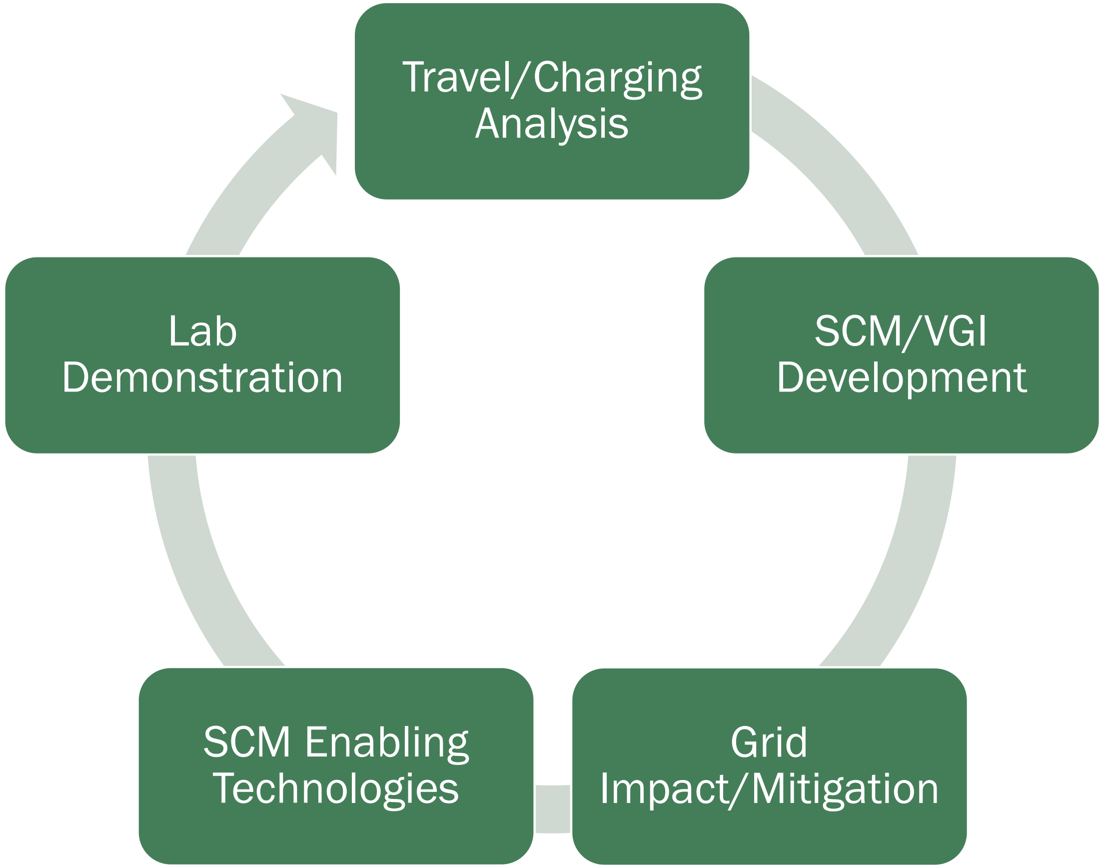
Jason Harper
Dan Dobrzynski
Bryan Nystrom
Nithin Manne
Salman Yousaf

Sandia National Laboratories

Jeewon Choi
Matt Lave
Andrea Mammoli
Emily Moog
Will Vining

EVs@Scale FUSE - Approach and Outcomes

- This project will analyze and demonstrate SCM and VGI approaches to reduce grid impacts from EVs@Scale as a result of the charging needs of the LD, MD, and HD on-road electrified fleet.
- **SCM/VGI Analysis**
  - Assess the potential charging demand for EVs@Scale and determine the uncontrolled charging grid impacts.
  - Develop and analyze the effectiveness of various VGI and SCM strategies at mitigating the grid impacts of charging EVs@Scale
- **SCM/VGI Demonstration**
  - Expand on existing SCM/VGI strategies to adapt to the evolving needs EVs@Scale throughout a wide range of vehicles and vocations.
  - Develop enabling technologies to demonstrate the potential for new and existing SCM and VGI in a laboratory and real-world environment.
  - Coordinate with Codes and Standards Pillar to determine the potential of existing technologies and need for future developments.



Topics of Interest

1. **Transportation/Charging Analysis**

   NREL: short-dwell itineraries

   Sandia: Trip chaining/mid-route charging

2. **Co-simulation/Grid Impacts**

   INL: Caldera mid-route simulations

   NREL: Co-simulation grid impacts

3. **Enabling Tech/Field Demos**

   NREL: Lab testing updates/field demo plans

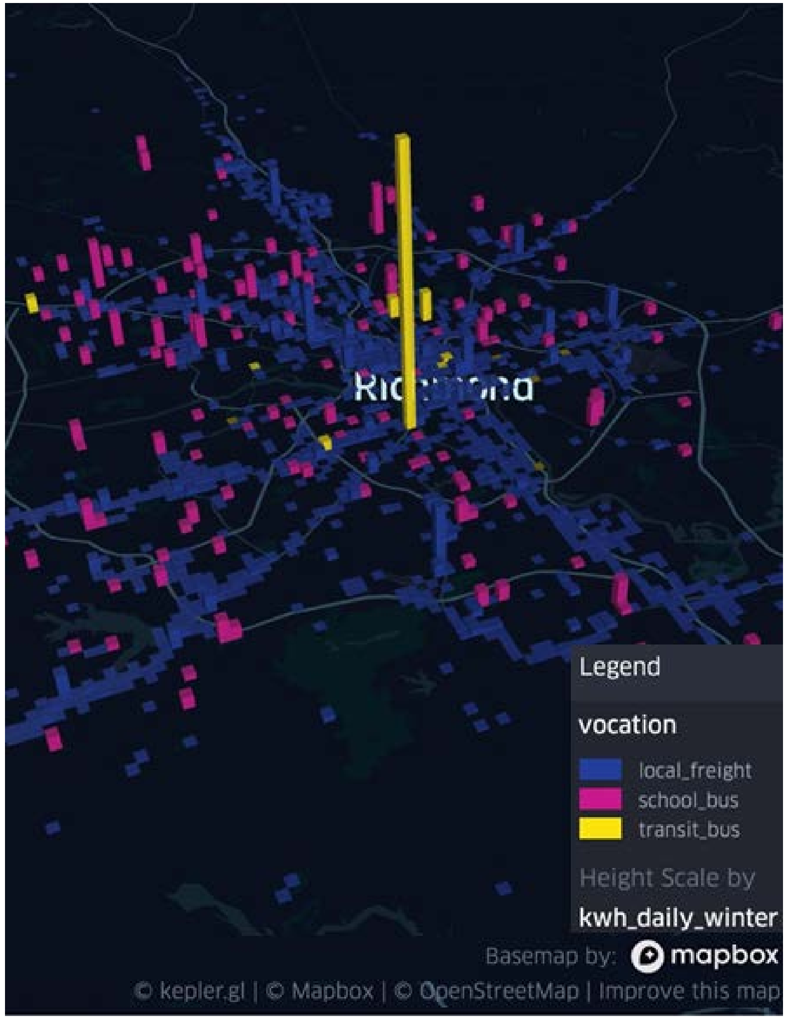
   ANL: EVrest pilot at lab/reservation data

NREL Transportation Load Modeling

- **Medium- and heavy-duty vehicle charging load estimation:**
  - Refined charge load results for "long-dwell" vocations (school bus, transit bus, local freight) and combined results across vocations
  - Developing travel itineraries for long-haul tractors, drayage, and other regional freight using Geotab's Altitude API and public datasets
    - Will serve as an input to "short-dwell" charging demand models
  - Analyzing spatial and temporal coincidence of load profiles across light-, medium-, and heavy-duty vehicles to help characterize the value of SCM

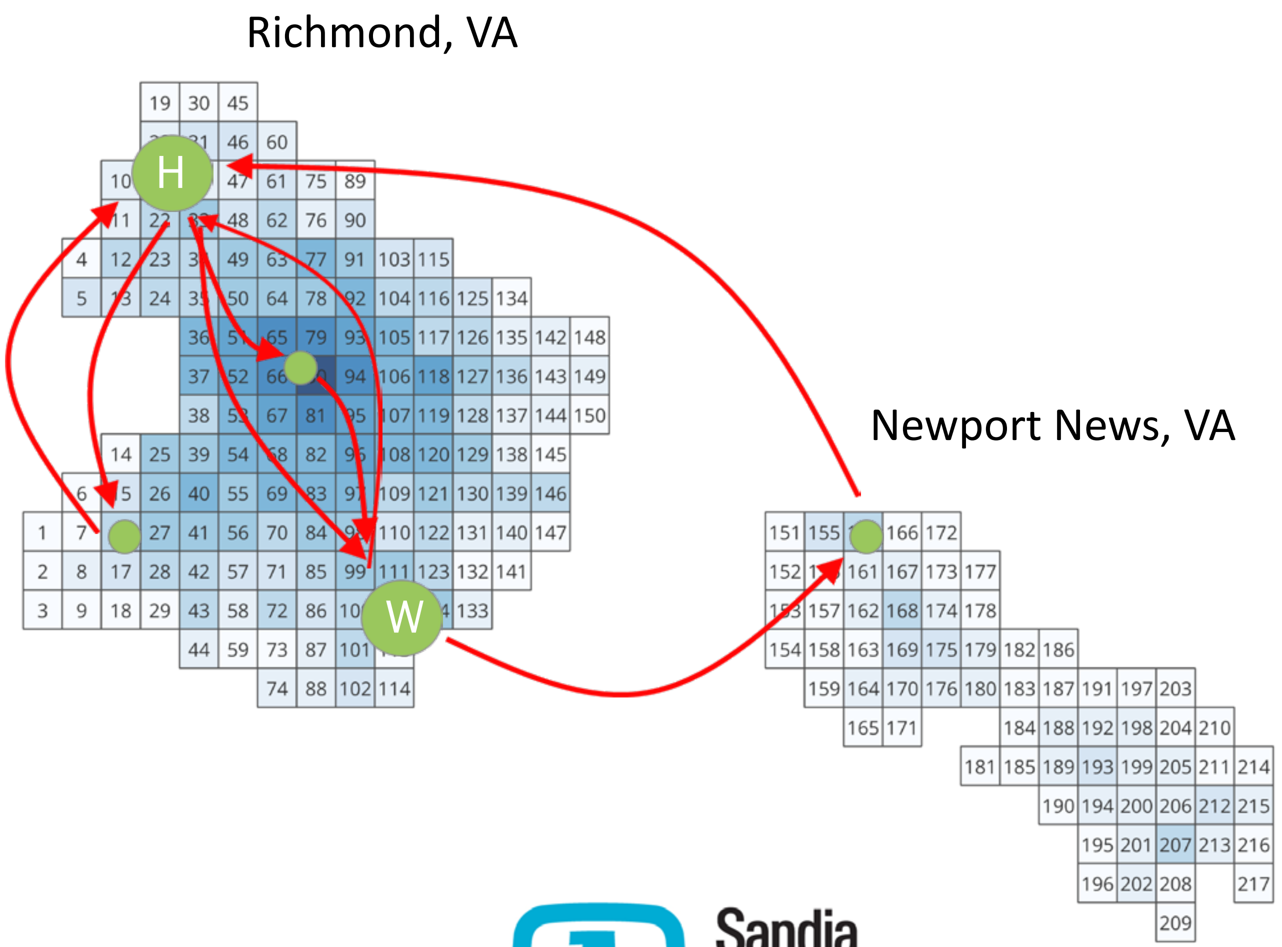
- **Publications and presentations:**
  - Light-duty vehicle analysis published in Transportation Research Part D: Transport and Environment, presented at 2024 Transportation Research Board conference
  - School bus vocational analysis submitted to Transportation Research Part D: Transport and Environment
  - Journal manuscript in development characterizing domicile-based charging demand across light-duty vehicles, school bus, transit bus, and local freight

"Long-dwell" medium- and heavy-duty vehicle charging demand (winter daily kWh, Richmond)



Improved methodology for reconstructing trips

- We are interested in the interplay of charging opportunities at home, at work and en-route
- We want to model when, where and why drivers charge their vehicles, via a Markov Chain-based ABM
- We need to generate large numbers of synthetic trip sequences that match the statistics
- From traffic "big data", we can extract origin-destination pair distributions
- Problem - how to reconstruct trips in a realistic way, that reflect commuting behavior and daily / weekly schedules?



Sandia National Laboratories

List-constrained Markov chain trip sequence generation

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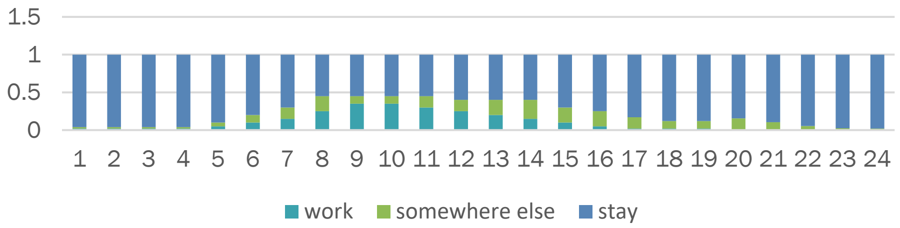
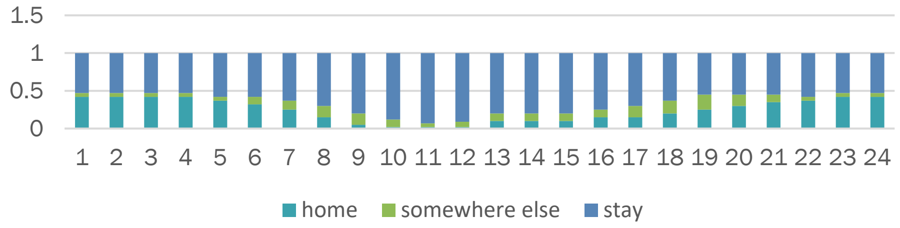
Long list of trips based on O-D pair distribution

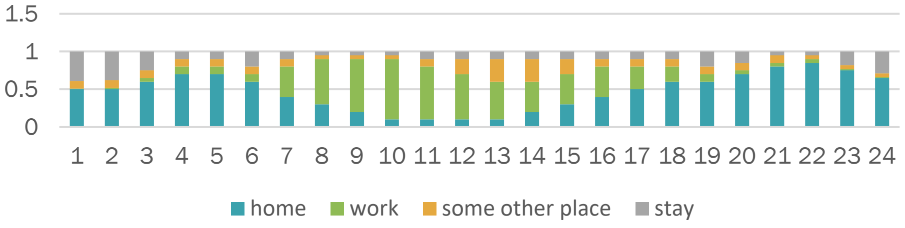
destination from home



destination from work

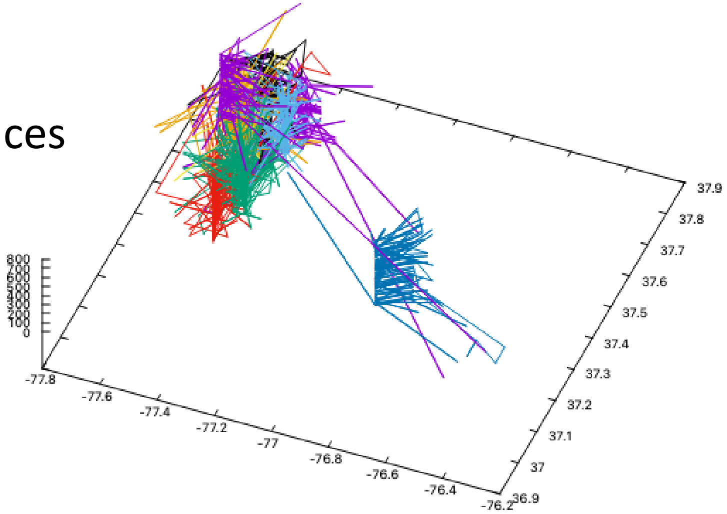


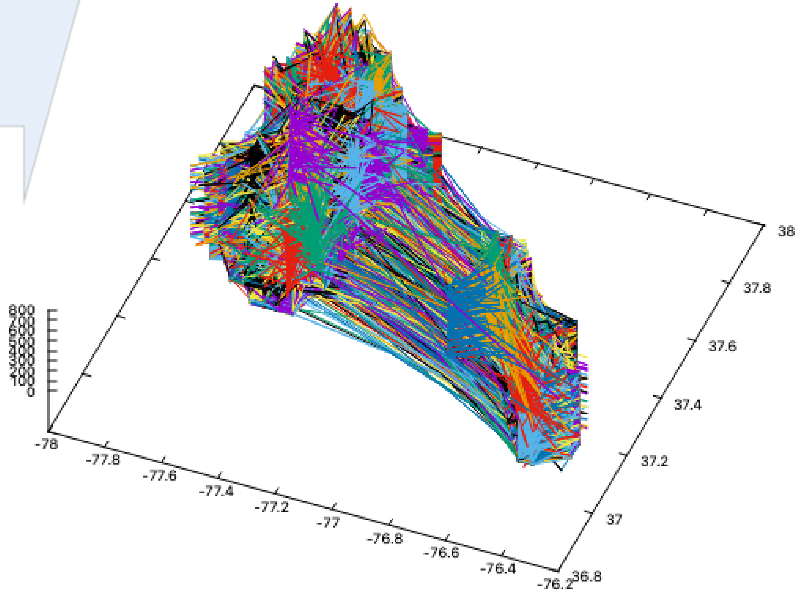
destination from somewhere not home or work



Stats from various sources

10 trip sequences

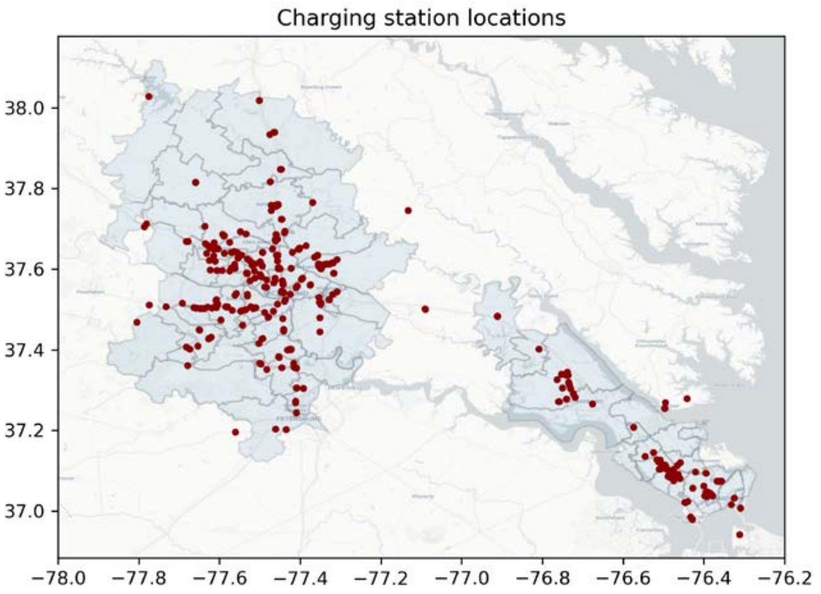


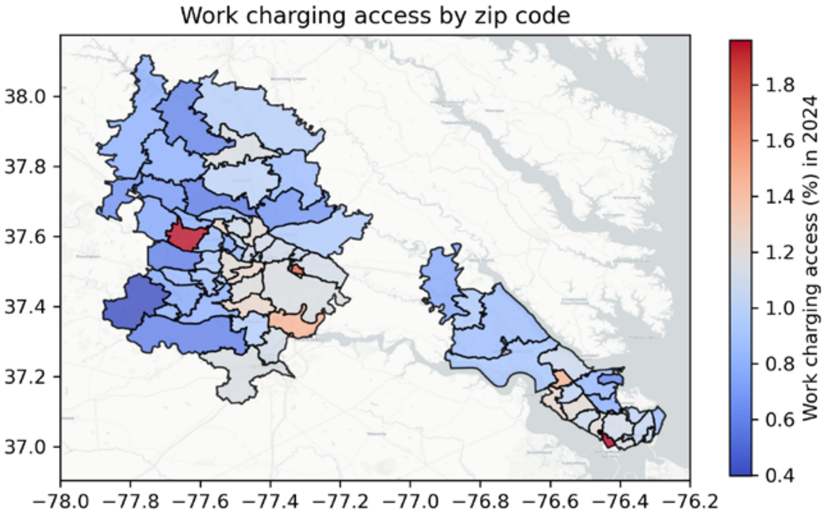


10,000 trip sequences

Mid-Route Charging

- **Mid-route charging infrastructure**
  - Home charging access is determined using the data from: There's No Place Like Home: Residential Parking, Electrical Access, and Implications for the Future of Electric Vehicle Charging Infrastructure.
  - Working charging access is determined by a generalized linear model using data such as population density, establishment density, median income, average annual payroll, average company size, company size distribution in a zip code.
  - Destination charging access (i.e L2 charging at malls, movie theaters, grocery stores) is stochastically assigned to 6.7% (EVI-pro tool) of public dwell events.
  - 318 charging station locations with 1500 charging ports (EVI-pro tool) determined from existing charging and gas station location data.
- **Vehicle travel itinerary data**
  - 505,079 LD itineraries derived from Wejo data (NREL)
  - Itineraries for situation specific scenarios generated using Markov chain approach (Sandia)
- **Using the infrastructure and itinerary data, Caldera CDM models the effects of different price based smart charge management strategies on mid-route charging.**
  - Variations in grid and local charging station conditions impact temporal and spatial shifting of energy.





NREL Grid

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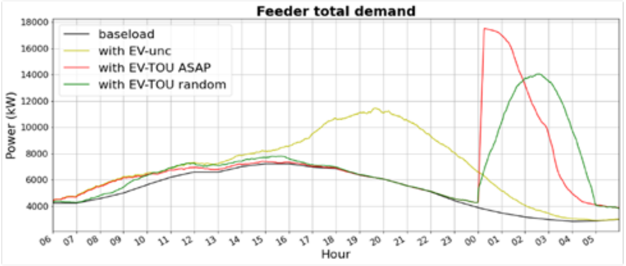
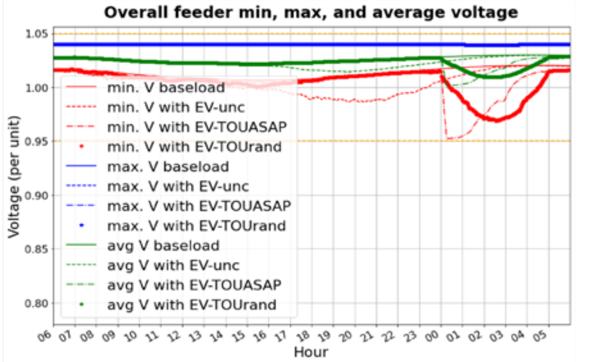
- **Grid impact scenarios considered**
  - **Basecase** - no EVs, grid infrastructure as is
  - **Uncontrolled charging** - with EV charging as per customer choice – EVs are charged anytime without any restriction
  - **TOU ASAP charging** - with EV charging based on TOU pricing time; If available, EVs will only charge during super off-peak hours, starting within 15 minutes of super off-peak time
  - **TOU random start** – with EV charging throughout the super off-peak hours (TOU-based); EVs will randomly start charging within the first 4 hours of Dominion's super off-peak period (if available)

- 1 day simulation analysis is conducted considering a day in September
- 1 min timestep





- EV charging significantly increased the feeder peak demand with all 3 charging strategies
- TOU ASAP creates a huge spike on the feeder demand and drops the minimum voltage close to 0.95 per unit

- **Summary of analyses on a selected feeder**
  - Initial time-series grid impact analysis was conducted with 3 basic EV charging strategies
  - Uncontrolled charging increases peak demand during evening hours and leads to overloading of distribution transformers
  - TOU-based EV charging strategies shift the EV charging from traditional peak demand period, but worsen grid impacts, specifically when the off-peak period is short-duration and when all the EVs start charging immediately

For a feeder from Newport News region - Highly residential feeder with a Peak demand of 8 MW	Base-case	Uncontrolled	TOU ASAP	TOU random start
Peak demand (MW)	7.22	11.4	17.51	14.05
Peak demand time	15:00	19:40	00:17	02:35

SCM Simulations and Demonstrations

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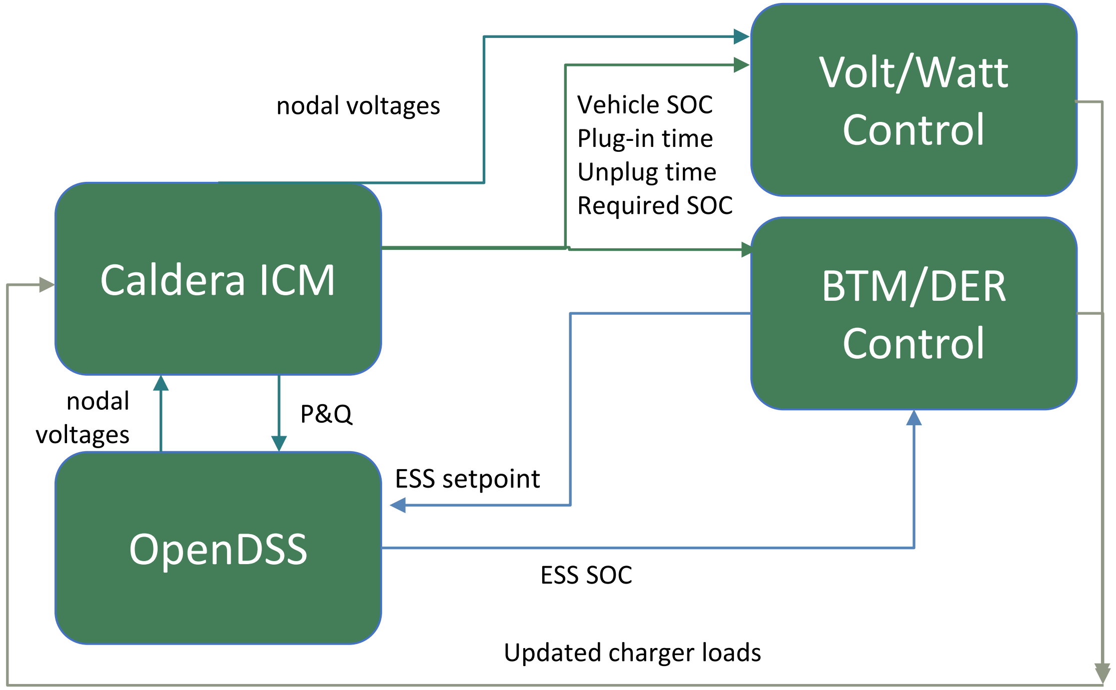
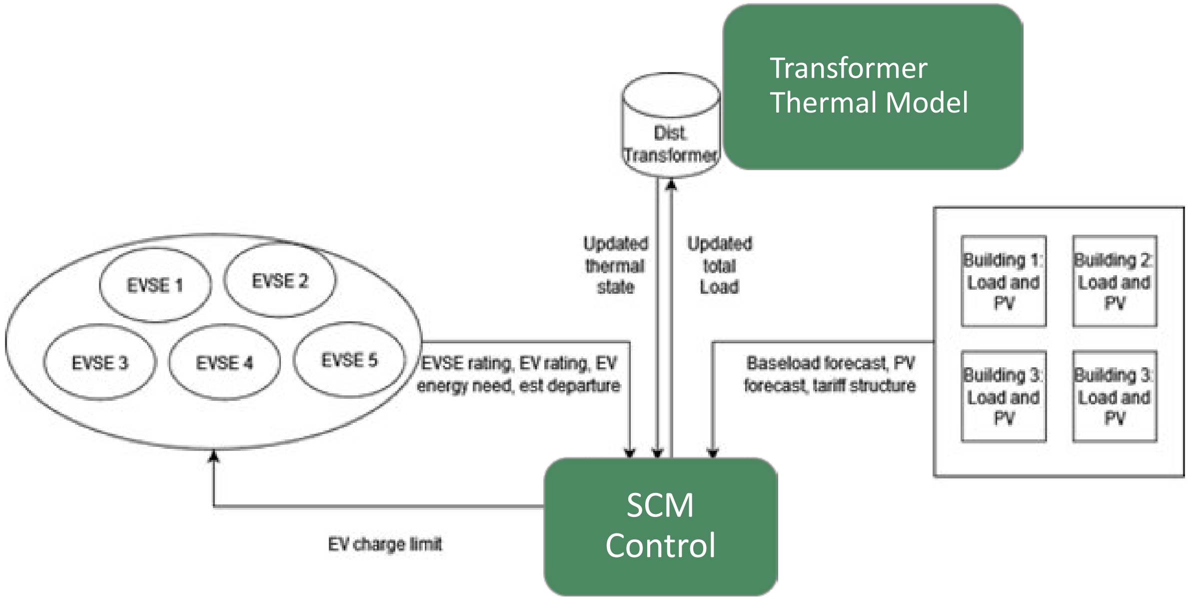
Simulated Control:

SCM for Voltage response, Peak Load Reduction



Field Demonstration:

SCM for Distribution Transformer Limits



- Charge session needs from transportation/charging analysis
- Nodal grid impact assessment from Caldera and OpenDSS
- Various SCM objective functions to mitigate grid impacts
- HELICS co-simulation framework to assess SCM value

- Developing SCM field demonstrations to prove viability
- Simulations help identify optimal SCM objective functions
- Lab demos/enabling technology efforts develop capabilities
- Utility partnerships provide opportunity to test solutions

SCM Hardware Demonstrations

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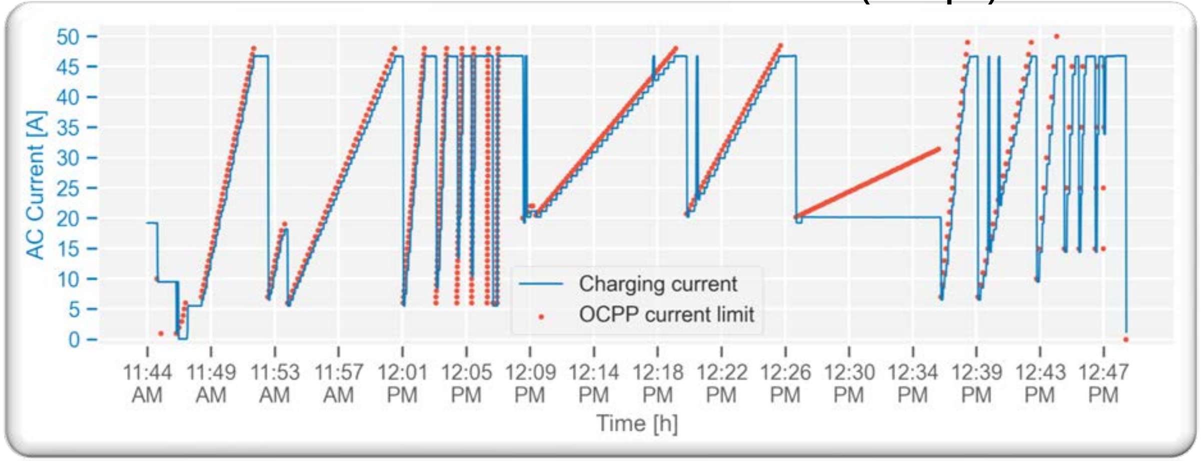
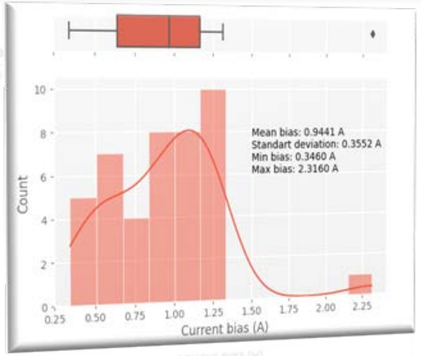
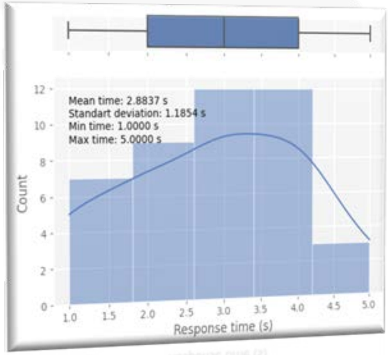
OCPP Control Characterization Tests (Ioniq 5)







Max curr. error: 2.25 A

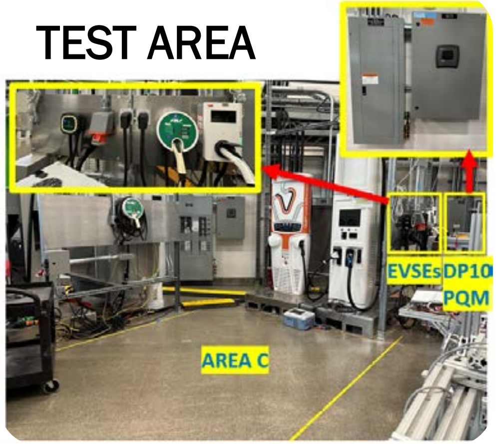
Max res. time: 5 s

Recent tests

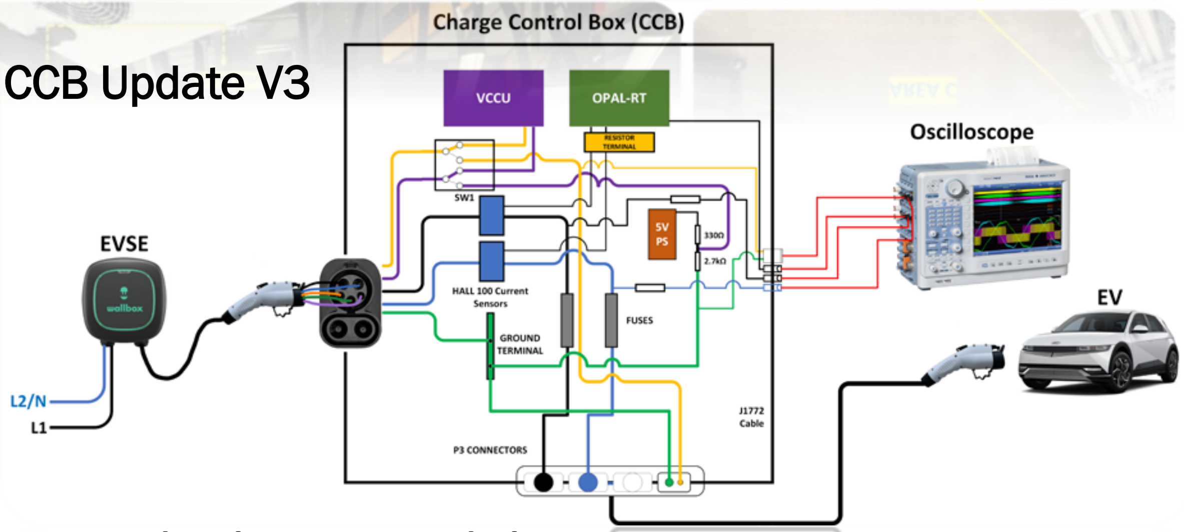
- Characterization of OCPP charging control barriers
- Investigation of factors impacting accuracy, precision, resolution and speed of smart charging control
- Identification of different EVSE and EV responses

TEST-BED

TEST AREA



CCB Update V3



Ongoing developments and plans

- Improving measurement resolution and disaggregation
- Testing and verification of EVSEs under power quality events
- Implementation of different SCM solutions

Argonne EVrest Pilot Demonstration

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10-09-23 — Registration Opened

10-13-23 — 10 of 12 AC Ports at Bldg. 300 go live

11-22-23 — 7 of 8 AC Ports at Bldg. 242 go live

11-29-23 — 3 of 4 DC Charger at Bldg. 300 go live

1364
AC and DC Charge Sessions

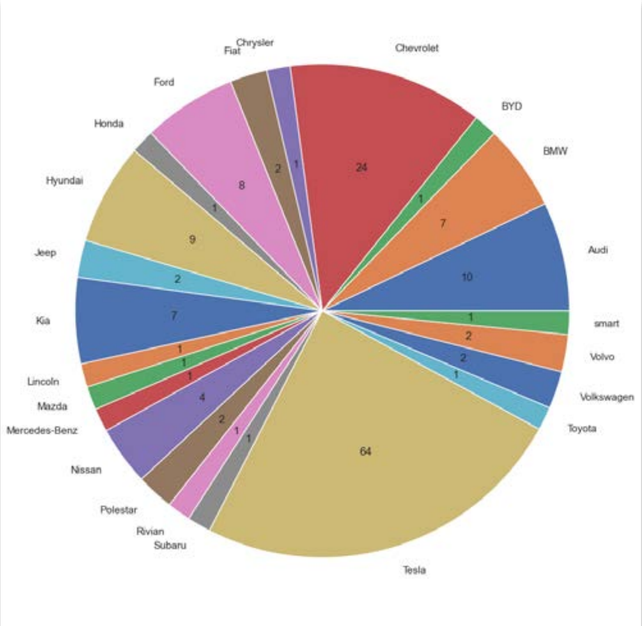
28 MWh
Total Energy Dispensed

100
Registered Users who have completed at least one reservation

127
Registered Users

79
iOS Devices

53
Android Devices

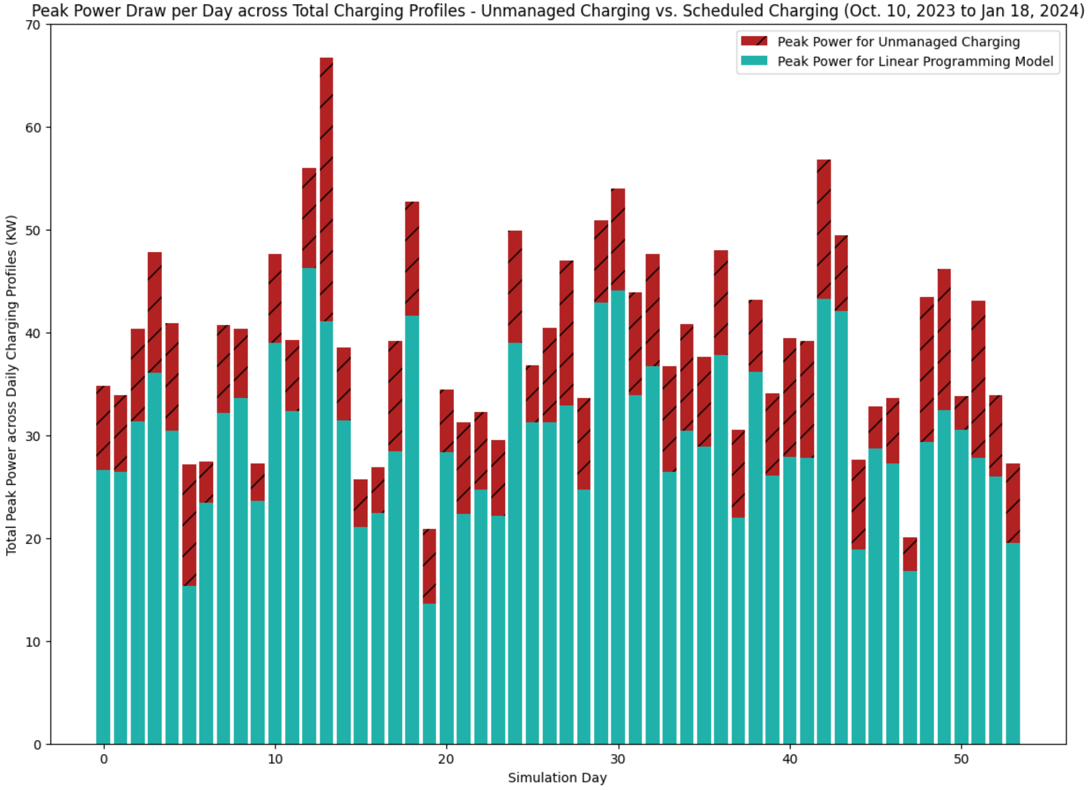


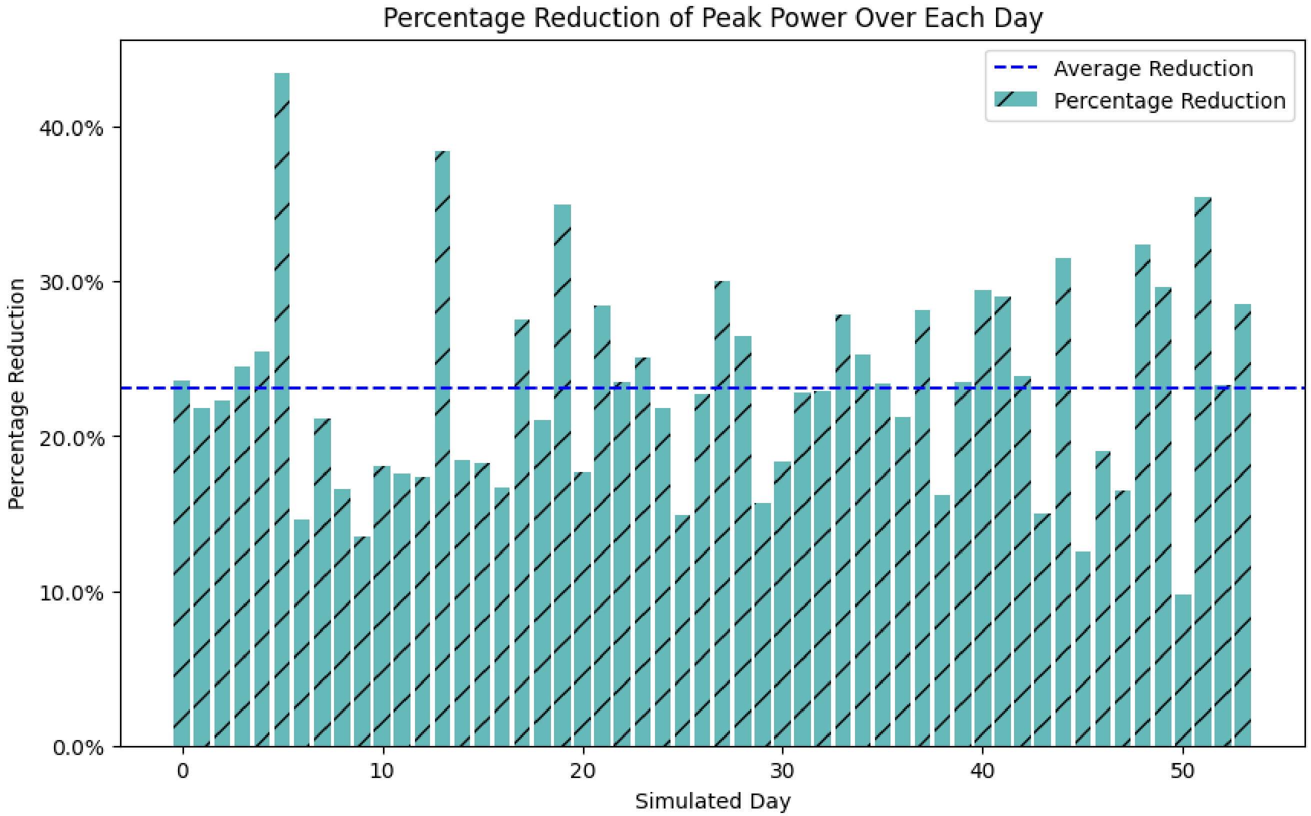
Some interesting correlations:

- *Average Requested Miles & Average Actual Miles Charged*
- *Average Reservation / Session Duration & Pre / Post-Flexibility*
- *Average Accuracy & Average Actual Miles Charged per Session*
- *Total Number of Sessions by EV Driver & Post-Flexibility*

	Number of Sessions	Average Requested Miles	Average Accuracy for Requested Miles	Average Actual Miles Charged	Pre-Flexibility	Post-Flexibility	Total Energy Across Sessions	Average Power Draw	Peak Power Draw	Average Reservation Duration	Average of Session Duration
Number of Sessions	1.00	-0.08	0.01	0.00	-0.01	-0.26	0.88	-0.29	-0.11	0.43	0.42
Average Requested Miles	-0.08	1.00	-0.14	0.73	-0.10	0.04	0.17	0.48	0.30	-0.18	-0.11
Average Accuracy for Requested Miles	0.01	-0.14	1.00	0.36	0.14	-0.22	0.06	0.22	0.10	-0.12	0.05
Average Actual Miles Charged	0.00	0.73	0.36	1.00	0.29	-0.01	0.31	0.70	0.38	-0.27	-0.11
Pre-Flexibility	-0.01	-0.10	0.14	0.29	1.00	0.66	0.03	0.53	0.27	-0.42	-0.52
Post-Flexibility	-0.26	0.04	-0.22	-0.01	0.66	1.00	-0.27	0.40	0.25	-0.46	-0.75
Total Energy Across Sessions	0.88	0.17	0.06	0.31	0.03	-0.27	1.00	-0.04	0.06	0.29	0.35
Average Power Draw	-0.29	0.48	0.22	0.70	0.53	0.40	-0.04	1.00	0.49	-0.75	-0.65
Peak Power Draw	-0.11	0.30	0.10	0.38	0.27	0.25	0.06	0.49	1.00	-0.34	-0.29
Average Reservation Duration	0.43	-0.18	-0.12	-0.27	-0.42	-0.46	0.29	-0.75	-0.34	1.00	0.89
Average of Session Duration	0.42	-0.11	0.05	-0.11	-0.52	-0.75	0.35	-0.65	-0.29	0.89	1.00

Charge Scheduling Analysis with Real Reservation Data





- Instantaneous peak power demand per day at ANL Building 300
- Charge Scheduling Algorithm, successfully reduces daily peak power draw loads across simulated days while meeting the needs of the driver

- Average peak power reduction of ~22% across days where charging is above 20kW utilizing Charge Scheduling Algorithm

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Thank You

Join us for the SCM/VGI Deep Dive

Thursday April 4th

Additional Details to Follow

Agenda

8:30 a.m. – 9:30 a.m.	**Pillar Presentations and Participant Feedback** Cyber – CyberPUNC | Barney Carlson Cyber – Zero-Trust | Tom Carroll
9:30 a.m. – 9:45 a.m.	Break
9:45 a.m. – 11:00 a.m.	**Panel Discussion** **Cyber Security** 5 min. intro 30 min. panelist presentations 40 min. discussion
11:00 a.m. – 11:45 a.m.	**Consortium Feedback** Consortium Audience Feedback Session | Lee Slezak, Austin Brown Open Mic Audience Feedback Session | Attendees

U.S. Department of Energy

Cyber-Physical Security Pillar

Barney Carlson: Idaho National Lab

Feb. 29, 2024

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

INL/MIS-24-76520

Cyber-Physical Security Pillar Overview

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Objective: Contribute to the continuously evolving cyber-physical security methods and solutions needed to ensure EV charging infrastructure safety, reliability, & resiliency

Projects:

– *CyberPUNC* assessments, mitigation R&D, cyber workforce training
– *Zero Trust Architecture* for EV charging infrastructure

Barriers Addressed:

- Rapidly expanding features, standards, & cyber provisions:
- Lack of holistic understanding of EV ecosystem vulnerabilities
- Inconsistent implementation of effective security methods
- Insufficient EV Charging Infra. (EVCI) cyber workforce
- Unknown potential cyber impacts of NACS
- Potential ISO 15118-2 & -20 compatibility vulnerabilities
- Lack of cyber metrics & verification methods for EVCI
- Lack of EV Charging Infra. cyber mitigation tools and solutions
- Previously secured & new vulnerabilities with Quantum computing capabilities
- Poor charging resiliency - lack of resiliency metrics, detection, response, recovery, controls, & evaluation

Idaho National Laboratory · Sandia National Laboratories · Pacific Northwest National Laboratory · Argonne National Laboratory · NREL Transforming ENERGY · Oak Ridge National Laboratory

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CyberPUNC Project

Barney Carlson: Idaho National Lab

Feb. 29, 2024

CyberPUNC: Results & Accomplishments over past 2 years:

- PKI testing environment creation has progressed; aligned with industry needs & developments
- Completed first automated testing of many EV-EVSE device interactions
- Completed EVSE security control catalog for cybersecurity risk assessments
- “Cerberus” mitigation solution developed and demonstrated
- “AcCCS” CCS communications tool developed; now open-source
- Continued support of *CyberAUTO* Challenge
- EVSE upstream and backend system analysis

CyberPUNC: Future Efforts – What’s Next

CyberPUNC Project - Secure EV charging w/PKI Integration

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Background

- Baseline cybersecurity requirements include ISO 15118-2 and -20 certificate profiles
- Research extends prior and upcoming EV charging industry PKI testing events with SAE

Current Focus and Progress

- Using open-source Emulytics (minimega/Phēnix/SCORCH) tools for PKI simulation and testing within NREL Cyber Range
  - Have implemented VMs emulating EV, EVSE, CNO essential functions
    - Using 15118-2 and OCPP 2.0.1 protocols
    - Focus on the PKI integrations for encrypting communications
  - Tested scenarios with 100 and 500 EVs with experiment orchestration
- Will leverage EVerest OSS developments in future implementations
- Continuing integration with SAE prototype PKI provider

Insights

- Creating a scalable, repeatable environment for scenario evaluation including architecture, operations, and governance decisions
- Building in a range of EVCI PKI validation functions and metrics to understand system outcomes
- Gaining better understanding of relying party/end device PKI requirements with industry engagements

Future Directions

- Interface with pilot and production PKI hosts; align with industry and CESER/JOET initiatives
- Enable assessment of EVerest security capabilities in a closed (Cyber Range) environment
- Use defined scenarios (from CESER efforts) to generate test outcomes and insights for future challenges

Implementing the latest security methods and best practices

Outreach Completed

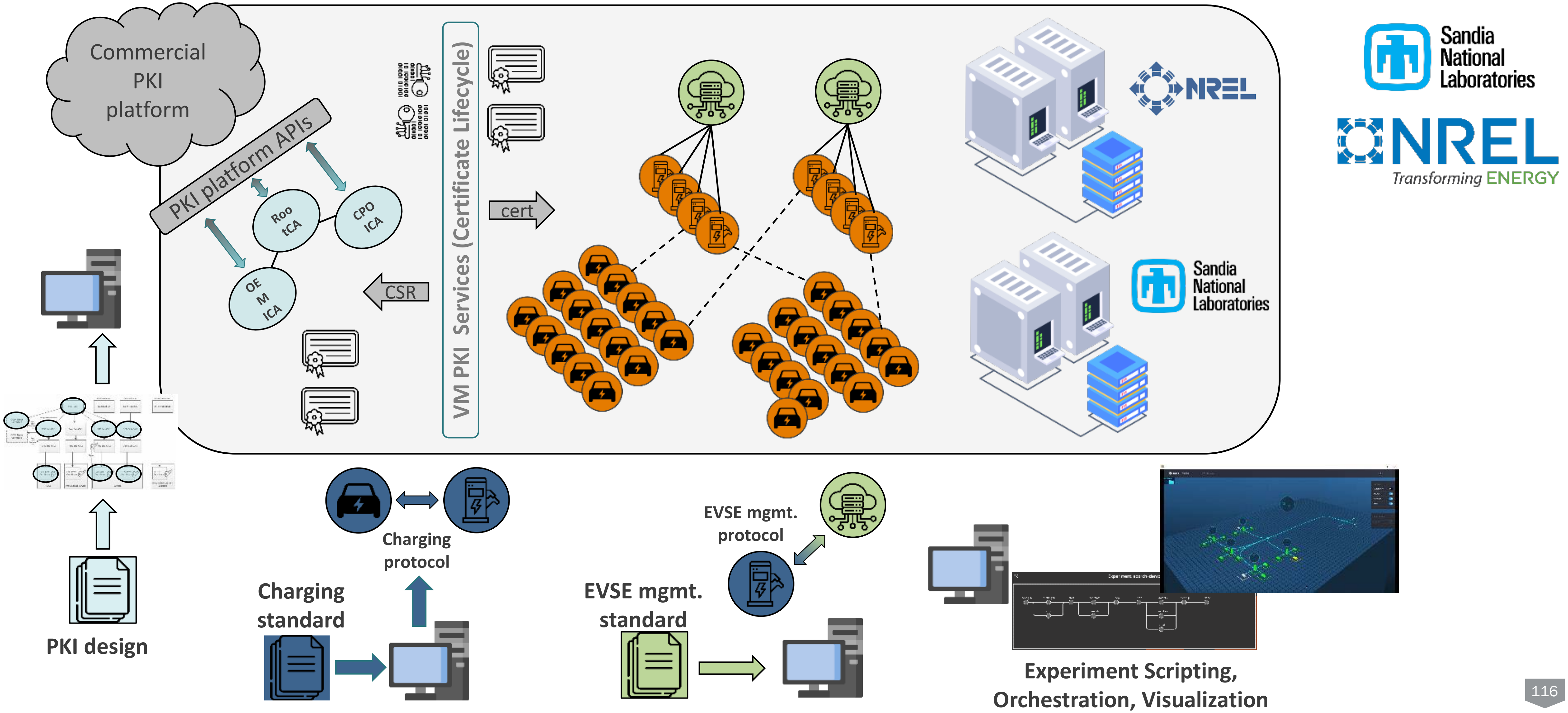
- DOE Cyber and Tech Innovation Conf
- Embedded Security in Cars (ESCAR)
- Network and Distributed System Security Symposium (NDSS) 2023 - Vehicle Security
- Energy Transition Summit – Charging Ahead

Sandia National Laboratories

NREL Transforming ENERGY

CyberPUNC Project - Secure EV charging w/PKI Integration

EV charging PKI emulation on minimega/Phēnix



CyberPUNC Project – Cyber Tools and Solutions for EVSE

Implementing the latest security methods and best practices

Background

– Prior national lab work collected insights on subset of industry tools and capabilities

– Opportunity to map tools and capabilities to EVSE security functions and needs

Current Focus and Progress

– Previously constructed a dynamic database (OpenEI platform) for engaging with industry using initial security tool surveys

– Recently drafted EVSE specific cyber assessment question sets that align with DERCF (cyber framework assessment tool)

Future Directions

– Develop tailored cybersecurity mitigations and prioritized action items for the assessment outcomes

– Test facility-specific EVSE cybersecurity controls progress and needs

– Maintain and update EVSE tools site and build connections between needs and solutions

Controls Catalog can a First Step toward Priority Actions

Controls	Implementation	Criticality	Metric/ Security Function	NIST CSF Category
Does the EVSE protect the confidentiality of the communication on the Wide Area Network (WAN) interface by encrypting it using a protocol allowed by the cryptographic algorithms and key length requirements?	Yes/ No	High	Confidentiality	Protect
If passwords are used on the EVSE, are they stored in readable plaintext?	Yes/ No		Confidentiality	Identify
Are the hashing function open-sourced and proven to be collision resistant one-way hash functions?	Yes/ No	Moderate	Confidentiality	Protect
Is there a process to verify no known vulnerable hash functions are used?	Maturity		Confidentiality	Detect
Is the EVSE able to detect messages that have been modified or verify the integrity?	Technical [Select One]	Moderate	Message Integrity	Detect
If yes, does the EVSE reject or drop the modified/tampered message?	Yes/ No	Moderate	Message Integrity	Detect
Is the EVSE able to verify the cryptographic integrity of messages received on the Local Area Network interface?	Yes/ No	Moderate	Message Integrity	Detect
Can the EVSE verify the source and integrity of firmware images before they are applied using a hashing function and hash provided by the vendor?	Yes/ No	High	Firmware Integrity	Detect
Is the EVSE capable to reject installation of firmware updates if it detects the firmware has been modified, or it cannot verify the firmware's integrity?	Yes/ No	High	Firmware Integrity	Detect
Does the EVSE provide mechanism to check the authenticity of firmware images obtained through any of its available update mechanisms (both remote and local)?	Technical [Select Multiple]	High	Authentication	Protect
Does the EVSE verify that the firmware came from the vendor by verifying its cryptographic signature against trusted issuer?	Yes/ No	High	Authentication	Protect

Responses lead to metrics

Metrics guide priorities

CyberPUNC – Cyber Mitigation Tools & Solutions

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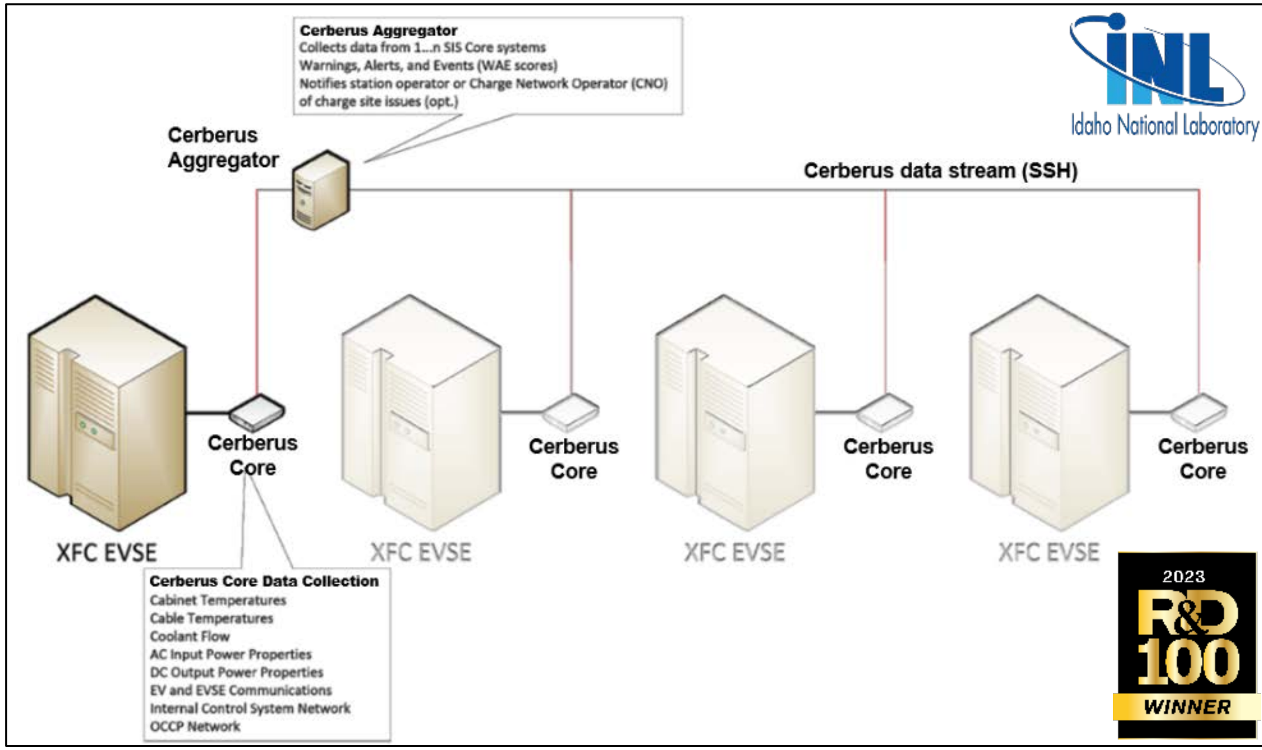
Cerberus: a cyber-physical anomaly detection and exploit mitigation solution

- Designed after industrial Safety Instrumented Systems (SIS)
  - Aggregator module (one per charge site)
    - Receives detection information from multiple core modules (warnings, alerts, errors)
    - Responds accordingly for site operation resiliency
  - Core module (one per EVSE)
    - Monitors EVSE internal & external comm.
    - Dedicated sensing
      - Voltage and current
        - high-voltage and low-voltage systems
      - Temperature
      - Component state
        - doors, contactors, pumps, etc.
    - Responds to mitigate detected anomalies

- Patent filed: May 10, 2023
- 2023 R&D100 Winner
- Tech Transfer meetings w/ industry interested parties



CyberPUNC – Cyber Mitigation Tools & Solutions

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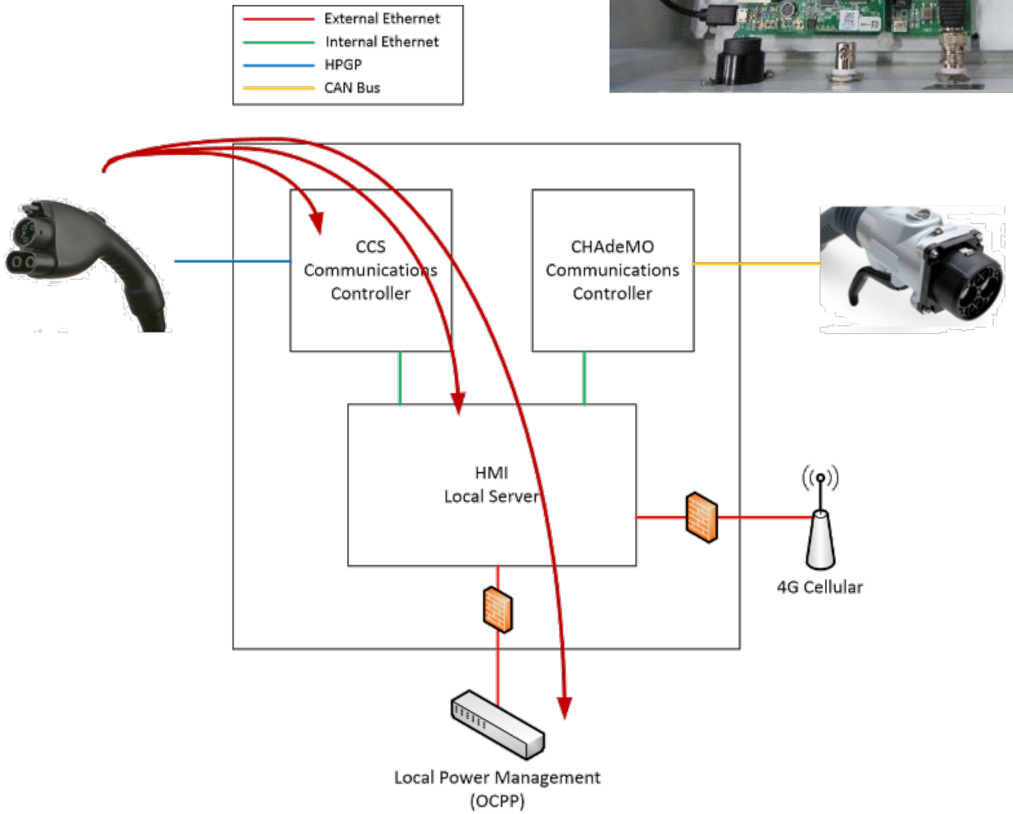
“AcCCS” to Evaluate CCS Communication Vulnerabilities

- Able to emulate and exploit EV and/or EVSE CCS entire communication stack via the CCS control pilot wire (J1772, SLAC, SDP, TCP/IP, 15118)

- *CyberPUNC* team identified an exploitable vulnerability in some DC chargers
  - *AcCCS* establishes a CCS charge session
    - XFC internal network access was achieved through the CCS communications (SECC)
    - Network vulnerabilities were identified
    - Access to external systems connected to XFC internal network possible (ex. OCPP server)

- AcCCS is open-source software using COTS components
  - https://github.com/IdahoLabResearch/AcCCS
    - Raspberry Pi4
    - EVSE configured Devolo
    - EV configured Devolo
    - PWM circuit, relays, and power isolators



Idaho National Laboratory

CESER - Cyber Best Practices for High-Power Charging Infra.

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Development & Demonstration of Cyber Best Practices for High-Power Charging Infra.

- Demonstration event, called “EV SALaD”, of Cyber Best Practices highlighted XFC mitigation solution effectiveness
  - Collaborative effort: Idaho, Sandia, and Pacific Northwest National Labs
  - Pre-scripted test effect payloads (exploits) launched with & without cybersecurity best practices enabled to:
    - Highlight potential impact severity without cybersecurity solutions enabled
    - Demonstrate cybersecurity best practices effectiveness

INL Idaho National Laboratory
Sandia National Laboratories
Pacific Northwest NATIONAL LABORATOF

Cybersecurity Recommended Best Practices:

- **EVSE external communications with EV and energy management systems**
  - Zero Trust and Principal of Least Privilege
  - Network Security: Authorization, encryption, authentication, PKI
    - Smart Energy management: OCPP 2.0.1 (or similar) with full TLS
  - Cyber Informed Engineering
- **EVSE internal controls communications**
  - Network segmentation to isolate critical assets: Secure gateway, Firewalls
  - Network Monitoring: Message integrity, deep packet inspection
  - Cyber Informed Engineering
    - Monitor for abnormal or invalid values (i.e. SOC=254%)
    - Thermal management control & feedback based on DC current & CCS temp.
    - Cable contactor XOR control logic (not mutually exclusive)
  - Physical access security preventing communication connection access (JTAG, CAN, USB, Ethernet, etc.)

CyberPUNC – Cybersecurity Workforce Training

CyberAuto Challenge: Training the Next-Generation of Cyber Workforce

- Annual 1-week long, collegiate event in Mich. focused on automotive cybersecurity
- *CyberAuto* 2018 - present: increased focus on elec. transportation and charging infra.
  - EVs, DC chargers, and OCPP 1.6J network
  - In-vehicle / in-EVSE evaluations and training: Automotive Ethernet, CAN bus, OCPP, ISO 15-118, reverse engineering, Ghidra, attack strategies/methodologies
  - Vulnerability assessments:
    - EVSE internal communications network access and EV port scans through the CCS-1 control pilot via *AcCCS* tool
    - Attempted root access of EVSE 64-bit main control board

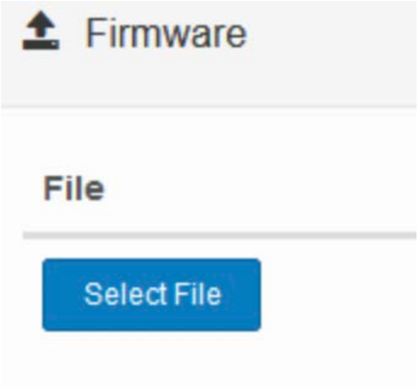
- **July 22-26, 2024** ***CyberAUTO:*** Industry highly encouraged to participate: EV & EVSE hardware, energy management software, etc.
  - www.cyberauto-challenge.org
  - contact: Karl Heimer (karl.heimer.pro@gmail.com)
- **2025 & beyond:** expand into ***CyberINFRASTRUCTURE Challenge*** focused on EV charging infrastructure (including bi-directional), microgrids, DER, and the associated communications

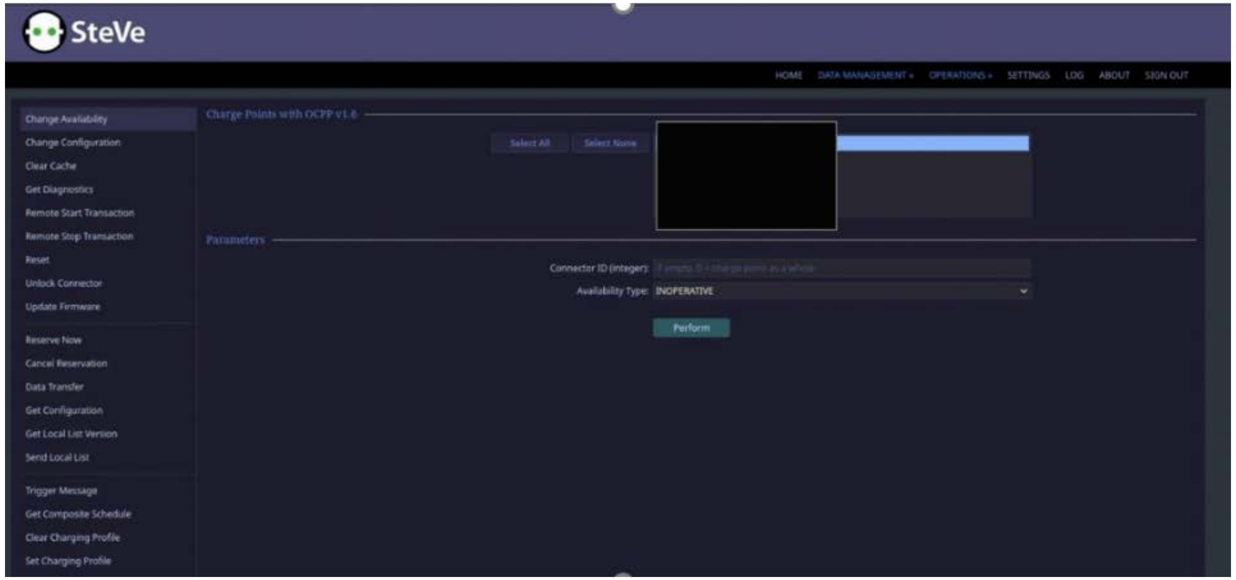
EVSE Upstream and Backend Systems Analysis

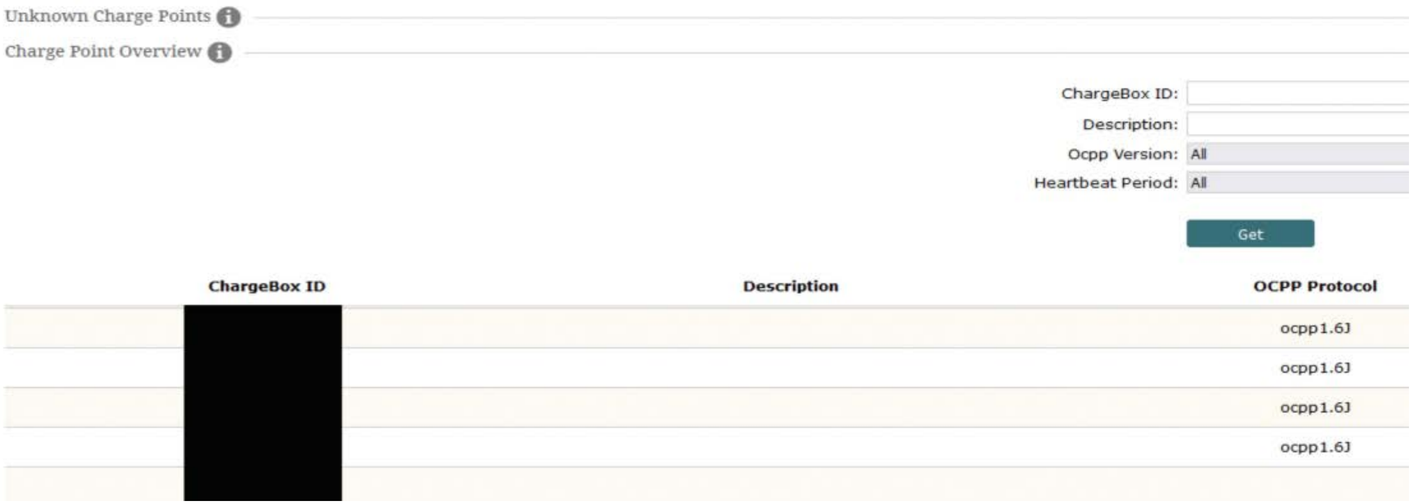
Open Source Intelligence gathering, processing, and analysis of backend systems (CS/CSMS, API endpoints, and integral IT services)

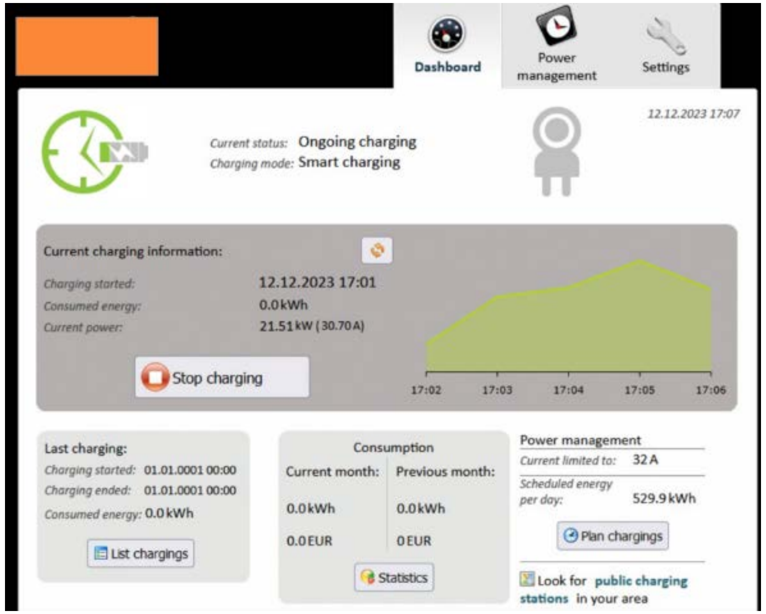
- DNS enumeration and subdomain expansion,
- API endpoint evaluation,
- Identification of security misconfiguration and/or misalignment,
- Analysis of consequence for bypassing intended security controls, and
- Correlation of data for best/worst practices

Experimental Results

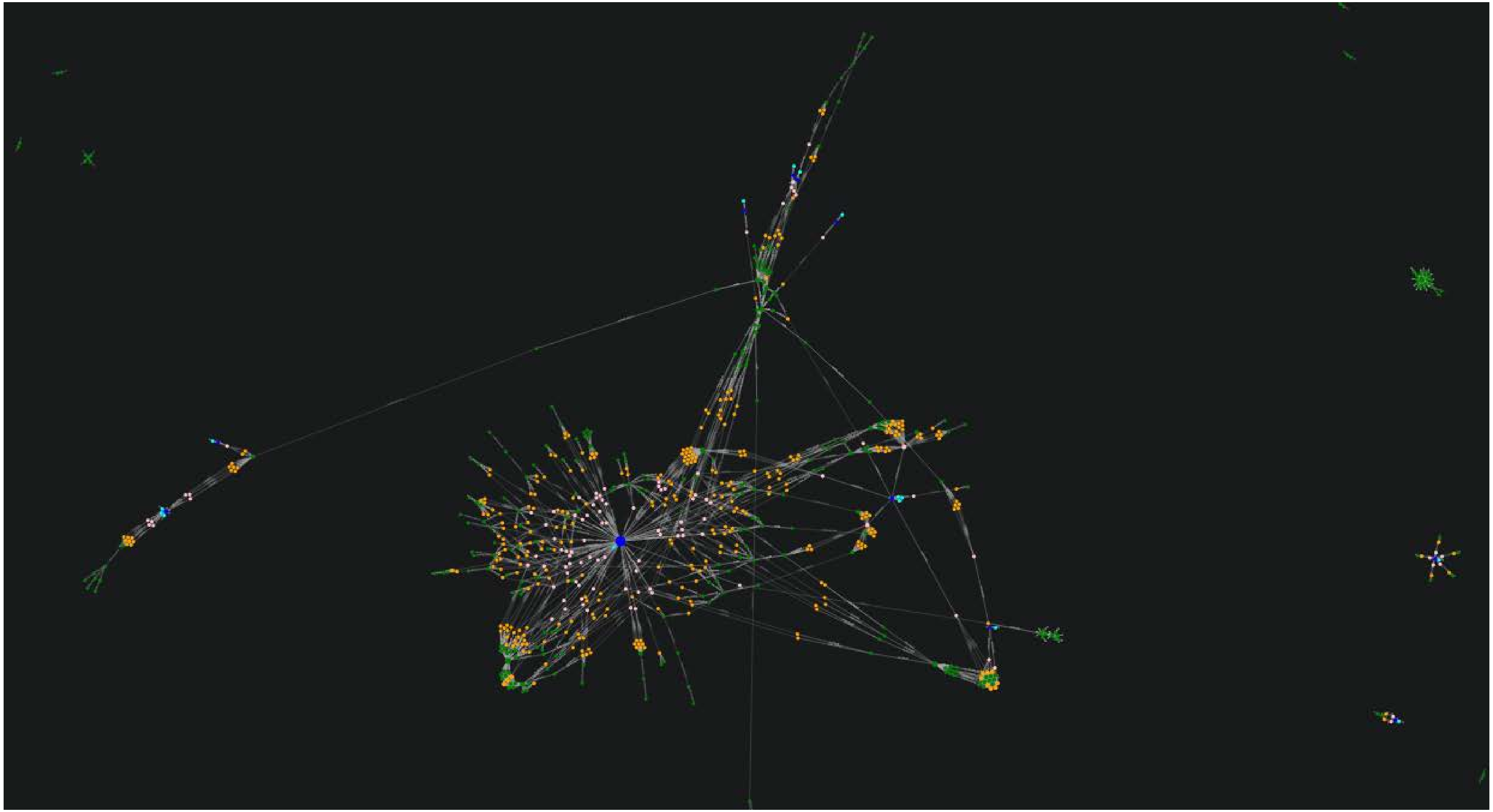








ChargePoint Network Map



CyberPUNC: Future Efforts – What's Next

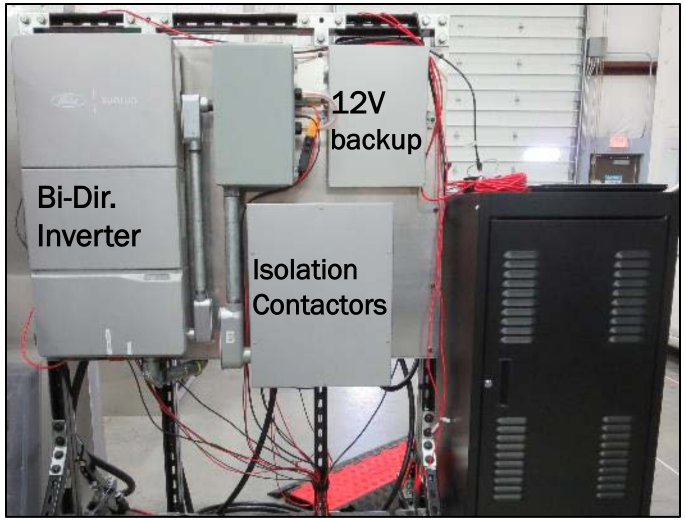
Bi-directional Charging (V2X) Cybersecurity

- Communications security: energy management, EV to EVSE comm., internal systems controls, remote management and control
- Grid security, safety, operational performance

• Three systems installed in EVIL laboratory
- V2G, V2H; Light duty, medium duty; CCS-1, CHAdeMO

Vehicle to Grid (V2G)

Vehicle to Home/Load (V2H)



Idaho National Laboratory

CyberPUNC – Review & Next Steps

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U.S. Department of Energy

Review

- PKI testing environment creation has progressed and is aligned with industry needs and developments
- Completed first automated testing of many EV-EVSE device interactions
- Completed EVSE security control catalog for cybersecurity risk assessments
- Mitigation tools and solutions developed and demonstrated
  - *Cerberus*: Detection, Response, and Recovery
  - *AcCCS:* EV and EVSE communication investigation and emulation
- Continued success and growth of *CyberAUTO* Challenge since 2018
- EVSE upstream and backend system analysis

Next steps

- PKI emulation will continue to leverage EVerest code as appropriate and begin cyber scenario testing
- Add metrics for assessing the robustness of PKI-based security for EVCI
- Identify and validate EVSE risk assessment with industry stakeholder
- Bi-directional charging (V2X) cybersecurity and cyber-physical security

Thank You!

EVs@Scale

U.S. Department of Energy

Back-up slides

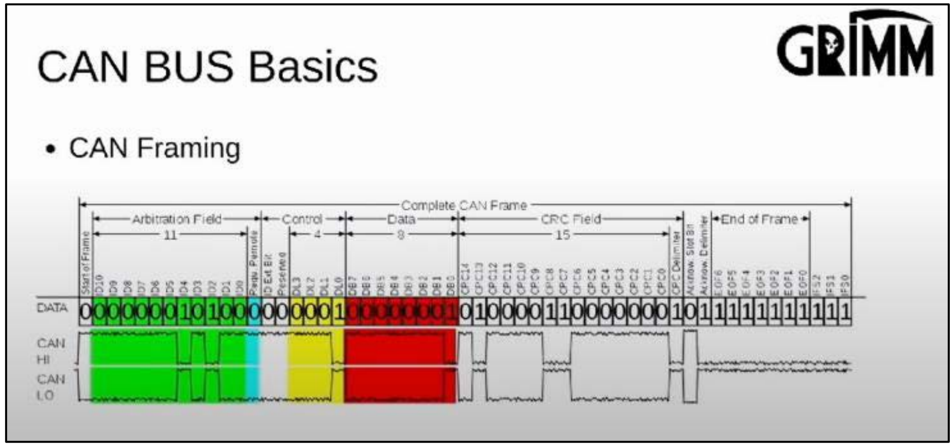
CyberPUNC – Cyber Mitigation Tools & Solutions

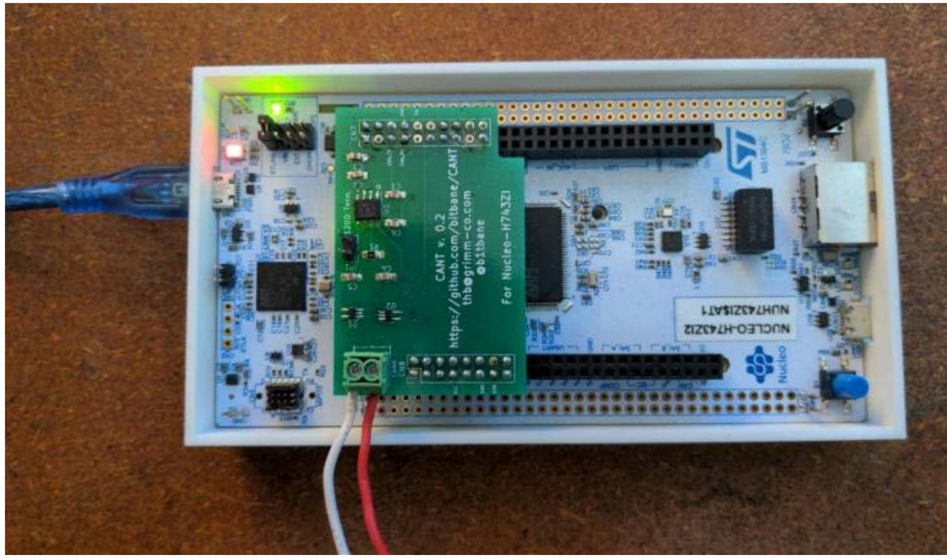
CANT Module: Security for CAN Communications

- Developed by *GRIMM*
- Provides ability to alter CAN in layers 1/2
  - Ability to force CAN message bit(s) to 0 or 1 midflight

- Open-source information
  - //github.com/bitbane/CANT

- Modified by INL for use & integration into *Cerberus* for CAN controls communication security (CANopen, CHAdeMO, etc.)
  - Detection of anomaly or exploit to CAN messages
  - Response executed to block anomalous messages
  - Recovery features focus on resilient, continued operation of the charging infrastructure





EVs @ Scale

U.S. Department of Energy

Securing Electric Vehicle Charging Infrastructure Using Zero Trust and Post-Quantum Cryptography

Thomas E. Carroll, PNNL

Feb 28th, 2024

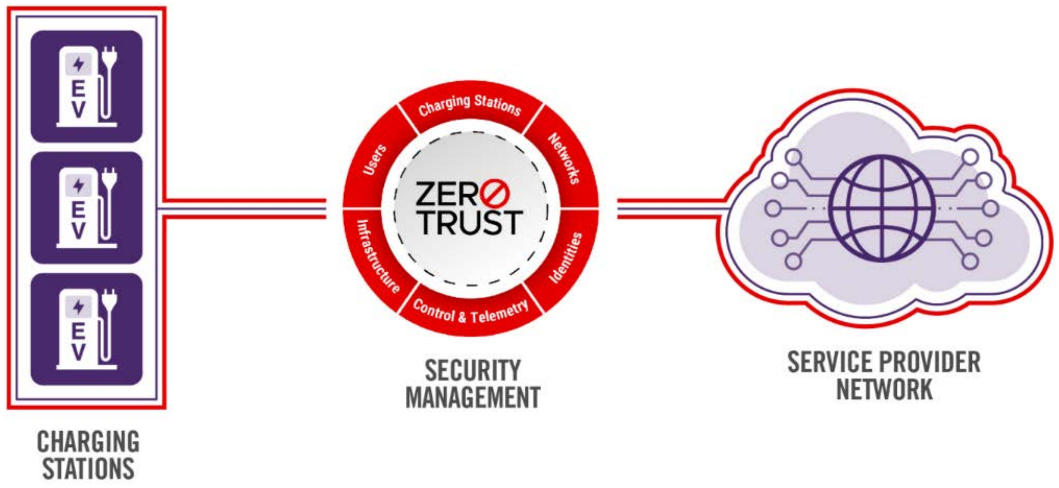
Why discuss Zero Trust and Post-Quantum Cryptography together?

Zero Trust will likely adopt PQC quickly.

Zero Trust is a means to accelerate PQC adoption.

Cyber-Physical Security (CPS): Zero Trust Overview

Objective: Develop, demonstrate, and evaluate Zero Trust approaches to bolster EV Infrastructure security by reducing the attack surface.



Outcomes:

– **Design architecture** for incremental deployment and infrastructure integration

– **Prototype architecture** in a testbed

– **Characterize and assess** prototypes to address vulnerabilities

– **Develop blueprint**

Industry Partners:

PATERO

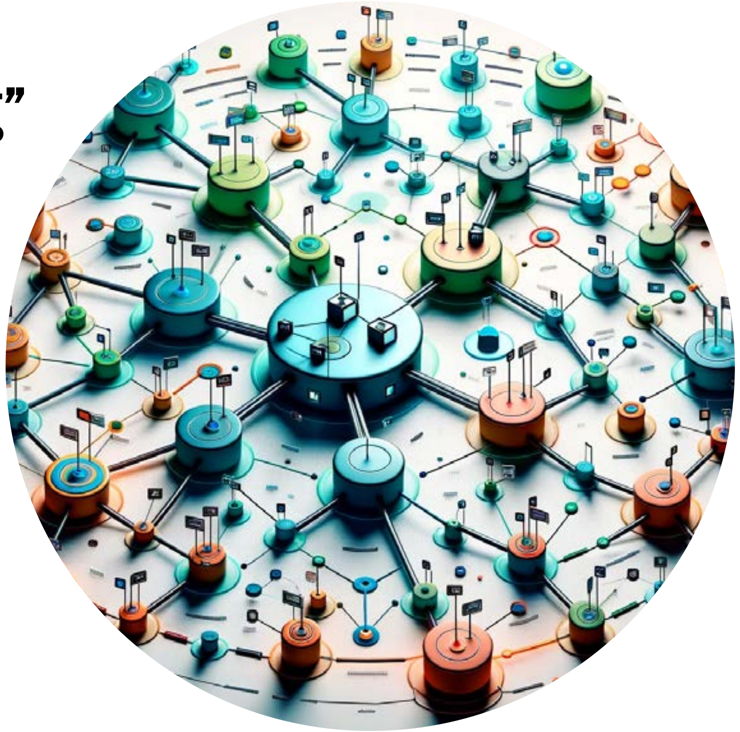
CISCO

NETFOUNDRY™

What is Zero Trust?

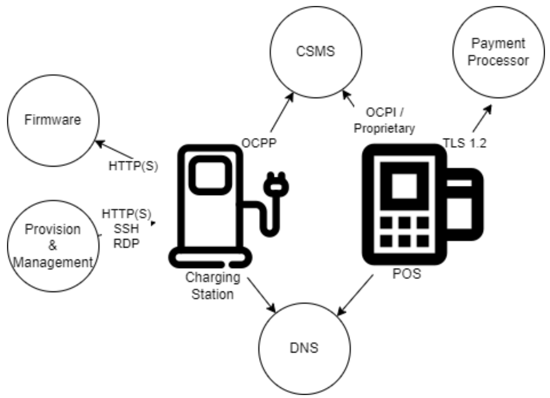
Zero Trust architecture implements network security approaches following the tenet "Never trust, verify everything"

- Zero Trust's goal is to reduce implicit trust
  - Removal of implicit trust limits compromise scope
  - Increases adversary cost to exploit the system
- Operationally Zero Trust:
  - Independently considers each access request
  - Uses policy, identity and environment in each access request decision
  - Ensures adherence to "least privilege" and "separation of duties" principles



Implicit trust – a vulnerability resulting from limited verification | Least privilege – authorization level | Separation of duties – privileges limited based on role

Zero Trust Project Approach



Define Requirements & Security Objectives

Design Architecture

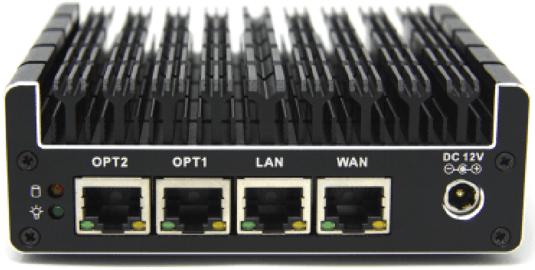
Prototype

Evaluate & Analysis

Focus on Charging Station Operator (CSO)

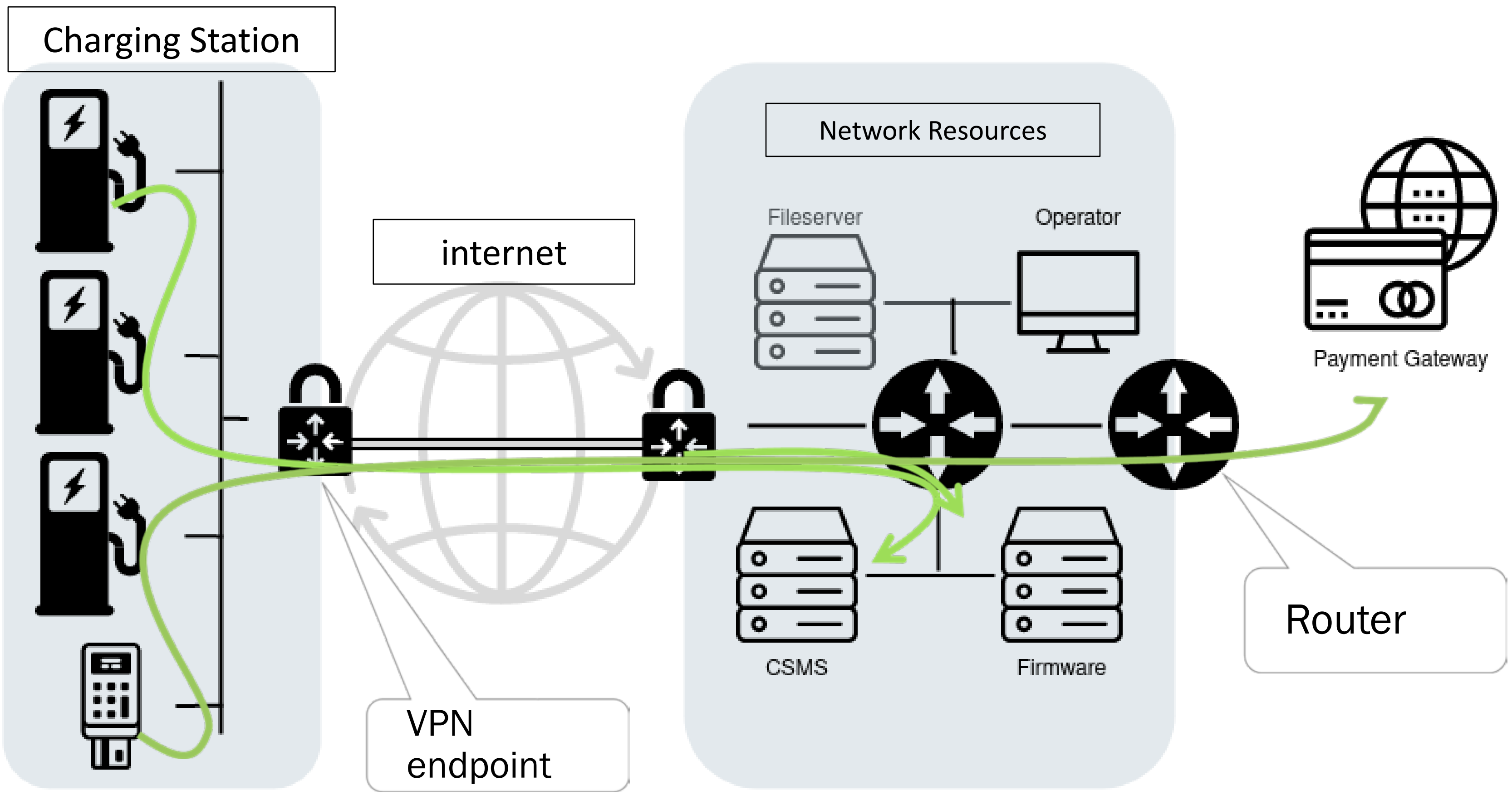
Patero QoR

Security Service Edge Gateway



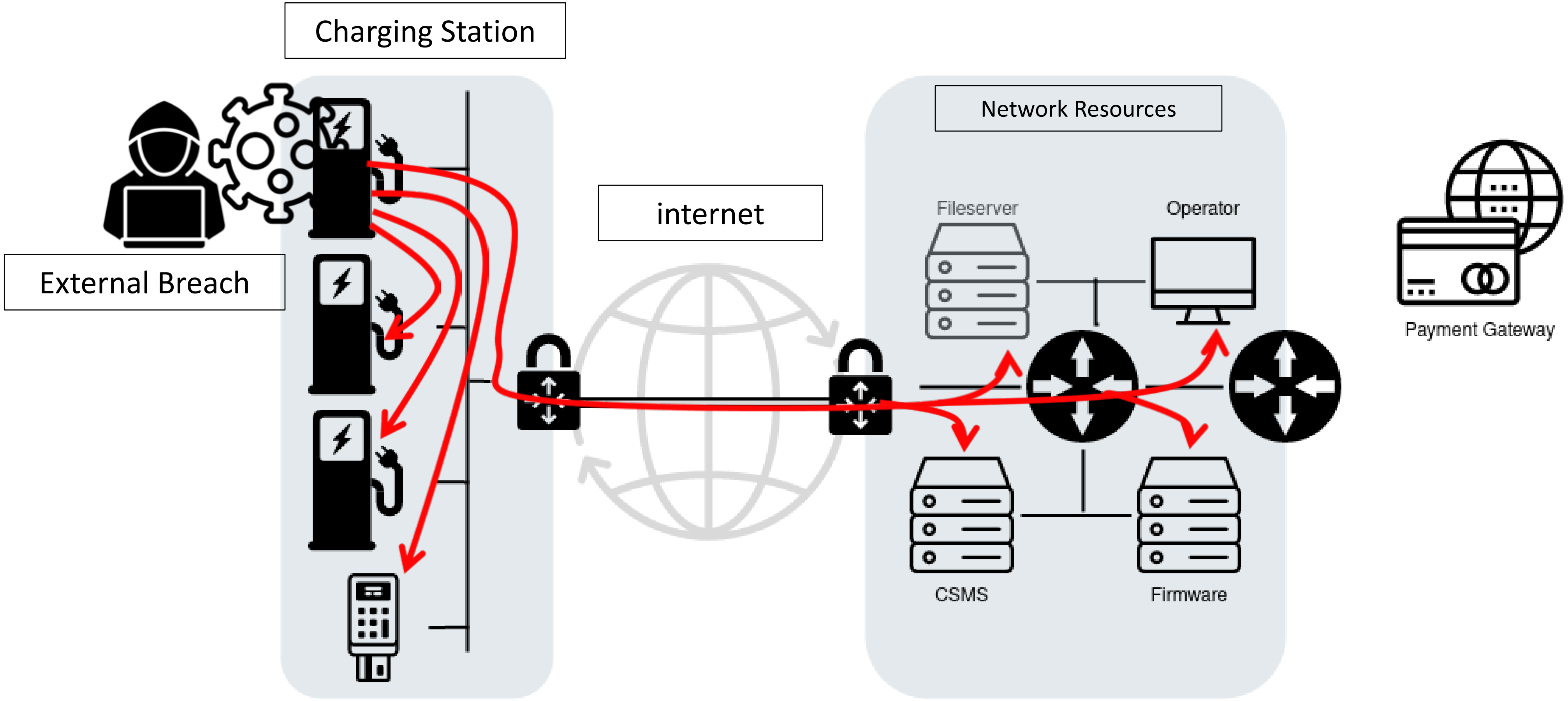
Charging Station Operator – entity responsible for the operation and maintenance of chargers and supporting equipment and facilities.

Conventional EV Service Provider + WAN

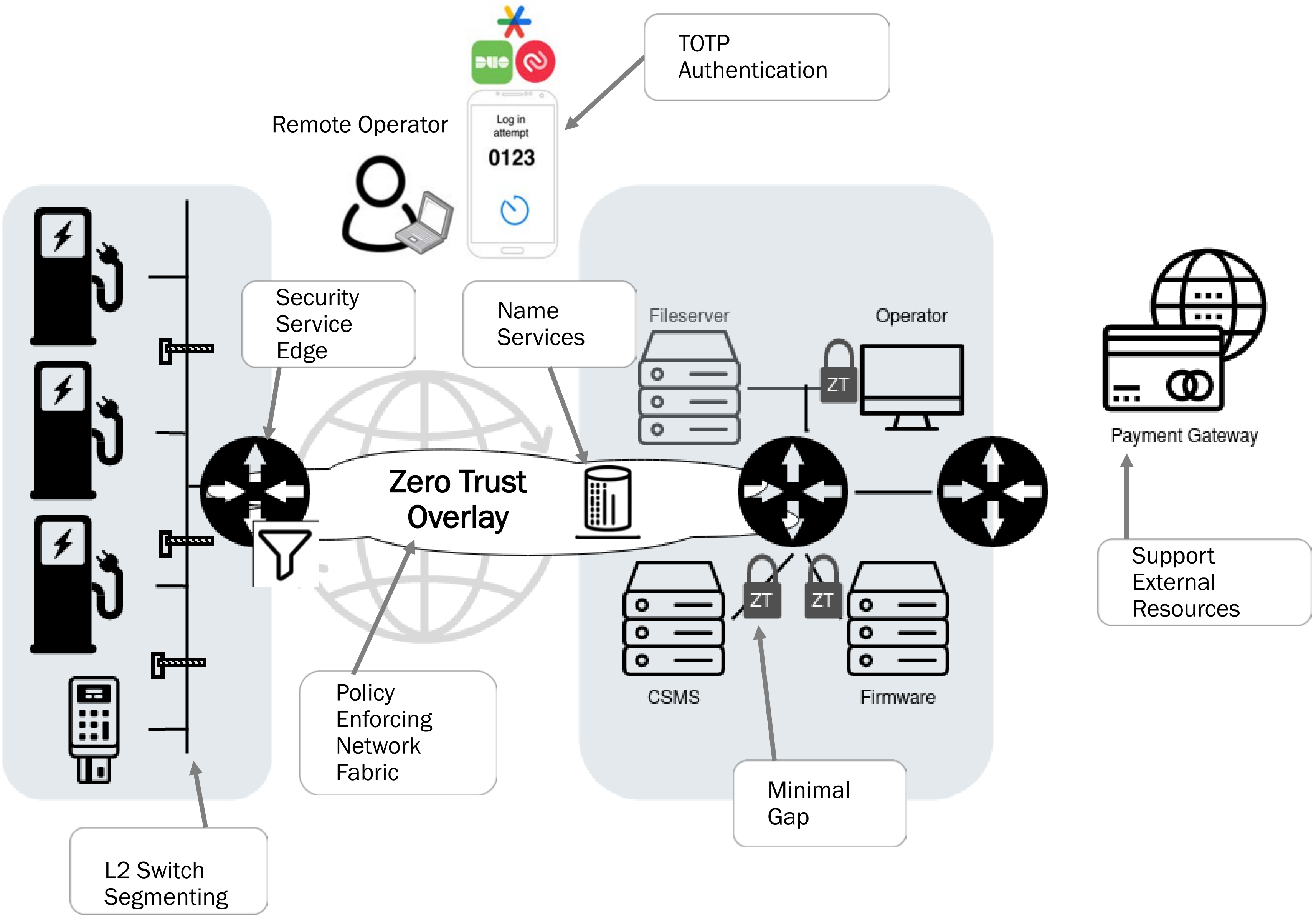


CSMS – Charging Station Management System - software for remote and real time charge point operation control (e.g., OCPP 2.0.1).

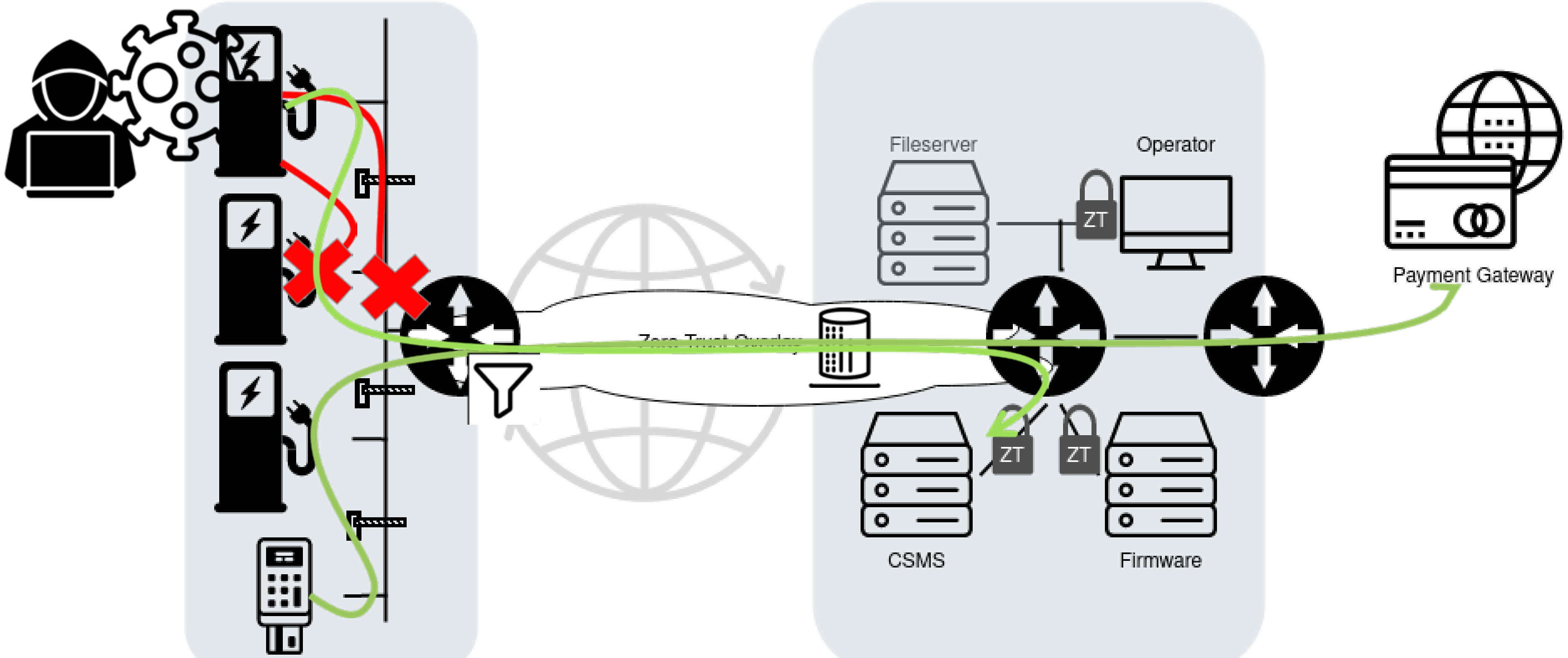
Breach to a Conventional EV Service Provider + WAN



Architect: Zero Trust Architecture for EV Service Provider

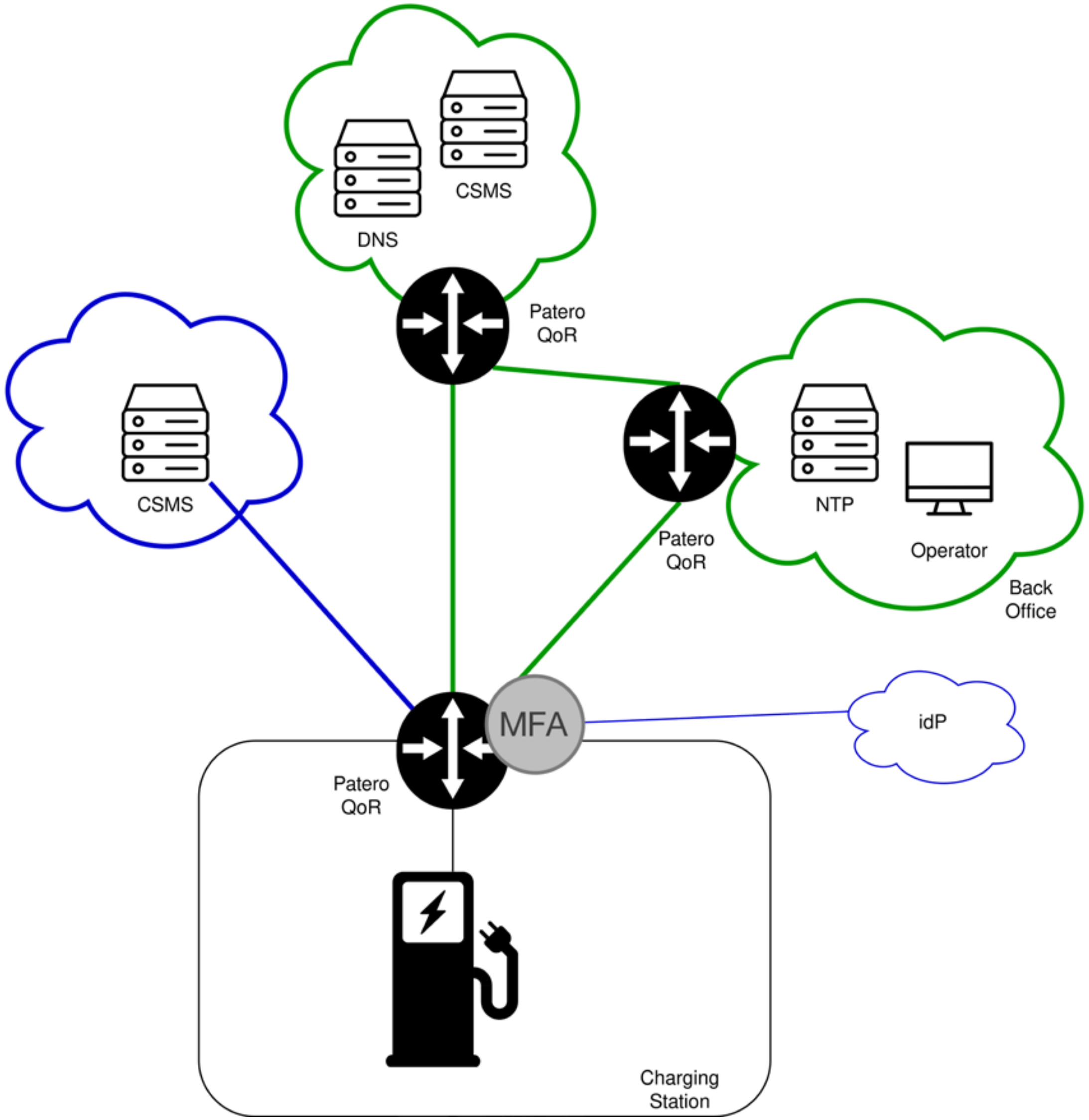


Zero Trust Architecture to Prevent Breach to a Conventional EV Service Provider



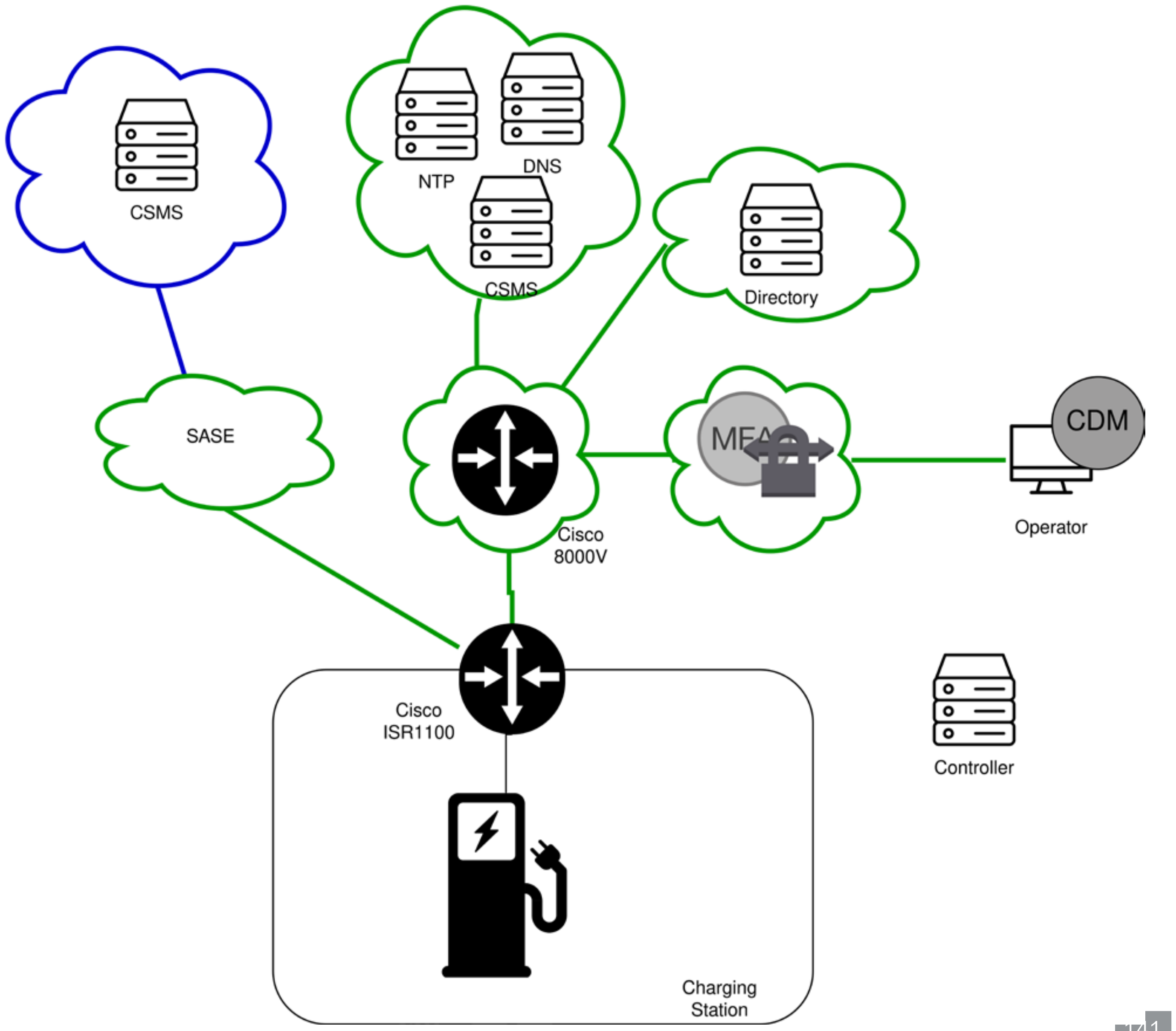
Proof-of-Concept #1

- Edge routers, running Patero QoR, provide the overlay network fabric
- Edge routers cryptographically secure the communications
  - Session keys are generated using PQ/T hybrid key exchange
- Those resources behind the edge routers can communicate with each other
  - Resources were unreachable from Internet
- Routers admit traffic based on routing- and protocol-based policies
- MFA gateway authenticates operator when requesting access to device management interface

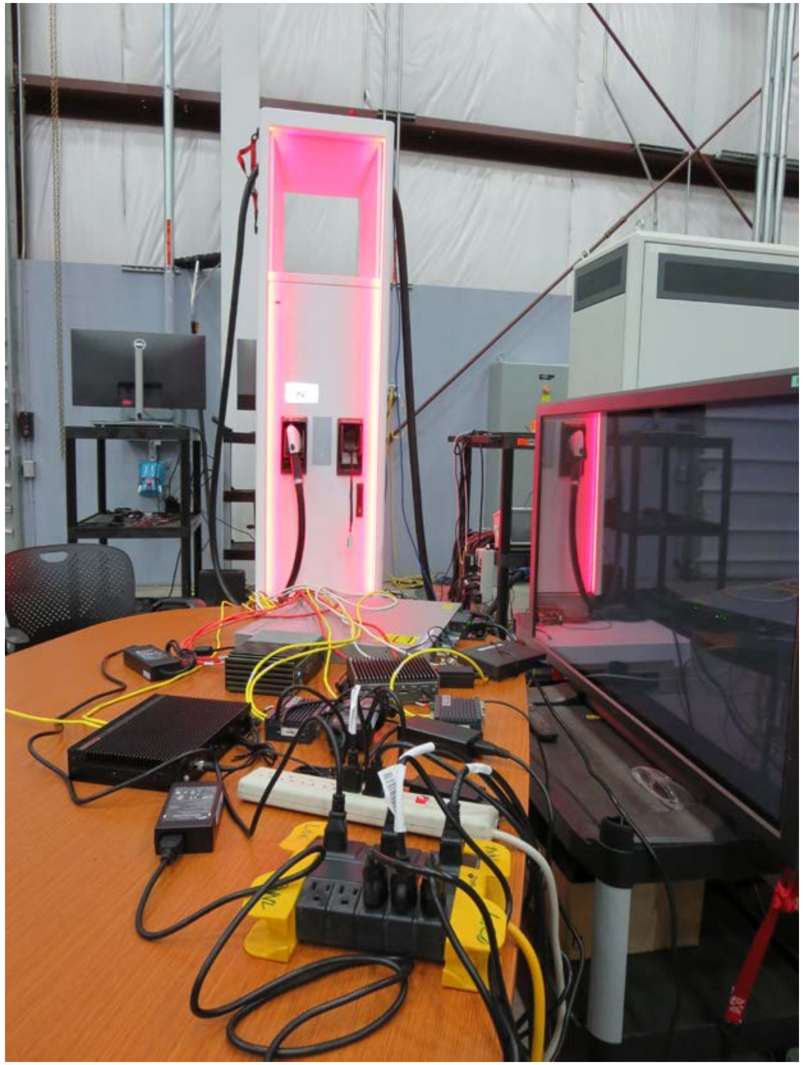


Proof-of-Concept #2

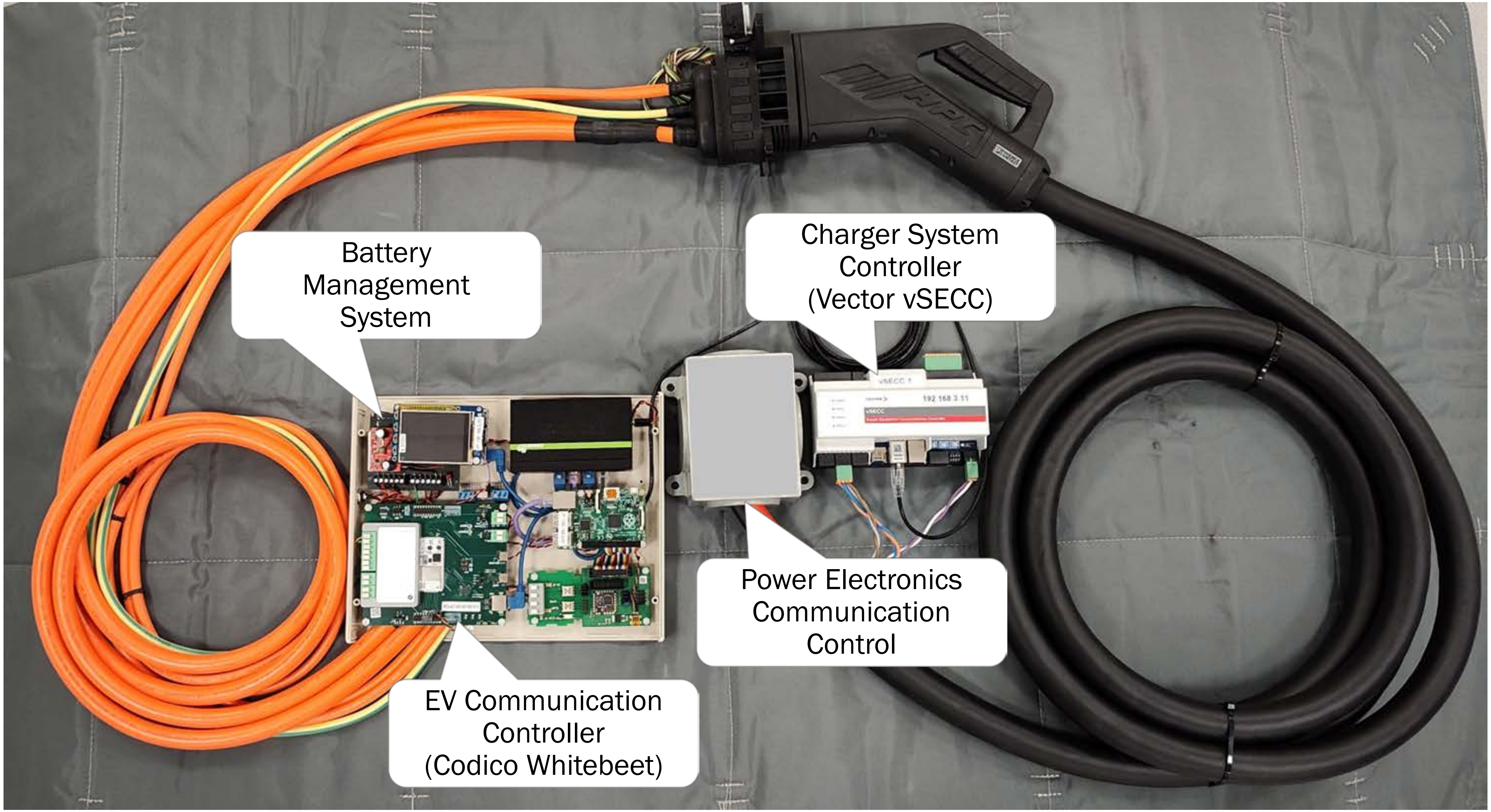
- Cisco SD-WAN provides the network overlay implementing network fabric
- Services and devices inaccessible from the public internet
- Furthermore, resources further segmented cloud-based controls
- Individual operators connect directly
- Internet-based resources are accessed through a cloud security service
  - Cisco Secure-Internet Gateway (SIG) provides means of matching on authorized applications while blocking those that have not been specified from propagating past the Cisco network



Patero, INL, and PNNL Testing at INL's EVIL

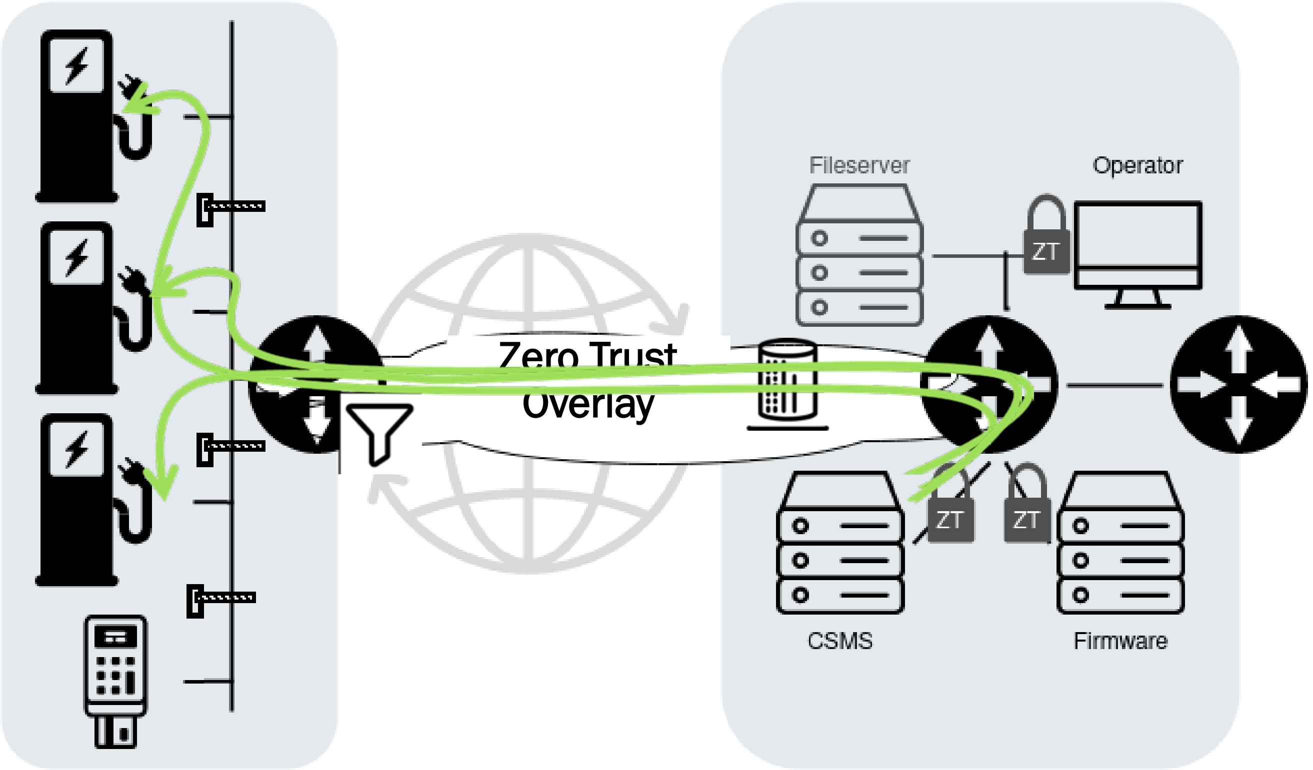


DC Fast Charge Emulator



OCPP Security Service

- Protocol-agnostic ZT effectively blocks 'non-authorized' network paths to the charging infrastructure
- Attackers will evolve to employ methods that use legitimate channels
  - E.g,, INL's inattentive operator model
- OCPP Security Service addresses this gap by strengthening the security around OCPP management, monitoring, and control functions
- Isolate the CSO from the CNP



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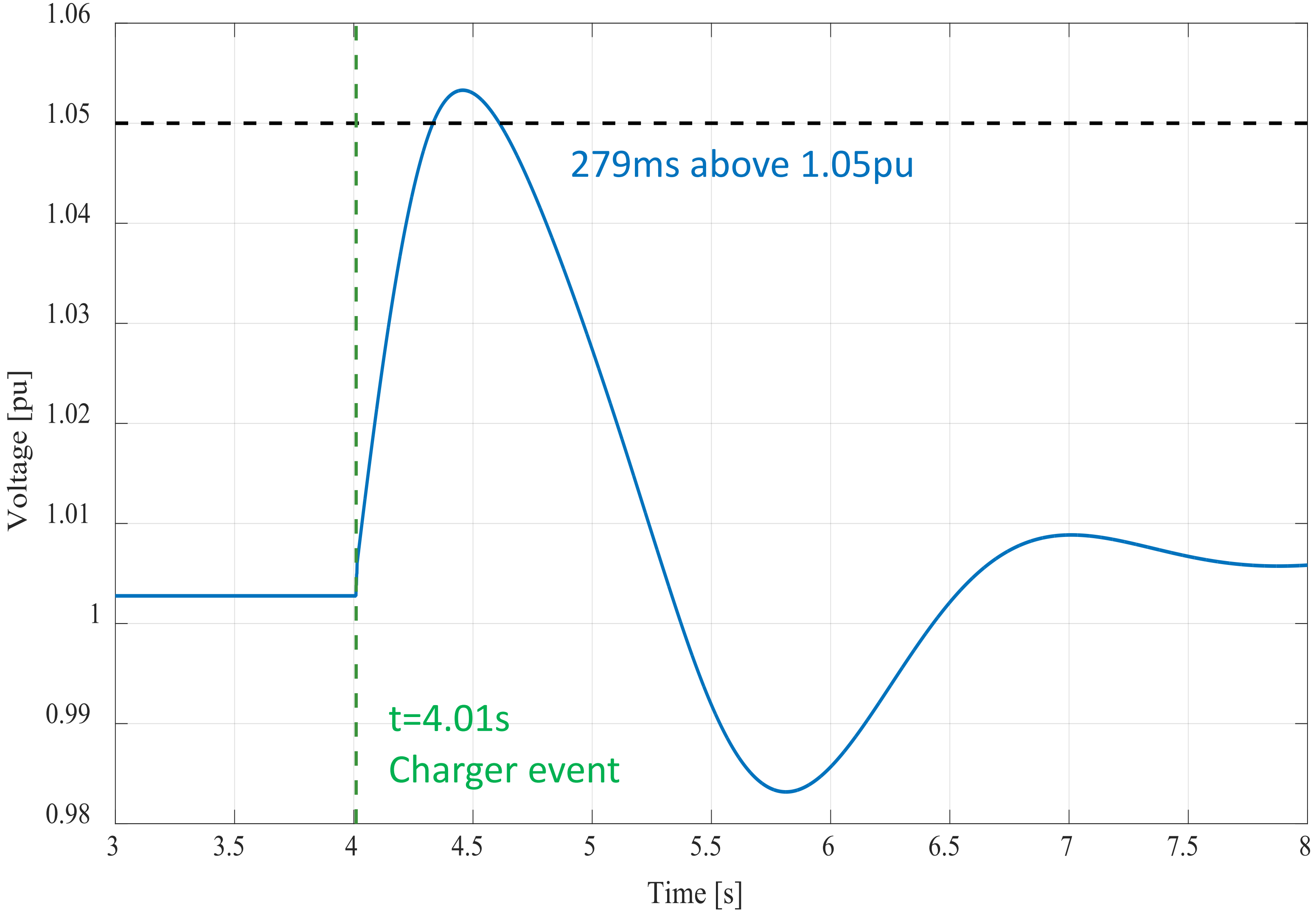
- Further isolates the CSO from the CNP



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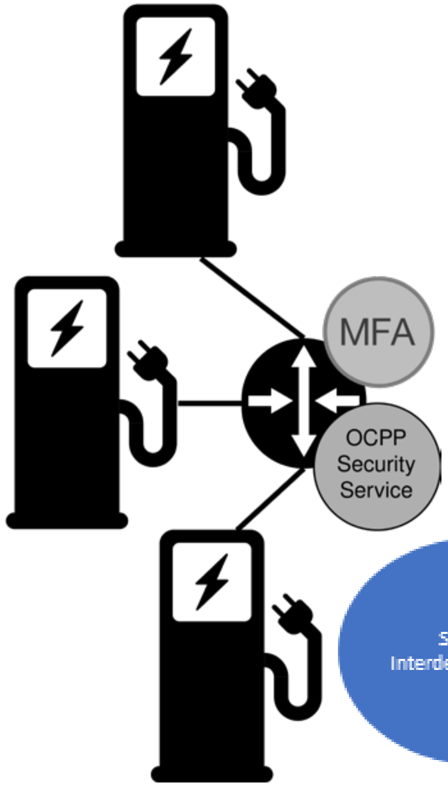

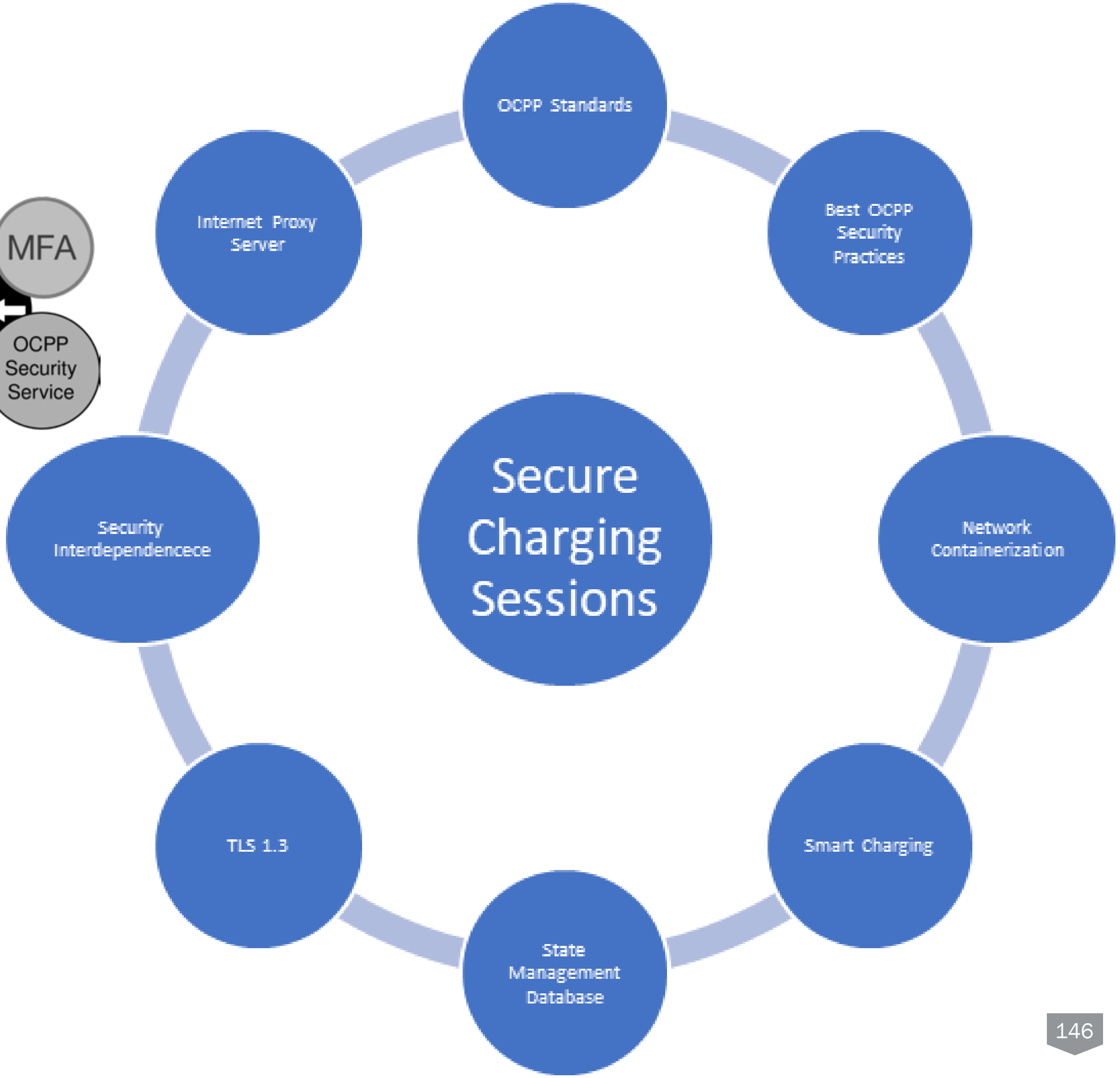

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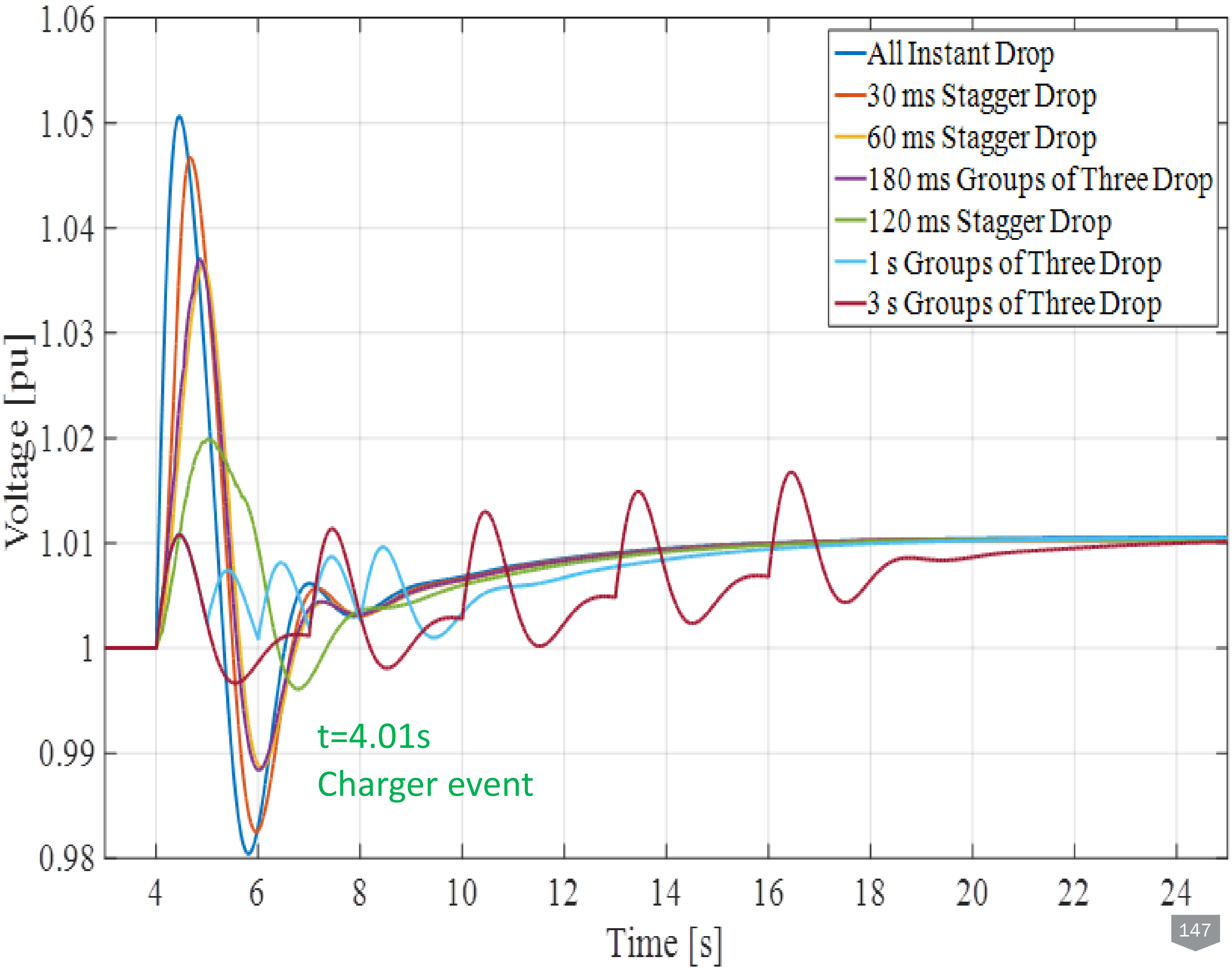
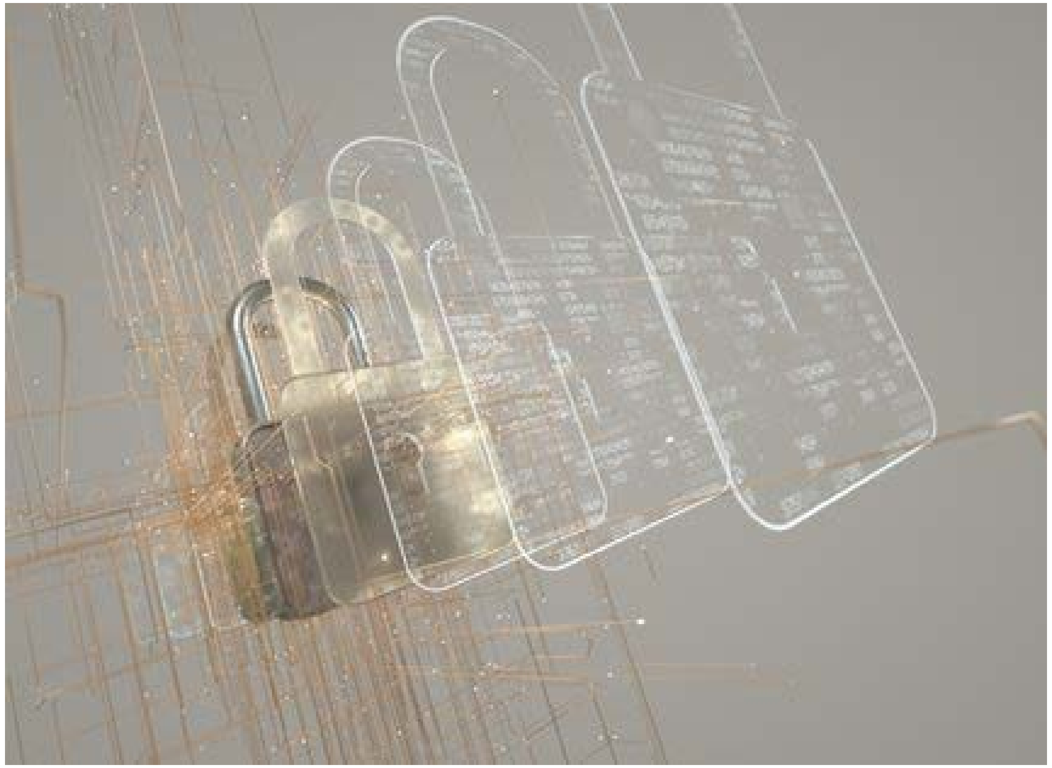


Post Quantum Cryptography (PQC) Overview

Objective: Study the impact of PQC and develop guidance for an orderly transition



Motivation:

- A Cryptanalytically-Relevant Quantum Computer (CRQC) will defeat traditional public-key cryptography in tens to hundreds of hours
- PQC transition is non-trivial

Outcomes:

- Identify traditional public-key cryptography applications
- Assess PQC impacts with a test-and-measure approach
- Identify challenges
- Develop guidance for an orderly PQC transition

Background

- Quantum bit (qu
- A QRQC will effi ... change schemes
  → Trust, commun
- PQC are cryptosyst ... omputers
  - PQC algorithms run
  - Different underlying
- NIST is expected
  - Kyber* (KEM, FIP ... d FALCON (DSA)
  - Expecting to selec
- Why start now?
  - The time for quan
  - Crypto transitions
  - Real-world implementation challenges
  - Global coordination

TIMEFRAME	WHAT ONE MAY EXPECT BASED ON THE EXPERTS' OPINIONS
NEXT 5 YEARS	Most experts (27/40) judged that the threat to current public-key cryptosystems in the next 5 years is "<1% likely". About a quarter of them (9/40) judged it relatively unlikely ("<5% likely"). The rest selected "<30%" (3/40) or "about 50%" (1/40) likely. Overall, *there seems to be a non-negligible chance of an impactful surprise within what would certainly be considered a very short-term future.*
NEXT 10 YEARS	Moving from the previous timeframe to this timeframe corresponds to the largest average sentiment shift (see Figure 7). Within this timeframe, more than half of the respondents (20/40) judged the event is more than 5% likely, and almost a quarter (9/40) felt it was "about 50%" or ">70%" likely, suggesting *there is a significant chance that the quantum threat becomes concrete in this timeframe.*
NEXT 15 YEARS	More than half (22/40) of the respondents indicated "about 50%" likely or more likely, among whom 11 indicated a ">70%" likelihood or higher. *This time frame appears to be a tipping point, as the number of respondents estimating a likelihood of "about 50%" or larger become the majority.*
NEXT 20 YEARS	More than 90% (37/40) of respondents indicated "about 50%" or more likely, with 10/40 pointing to ">95%" or ">99%" likely. This indicates *there is a significant tendency toward viewing the realization of the quantum threat as substantially more likely than not within this timeframe.*
NEXT 30 YEARS	Thirty-five experts out of 40 indicated that the quantum threat has a likelihood of 70% or more this far into the future, with more than a quarter of the experts (11/40) indicating a likelihood greater than 99%. Thus, *there appears to be a relatively low expectation of any fundamental show-stoppers or other reasons that a cryptographically-relevant quantum computer would not be realized in the long run.*

Mosca, Michelle and Marco Piana (2022) "*Quantum Threat Timeline Report 2022*"

Challenges to the PQC Transition

- Key, Signature, and Ciphertext Sizes
- Compute & Memory
- Interoperability
- Upgradability
- Ongoing standardization
- Certificate management practices
- Personnel

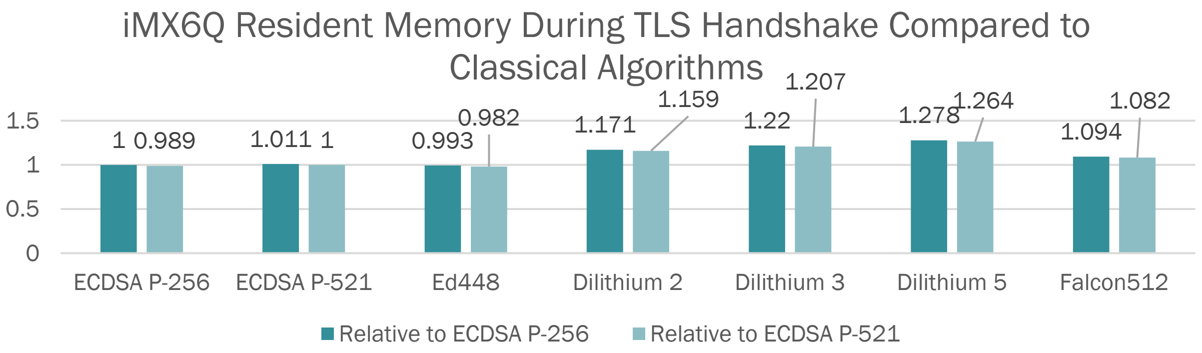
Key, Signature and Ciphertext Sizes

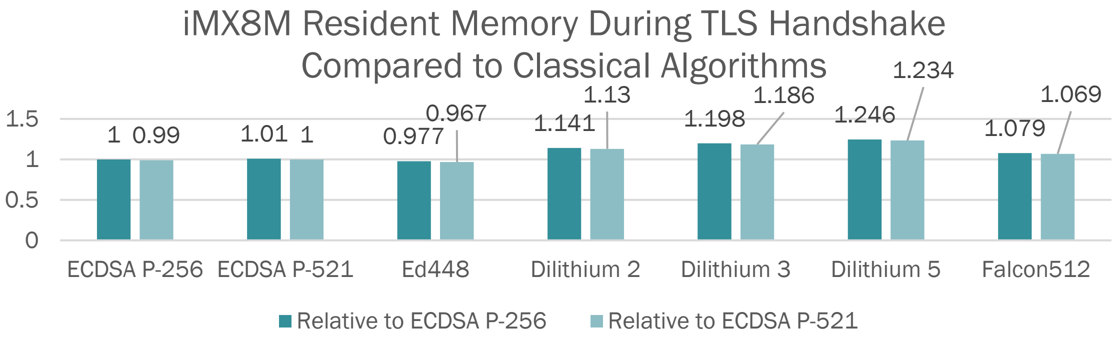
		Size (in bytes)		
		Public Key	Private Key	Signature
Traditional	P-256	65	32	65
	P-521	133	66	133
	Ed448	57	57	114
PQC	Dilithium2	1312	2528	2410
	Dilithium3	1952	4000	3293
	Dilithium5	2592	4864	4595
	FALCON512	800	1632	768
	FALCON1024	2592	4864	4595

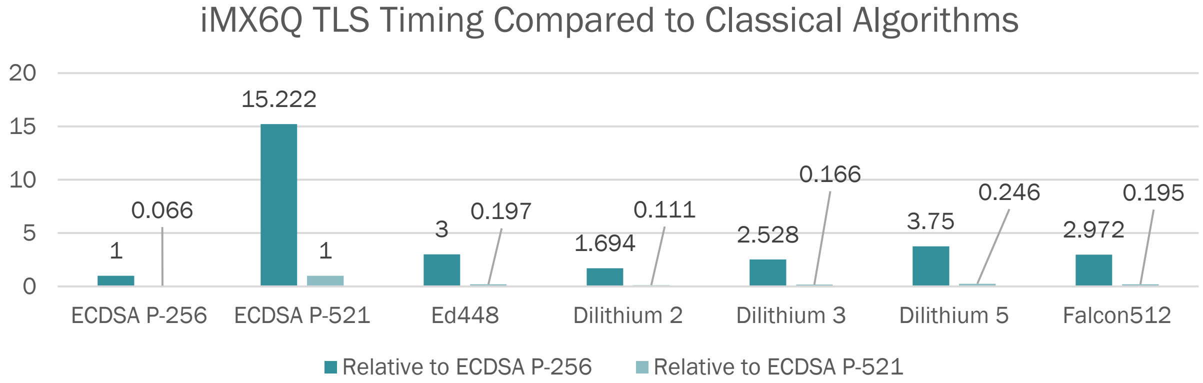
		Size (in bytes)			
		Leaf Cert	Leaf + 1ICA	Leaf + 2ICA	Cert Stat
Traditional	P-256	558	1085	1618	882
	P-521	692	1354	2023	1086
	Ed448	568	1106	1650	931
PQC	Dilithium2	4159	8288	12423	6838
	Dilithium3	5672	11314	16962	9224
	Dilithium5	7614	15198	22788	12468
	FALCON512	1960	3893	5831	2870
	FALCON1024	3475	6919	10368	4997

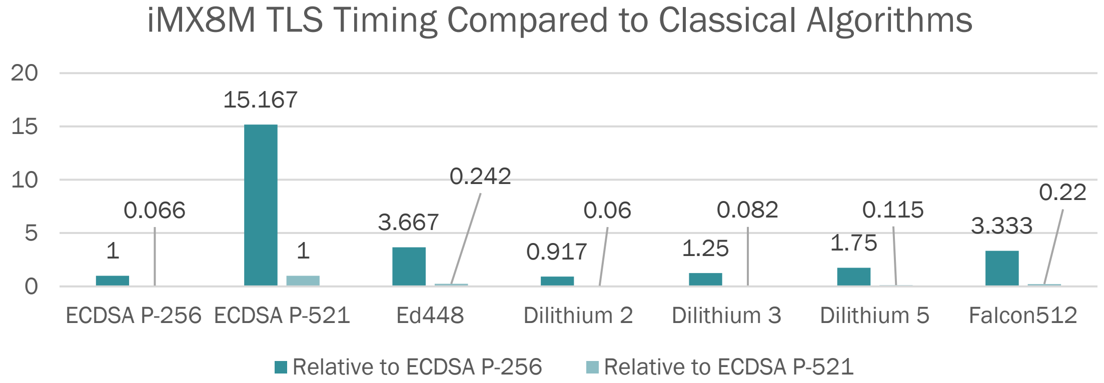
- Signatures are 11.8x-70.7x the size of P-256, 5.8x-34.5x compared to P-521.
- Certificates are 3.3x-14.1x the size of P-256; 2.6x-11.5x compared to P-521.
- Certificate and key stores must be sized accordingly

Compute & Memory



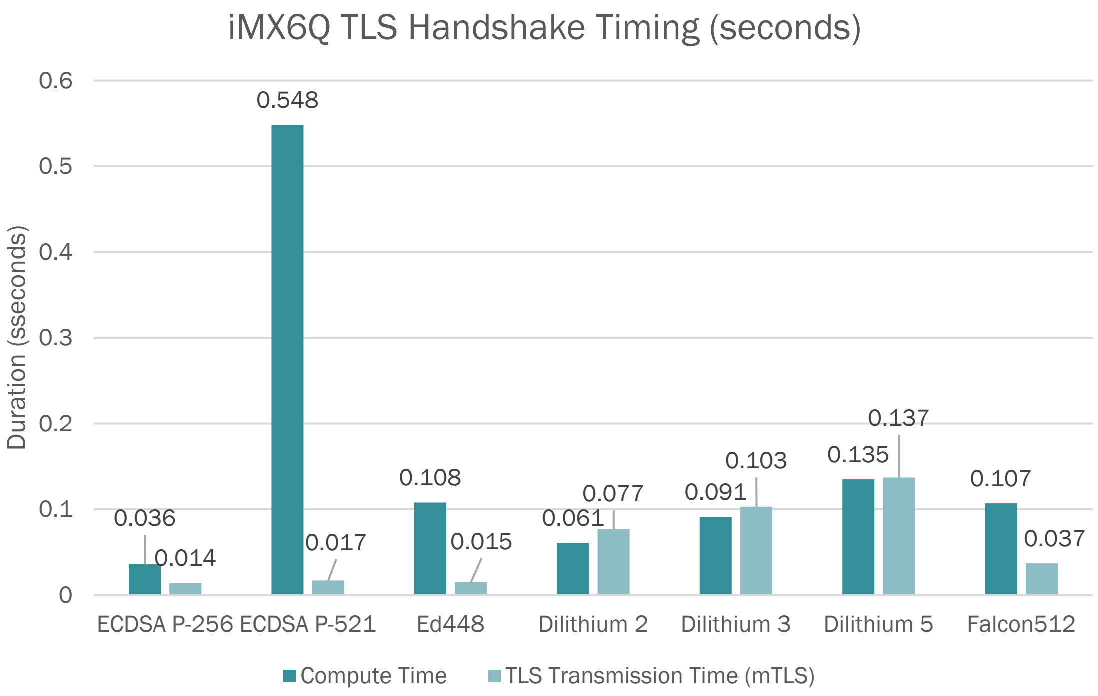


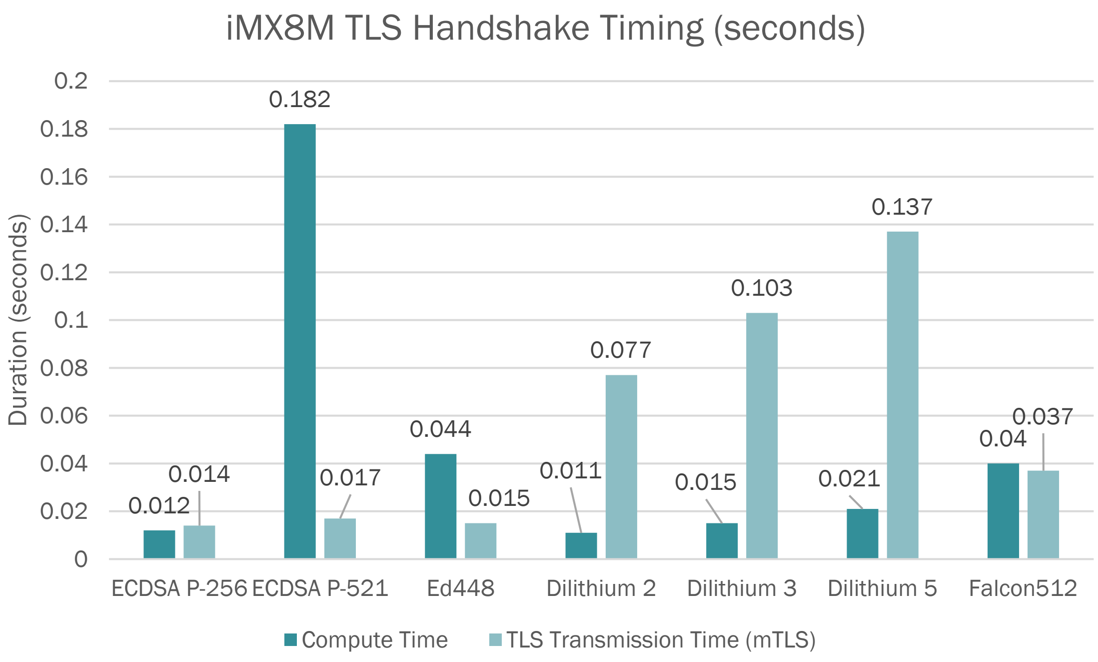




- PQC algorithms use 0.97x-1.3x the memory than P-256 and P-521 (between ~850 and 2500 kB more than P-256).
- PQC algorithms take 0.2x-3.75x the time than P-256 but all are faster than P-521 (between 0.025 and 0.1 seconds longer than P-256).
- PQC algorithms compute time & memory working set are larger, but not concerning for small EVCI devices.
- For TLS 1.3, cost is paid at connection setup. Once established, low-cost symmetric cryptography is activated.

Compute & Memory





- **Transmission time can be more than 6x (~0.07 seconds) longer than compute time.**
- **Larger data is not concerning for PLC, LTE, or Ethernet, but may delay connection setup, increase messaging latency.**

AuthorizationReq(PQCCertChain)

Interoperability: ISO 15118

```
<xs:schema targetNamespace="urn:iso:std:iso:15118:-20:CommonMessages">
  ...
<xs:simpleType name="certificateType">
  <xs:restriction base="xs:base64Binary">
    <xs:maxLength value="1600"/>
  </xs:restriction base="xs:base64Binary">
</xs:simpleType>
  ...
```

- The 15118-20 certificateType is too small (1600 bytes) to hold PQC certificates
- Sending the large certificates will cause the session to be terminated

Interoperability: ISO 15118

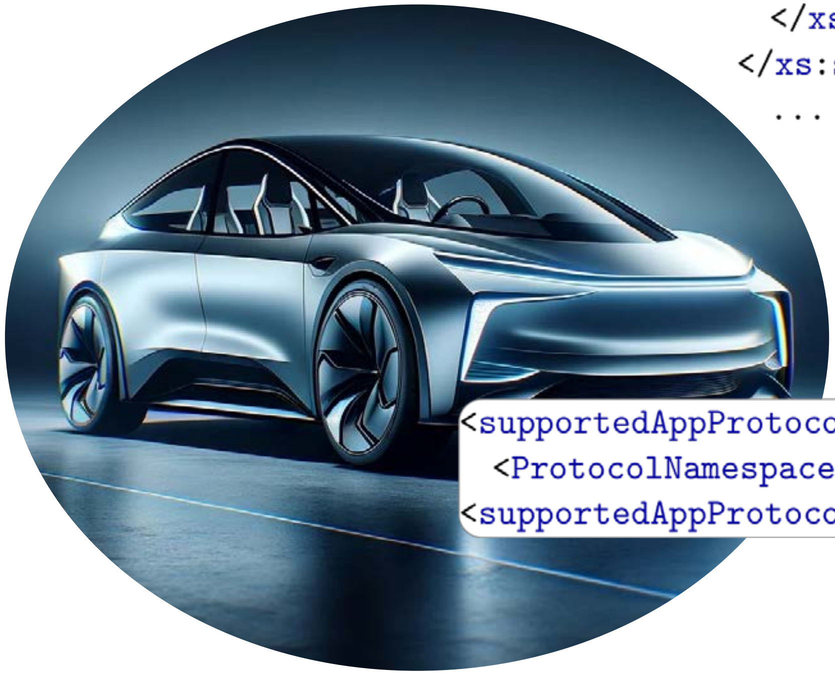

```
<supportedAppProtocolReq>
  <ProtocolNamespace>urn:crypto:post-quantum:protocol#iso:std:iso:15118:-20:DC</ProtocolNamespace>
  <ProtocolNamespace>urn:iso:std:iso:15118:-20:DC</ProtocolNamespace>
  <ProtocolNamespace>urn:iso:15118:2:2013:MsgDef</ProtocolNamespace>
<supportedAppProtocolReq>
```


Interoperability: ISO 15118


```xml
<supportedAppProtocolRes>
  <ProtocolNamespace>urn:iso:std:iso:15118:-20:DC</ProtocolNamespace>
<supportedAppProtocolReq>
```


Interoperability: ISO 15118

```xml
<xs:schema targetNamespace="urn:iso:std:iso:15118:-20:CommonMessages">
  ...
<xs:simpleType name="certificateType">
  <xs:restriction base="xs:base64Binary">
    <xs:maxLength value="12288"/>
  </xs:restriction base="xs:base64Binary">
</xs:simpleType>
  ...
```



```xml
<supportedAppProtocolRes>
  <ProtocolNamespace>urn:crypto:post-quantum:protocol#iso:std:iso:15118:-20:DC</ProtocolNamespace>
<supportedAppProtocolReq>
```

- EVCC can request to use PQC with **supportedAppProtocolReq**
- SECC selects the namespace by reporting it in **supportedAppProtocolRes**

Conclusion and Next Steps

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Review

- Evaluated two proof-of-concepts, each exhibiting different design concepts
- Released inventory of traditional public-key cryptography applications in EV charging
- Completed identifying EVCI-specific challenges to PQC adoption
- Directing two university design teams working on EV-EVSE ZT
- Patero and industry partner relationships are deepening with each engagement

Next steps

- Release EVCI-specific challenges report
- Report summarizing ZT proof-of-concepts
- Develop PQC transition guidance for EVCI community
- Engage and build relationships with stakeholders – Identify field deployment partners

Thank You!

Join us for the

Cyber-Physical Security Deep Dive on April 9th

Thomas.Carroll@pnnl.gov

EVs @ Scale

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Cybersecurity Panel Session: How to "Move the Needle" for EV Charging Infra. Cybersecurity

Feb. 29, 2024

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

INL/MIS-24-76520

How to "Move the Needle" for EV Charging Infrastructure Cybersecurity

Panelists:

- **Brendan Harris**
  - Technology Manager for Cybersecurity
    - *Supporting from the Volpe National Transportation Systems Center*
  - Joint Office of Energy and Transportation
- **Michael Slowinske**
  - Engineering Director
  - UL Solutions
- **Jordan Smith**
  - Grid Technology Innovation
  - Southern California Edison

Cybersecurity Panel Discussion

- Focus: how best for industry to improve cybersecurity & cyber-physical security for all system across the Electrified Transportation Ecosystem.
  - There will be many elements/systems from many manufacturers integrated to achieve a successful EV ecosystem.
  - What steps can be taken to ensure a safe and robust transition?

Joint Office of
Energy and
Transportation

Joint Office Cybersecurity Activities

Brendan Harris

2.29.2024

driveelectric.gov

Mission and Vision

JOINT OFFICE OF
Energy and Transportation

Mission

To accelerate an electrified transportation system that is affordable, convenient, equitable, reliable, and safe.

Vision

A future where everyone can ~~ride and drive~~ Hack? electric.

What makes us different?

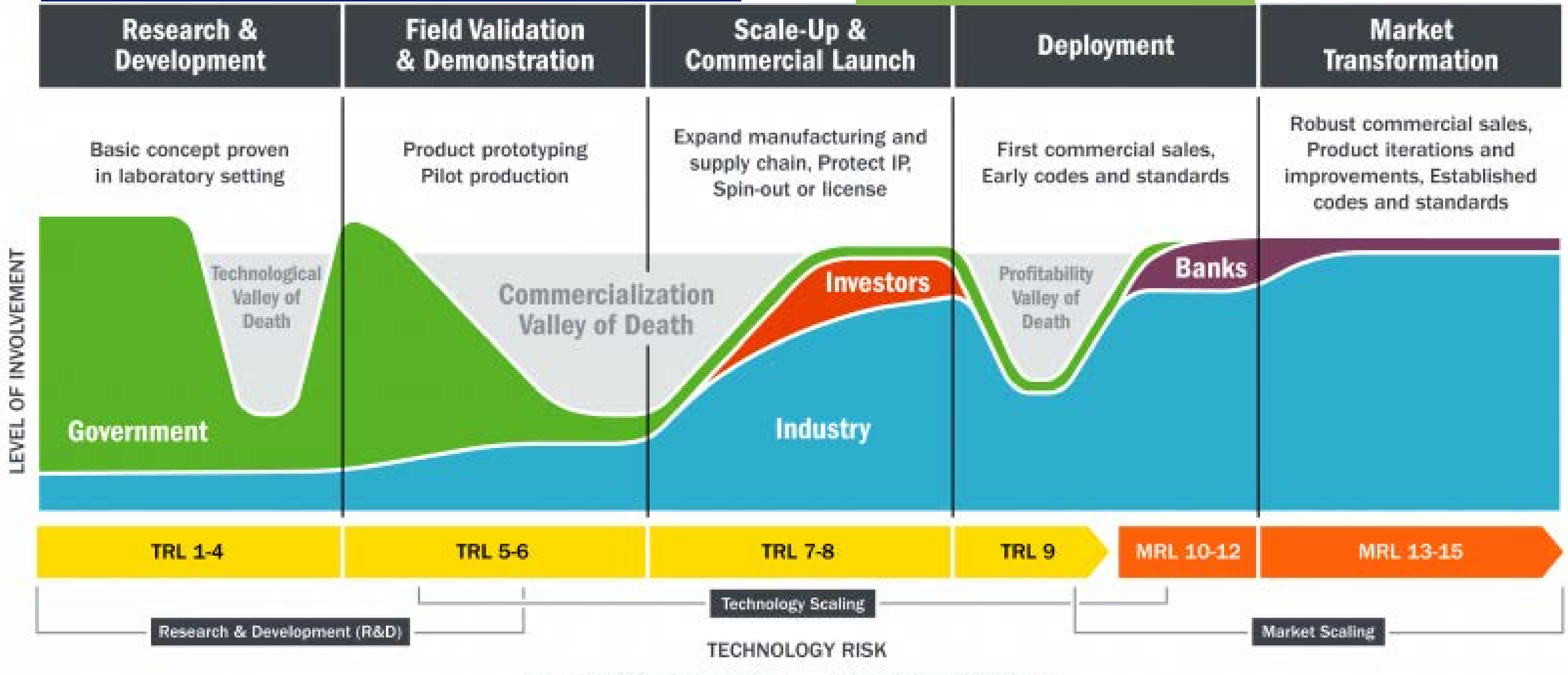
- Strategy: Waterfall
- Timeline: Years
- Failure: Informative
- Success: Incremental

- Strategy: Agile
- Timeline: Months
- Failure: Unacceptable
- Success: Transformative

Joint Office of Energy and Transportation

Traditional Fed RDT&E

Us



Guiding Principles for our Cyber Activities

- Be the center of gravity for coordinating federal EV charging cybersecurity efforts
- Collaborate proactively with builders, deployers, and maintainers
- Match the urgency and agility we expect from industry
- Execute projects quickly with results that are useful immediately
- **Bottom Line** bring friends to achieve impactful results with aggressive timelines

Recent and Ongoing Efforts

- **Guide** grant recipients via cybersecurity resources relevant to our grant programs
  - Sample procurement language
  - EVSE incident reporting framework

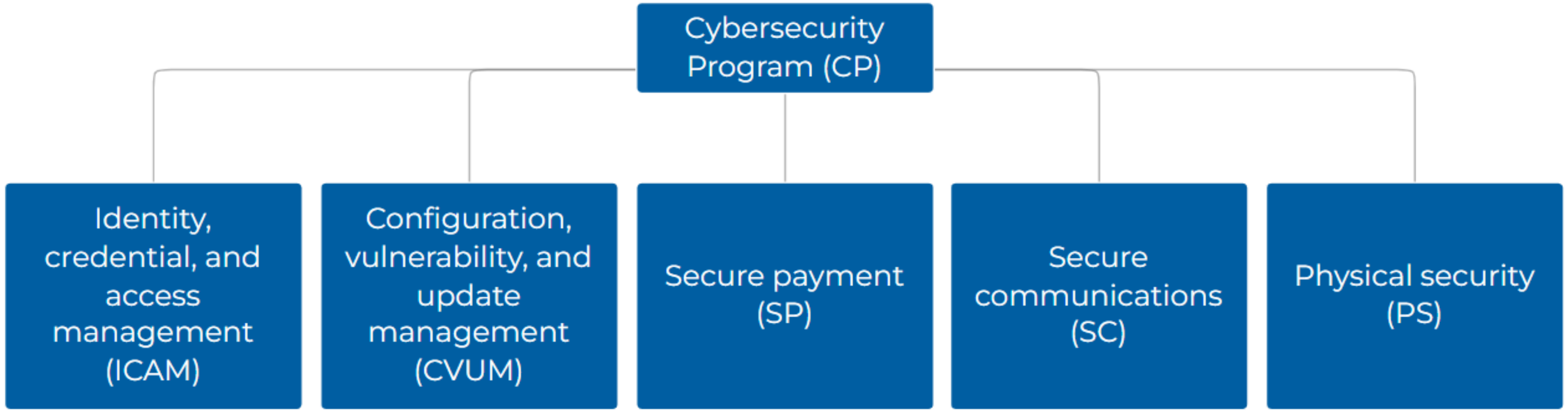
- **Analyze** complex multi-stakeholder barriers to aid industry decision-making
  - Theory and practice of the Plug-and-Charge Public Key Infrastructure
  - Field Testing informed best practices

- **Coordinate** product security experts from all parts of the EV charging community
  - Charging Ecosystem Security Working Group

Guide: Sample Procurement Language for NEVI Grants

Performer: PNNL

- States are the early implementers of federal EV charging investments
- Equip states with unified set of sample language to meet the NEVI minimum standards
- driveelectric.gov/cybersecurity-clauses

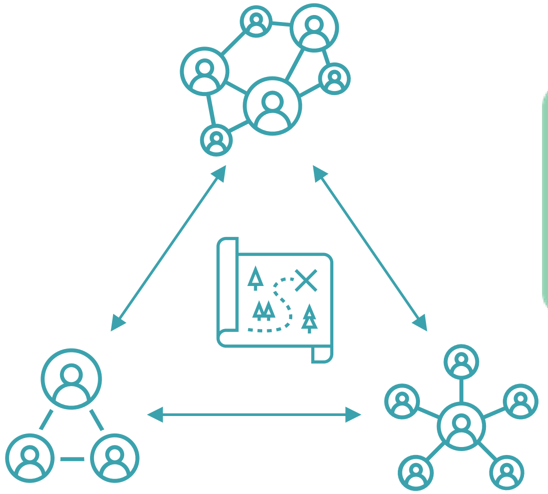


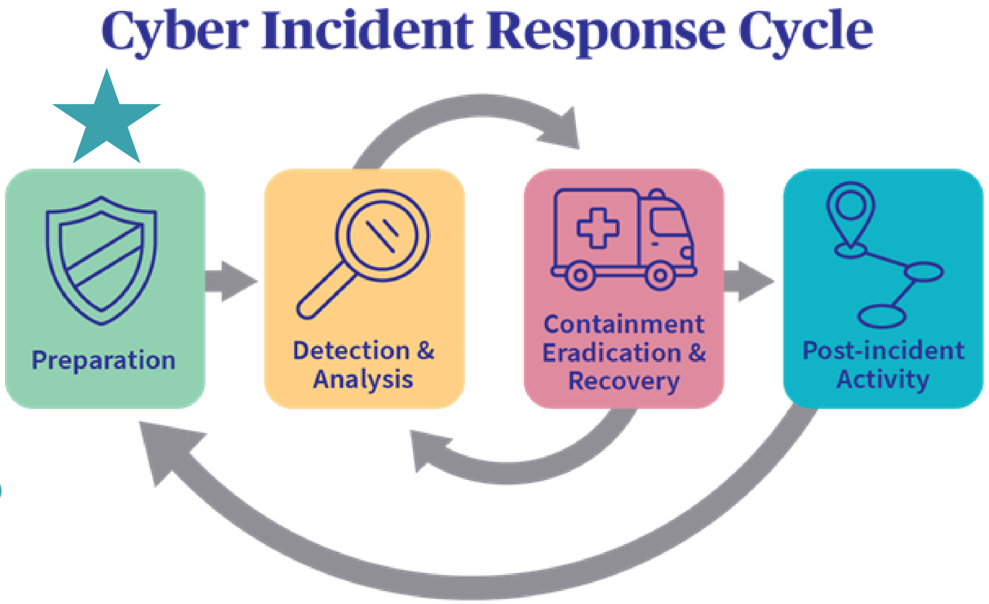
Visual representation of the cybersecurity procurement language

Guide: EVSE Incident Reporting Framework

Performer: PNNL

- Ensure EVSE stakeholders are prepared to respond to potential cyber incidents
  - What are existing incident reporting processes?
  - What does NEVI require?
  - How can EVSE incident reporting integrate with existing IR processes?
- Develop & validate approach with stakeholders and incident response professionals

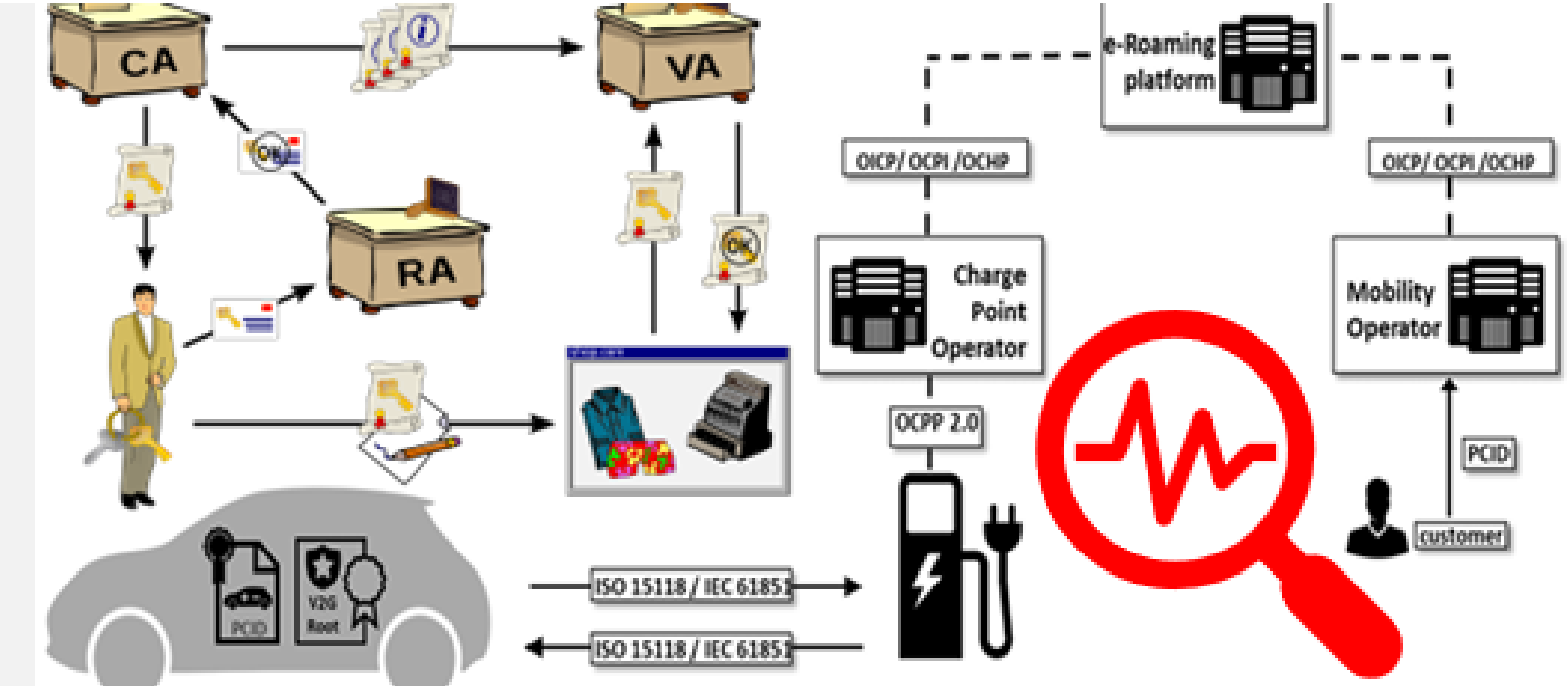




Analyze: NEVI Standards PKI Analysis

Performer: SNL

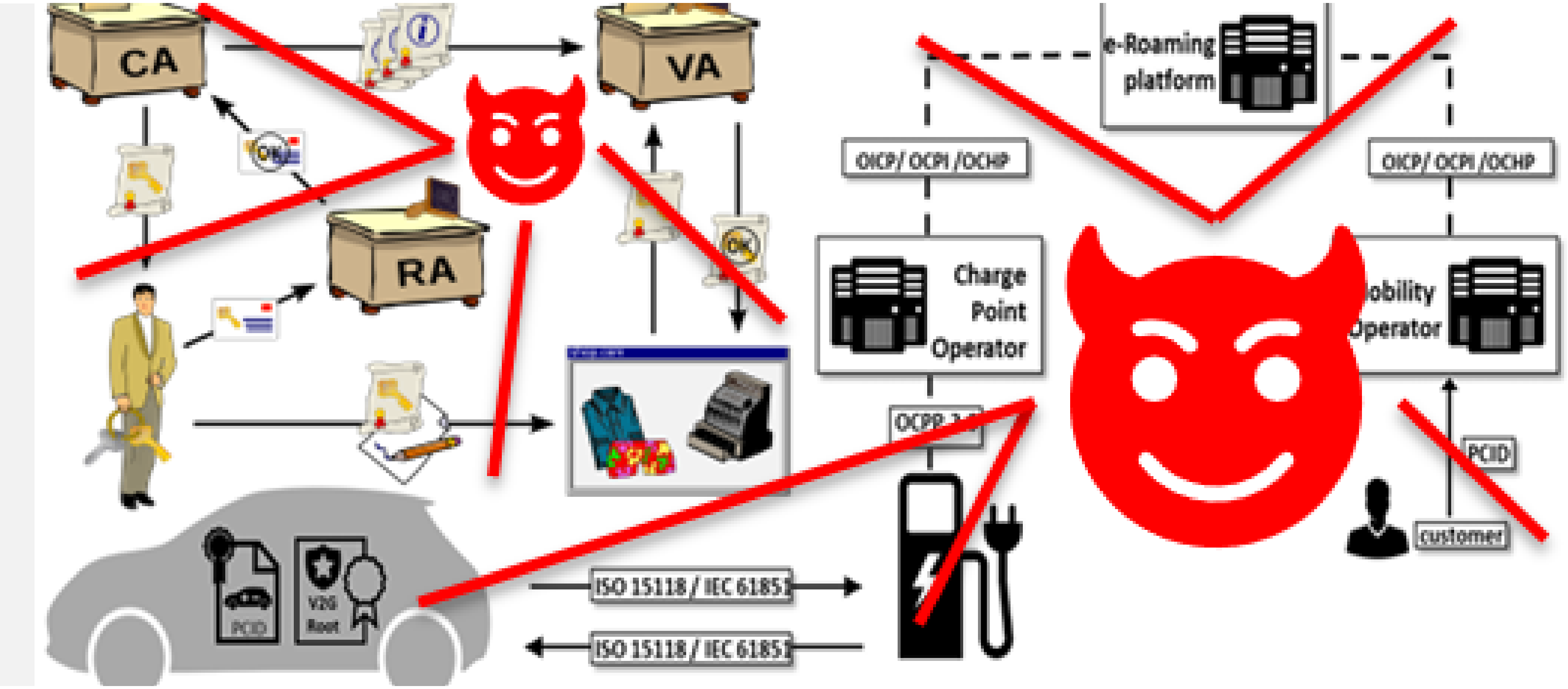
- Get our Theory right
- Ensure PKI does not introduce new “future legacy” cyber issues



Analyze: PKI Adversarial Testing Events

Performer: NREL

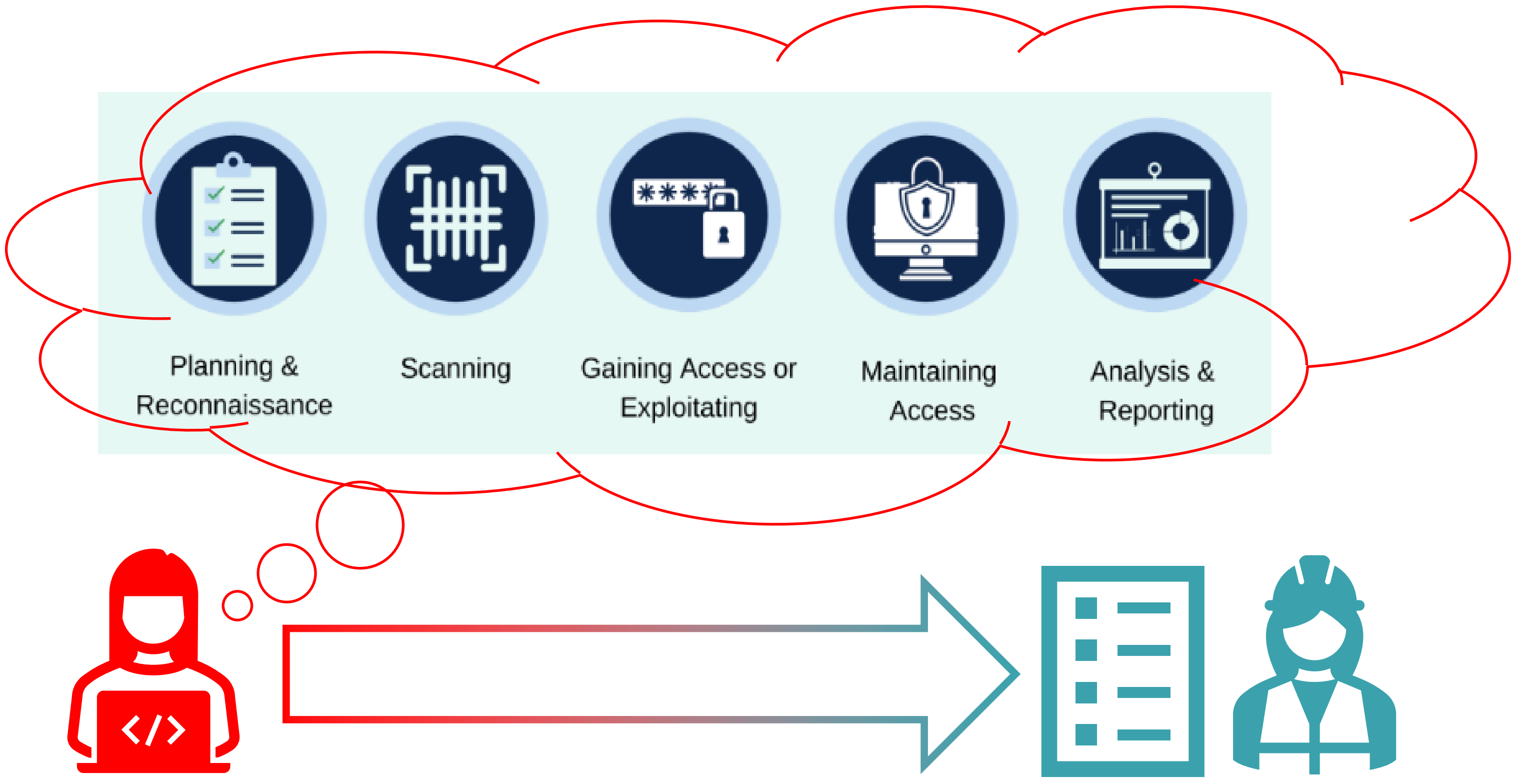
- Theory can be limited by practice
- No-fault stress testing of OEM preferred implementations of PKI in ISO 15118, OCPP, OCPI
- First event Q2 2024 focused on ISO 15118
- Second event Q3 2024 Focused on OCPP



Analyze/Guide: Field Testing Informed Best Practices

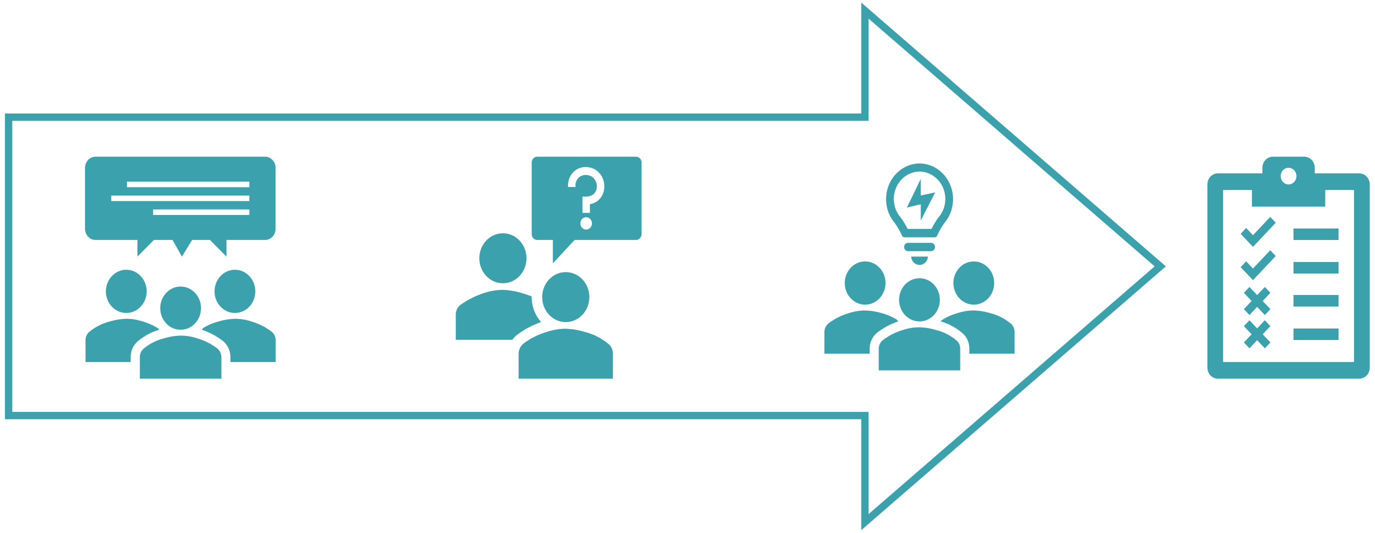
Performer: ANL

- Analyze state of practice via security assessment in real-world EV cyber deployment
- Develop risk mitigation best practices for NEVI deployers and existing buildout



Coordinate: Charging Ecosystem Security Working Group

- Membership- product security engineers
- Identify, prioritize, and assign short term, high impact actions that require a united approach
  - Consensus based
  - Interdisciplinary
- CIPAC, not FACA
  - Open (only) to Sector Coordinating Council member organizations and invited SMEs



Partnering Opportunities

- Charging Security Working Group
  - OEMs and suppliers of assets which make up and interface with EVSE
  - Owners and operators of
    - EVSE
    - Commercial or public fleets
    - Power generation and transmission equipment
  - Reach out to: Brendan.Harris@dot.gov

- PKI Adversarial Testing Events
  - OEMs and suppliers of EVs and EVSE
  - PKI service providers
  - Reach out to Tony.Markel@nrel.gov; Ryan.Cryar@nrel.gov

- Incident Reporting Framework
  - Threat analysts & responders from charging ecosystem
    - Public – Federal, State, Local, Tribal, Territorial
    - Private – OEMs, Suppliers, ISACs, ISAOs,
  - Reach out to Thomas.Carroll@pnnl.gov

UL Solutions

EV charger cybersecurity

Standards and certification

Mike Slowinske, UL Solutions
Feb. 29, 2024

Safety. Science. Transformation.™

Meet your speaker

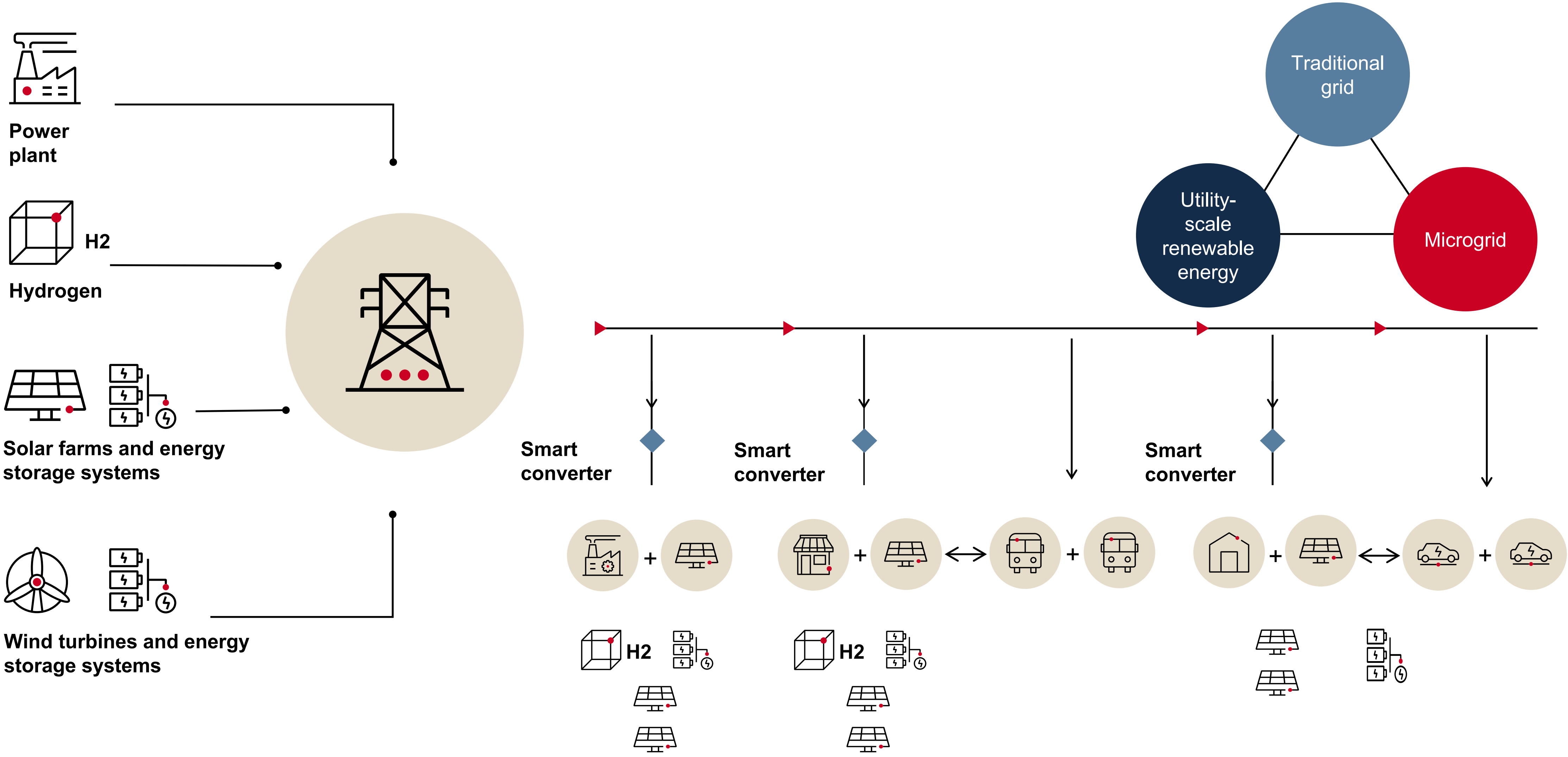
Mike Slowinske, PE, MBA

Engineering director, Energy and Industrial Automation

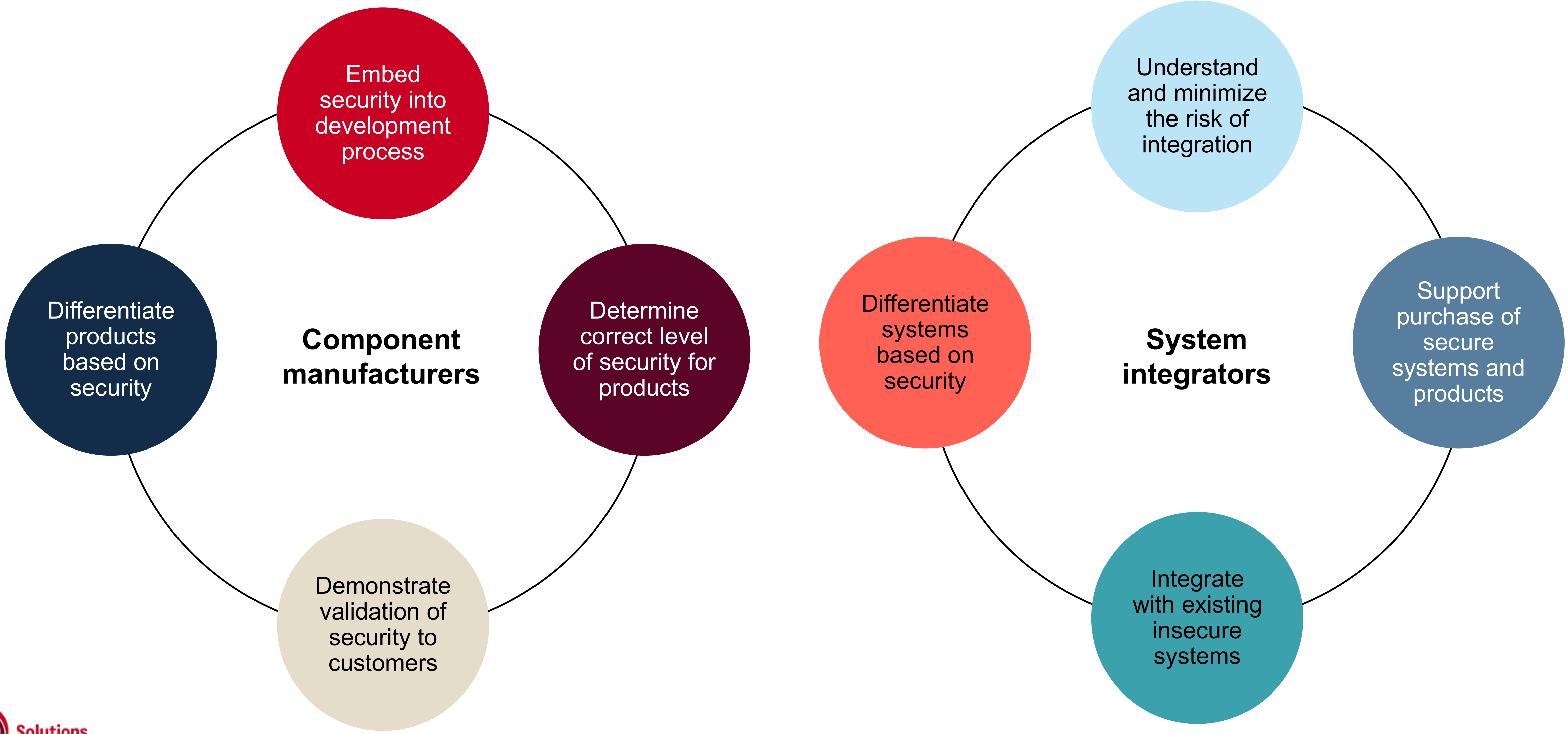
Background

- Bachelor of Science in environmental engineering
- Twenty-seven years of experience in product testing and certification
- Member, U.S. National Committee for Explosive Atmospheres Equipment
- Representative for multiple IEC, NFPA and UL standards committees

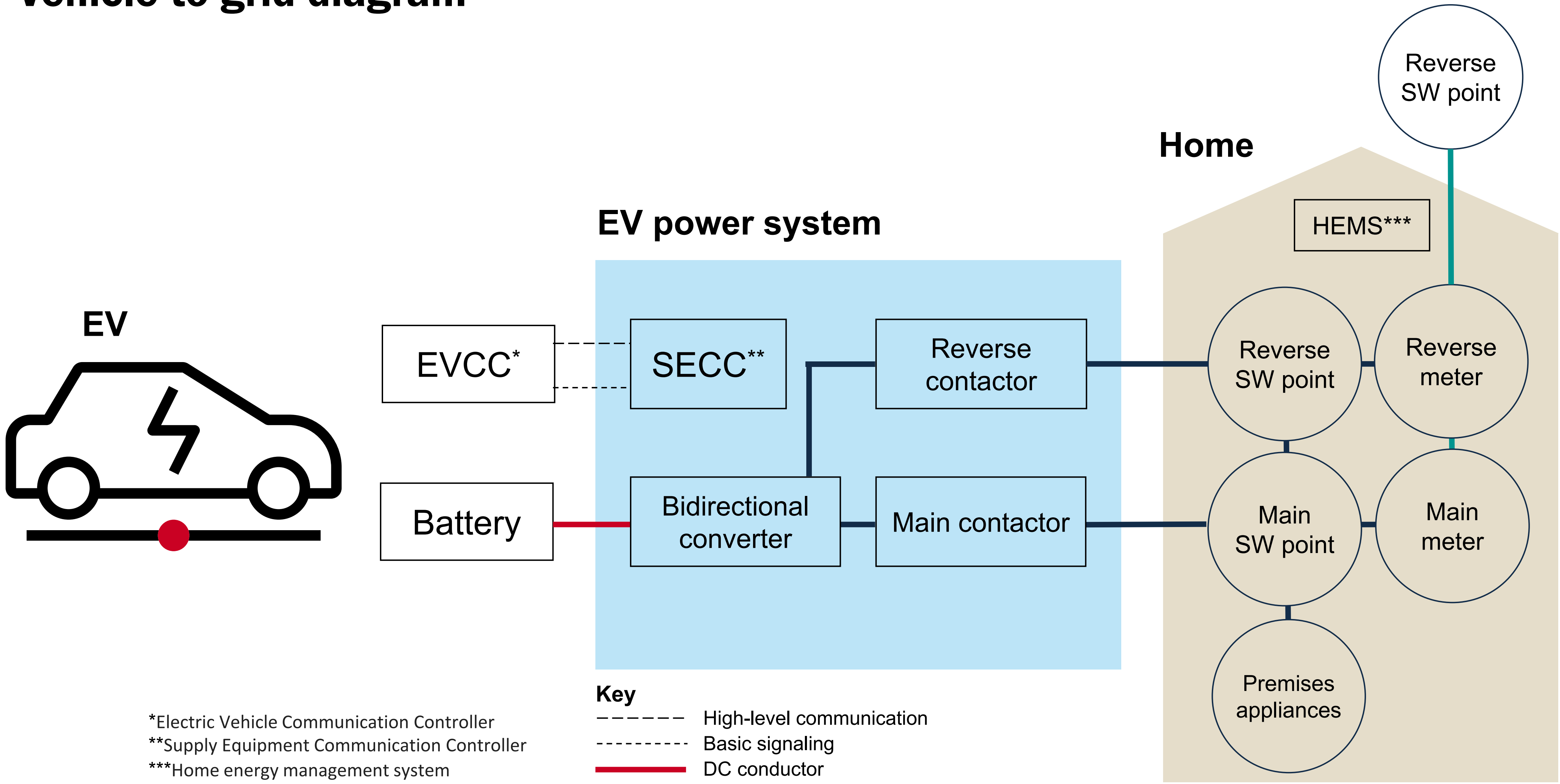
Rapid growth of renewables poses a security risk



Industry cybersecurity challenges



Vehicle-to-grid diagram



*Electric Vehicle Communication Controller
**Supply Equipment Communication Controller
***Home energy management system

Key
- High-level communication
- Basic signaling
- DC conductor
- AC conductor
- Low-voltage supply network

Source: ISO 15118-1

Vehicle-to-grid: Actors involved in handling data

Primary actors

Electrical vehicle

- Electrical vehicle communication controller
- Interlock
- ECU*
- Charger
- HMI**
- Residual current device
- Contactor
- Modular current breaker

ISO 15118 ⟷

User

Electrical vehicle supply equipment

- Supply equipment communication controller
- Electricity meter
- Residual current device
- Paying unit
- Contactor
- Interlock

Secondary actors

- E-mobility operator clearing house
- Demand clearing house
- Original equipment manufacturer
- Fleet operator
- E-mobility service provider
- Distribution system operator
- Meter operator
- Electricity provider
- Energy management system
- Charging station operator

Some elements are optional

*Electrical control unit
**Human Machine Interface

Source: ISO 15118-1

Codes and standards

Related standards

- ISO/SAE 21434, Road Vehicles – Cybersecurity Engineering
- UL 2941, Outline of Investigation for Cybersecurity of Distributed Energy and Inverter-Based Resources
- ETSI EN 303 645, Cyber Security for Consumer Internet of Things: Baseline Requirements
- ANSI/ISA/IEC 62443, Security for Industrial Automation and Control Systems
- IEC TS 62351, Power Systems Management and Associated Information Exchange – Data and Communications Security
- NIST IR 8473, Cybersecurity Framework Profile for Electric Vehicle Extreme Fast Charging Infrastructure

2023 National Electrical Code® (NEC®) revisions related to cybersecurity

NEC Section 110.3(A):

Cybersecurity is added to the list of considerations for equipment acceptance.

Section 240.6(D):

Cyber evaluation is required for remotely adjustable circuit breakers.

2023 NEC 240.6(D)

References

- ANSI/ISA 62443
- UL 2900, the Standard for Software Cybersecurity for Network-Connectable Products (series)
- NIST framework

Evidence

- NRTL certificate of compliance
- ISA Security Compliance Institute conformity assessment program
- Manufacturer certification

UL 2941: Contents

INTRODUCTION

GENERAL REQUIREMENTS

UL Solutions

UL 2941 for Inverter-Based Resources

- The Standard is now published.
- Joint effort by UL Standards & Engagement and the National Renewable Energy Laboratory (NREL) (as directed by SETO/DoE)
- Technical Committee (TC) is now working on a consensus standard

UL 2941 for IBR: Technical committee

- A TC is a balanced committee that will consider necessary revisions to the base document.

- A positive consensus vote by the TC results in ANSI status.

- The main themes in the proposals being discussed are:
  - Additional tests
  - Expansion of scope
  - Risk-based approach vs. hard requirements
  - Remote updates

Questions?

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Michael.Slowinske@UL.com

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Thank you

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EVs @ Scale
U.S. Department of Energy

Cybersecurity Panel Session: How to "Move the Needle" for EV Charging Infra. Cybersecurity

Jordan Smith

Join us for the:
Cyber-Physical Security Deep-Dive
April 9 & April 10 at 1:00pm eastern

Join us for the:
EVs@Scale Semi-annual Meeting
Sept. 25-26, 2024 at Idaho National Lab
Lab tours (EVIL, Batt. Test Center, etc.)
(less than 2-hour drive to Yellowstone or Grand Teton National Park)

EVs@Scale

U.S. Department of Energy