ChargeX Consortium Overview and Progress Update

CHARGEX consortium

LED BY

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | NREL Transforming ENERGY

9/30/2025

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INL/RPT-24-76367

CHARGEX consortium

Vision

Any driver of any EV can charge on any charger the first time, every time

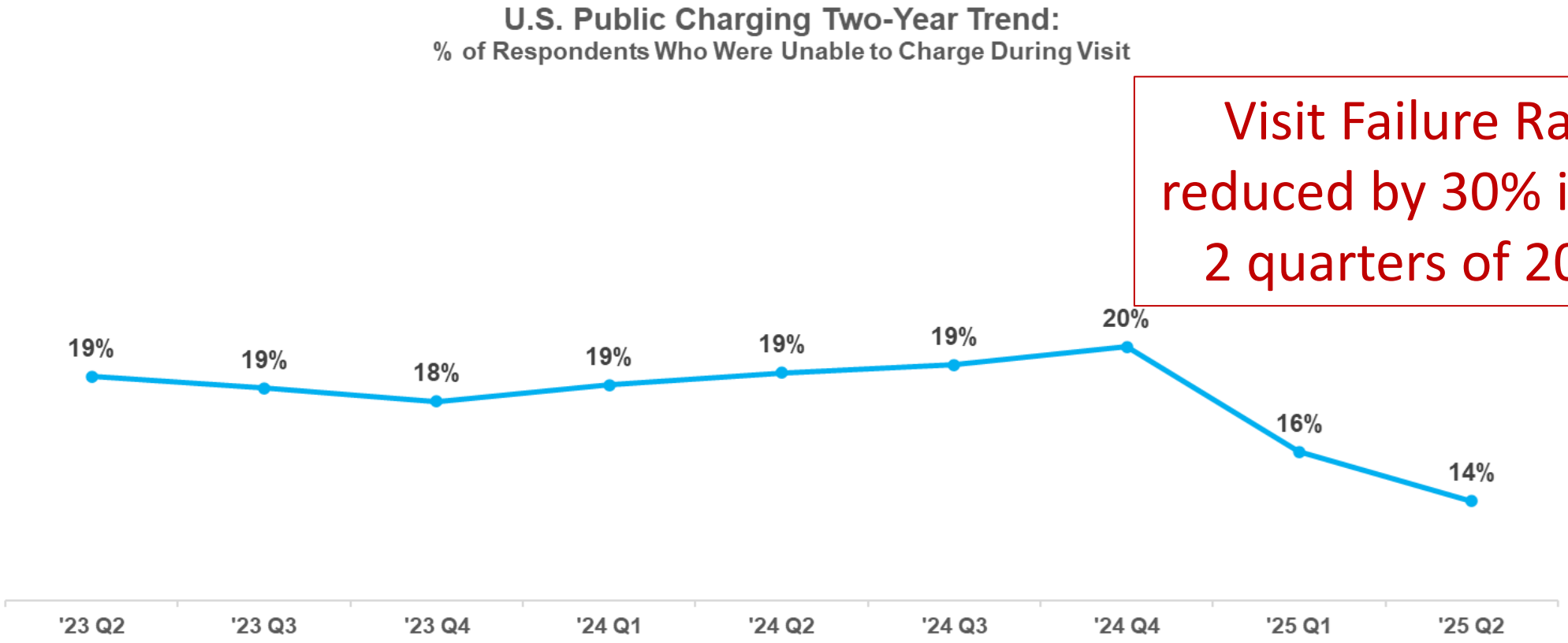
Mission

Bring together EV charging industry members, national laboratories, consumer advocates, and other stakeholders to measure and significantly improve public charging reliability and usability in North America **by June 2025**

Scope

Focus on complex issues that require multi-stakeholder collaboration and national lab support to solve and simplify

The Data Tell the Story



Visit Failure Rate reduced by 30% in 1st 2 quarters of 2025

Source: J.D. Power U.S. Electric Vehicle Experience (EVX) Public Charging Study℠

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Scope of Work

Defining the Charging Experience

- Define KPIs
- Develop and verify implementation instructions

Reliability/Usability Triage

Create fixes for:

- Communication
- Hardware

Solutions for Scaling Reliability

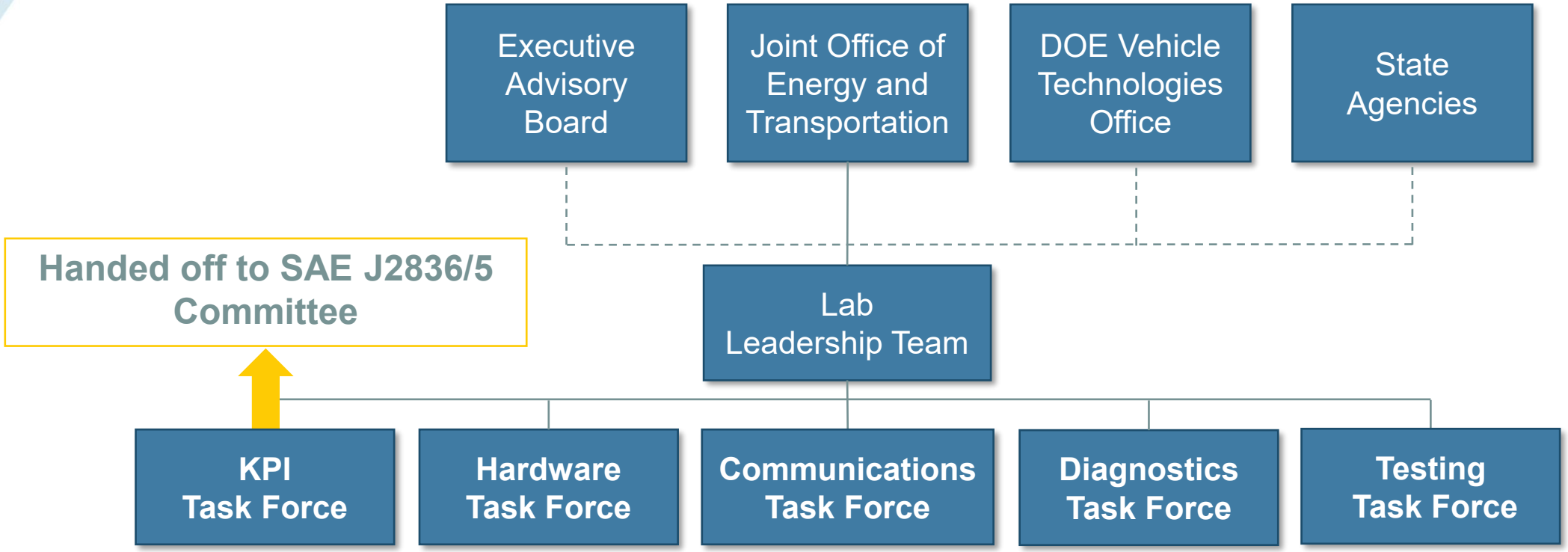
Improve:

- Diagnostics
- Interoperability testing methods

Outcomes

- Labs produce recommended practices, prototype tools
- Industry adopts practices and tools, improves standards

Structured Industry Engagement



Payment & UI Task Force - Discontinued Sept 30, 2024

Participants (95 to date as of 9/30/2025)

Charger Manufacturers and Suppliers	ABB e-Mobility, Amphenol, Autel, Bosch, BTC Power, ChargeTronix, Dover Fueling Solutions, Eaton, Evalucon, EVbox, Freewire Technologies, Heliox, IoTecha, Qualcomm, Siemens, SK Signet, Tritium, Tritium Power Solutions, Wallbox
Customer-Facing Charging Station Operators	Apple Green Electric, Blink Charging, bp pulse, ChargePoint, Electrify America, Enel X Way, EVgo, Evri Network, FLO, Francis Energy, HeyCharge, KIGT, Koulomb, Lynkwell, NovaCHARGE, NYPA, Rove, SWTCH, Xeal Energy
Charging Network and Software Providers	ampcontrol, AMPECO, ampUp, ChargeMate, Driivz, EV Connect, Noodoe, PIONIX, Switch
Auto Manufacturers	American Honda, BMW of North America, Ford Motor Company, General Motors, Lucid, Mercedes-Benz North America, Rivian, Stellantis, Subaru of America, Tesla, Toyota Motor North America, VinFast Auto, Volvo Car USA
3rd-Party Roaming Hubs and eMSPs	AeonCharge, Bluedot, ChargeHub, Emobi, Hubject
Field Services and Analytics Firms	Atlas Public Policy, ChargerHelp!, Energetics, Field Advantage, Paren, ReliON, Uptime Charger, WattsUp
Consumer Advocates	Cool the Earth, Consumer Reports, Evinfo.net, J.D. Power, Plug In America
Fleets	Hertz
Payment Industry Stakeholders	Discover Global Services, Nayax, Payter, WEX
Standards Organizations and Technology Alliances	CharIN North America, COVESA, NEMA, Open Charge Alliance, SAE Sustainable Mobility Solutions
Research Organizations and Universities	American Center for Mobility, EPRI, Transportation Energy Institute, University of California, Davis; University of Washington
State Agencies	California Air Resources Board, California Energy Commission, Caltrans

Project Updates

ChargeX Output by the Numbers

- 26 technical reports, 3 peer-reviewed articles
- 4 open-source code bases and 3 living documents on ChargeX Github repo
- 2 SAE Technical Information Reports
- 4 industry test events with 60+ companies participating
- 7 demonstrations at industry events
- 15+ invited presentations at conferences, workshops, committee meetings

The team:
320+ individuals from 96 external organizations,
30+ staff from 3 national labs

KPI Task Force

Goal: Establish customer-focused key performance indicators (KPIs) to standardize how industry measures the customer charging experience

Completed:

- Published KPI Report and Implementation Guide
- Collaborated with major CSO to pilot and validate KPI Implementation Guide
- Wrote KPI implementation code and published to public-facing Github sites

Hand-Off to Industry

- SAE reopened J2836/5 to add interim and ideal KPI definitions. Will be finalized and published 12/25 or 1/26.
- Informed CEC regulatory proceedings
- Multiple companies implemented KPIs internally

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Improving Payment System Reliability

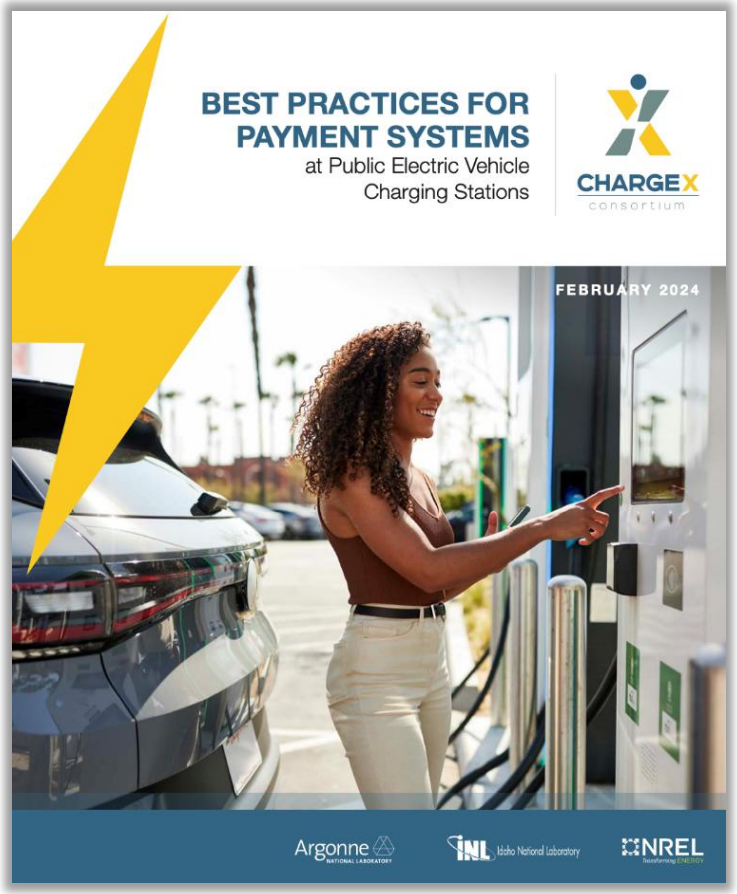
Goal: document problems and recommend solutions for wide range of payment system issues seen in the field

Progress:

- Published a best-practices report documenting problems and recommending solutions for wide range of payment system issues seen in the field

Next Steps:

- Project complete



Hardware Task Force

Goal: Ensure performance standards (J3400/1), conformance standards (UL 2252), and industry practices catch all major failure modes

Completed :

- Adapter Safety Failure Modes & Effects Analysis (FMEA) report published and resulting analysis supporting UL 2252 publication.
- Adapter, Connector, and Reference Inlet Thermal Evaluation report published
- Submitted comments for updates to UL Standard 2251, 2252, and 2202 leveraging FMEA, Thermal Evaluation, and Pin-Cap Evaluation
  - UL 2252 reopened on dielectric strength test clarification and temperature test revision-we will provide comments.
- Provided recommendations on EMC for arc detection to CharIN
- Loaned reference device hardware to connector manufacturers. Reference device acceptance by industry and work to write into J3400

Remaining Work:

- J3400/1 RP review and comments
- Evaluations of NACS, CCS, and Adapters on Side-load and Withstand Force report in NREL review process
- UL Inlet Evaluation Methods to Reduce pin-cap Retention in Connectors in NREL review process
- Adapter identification utilizing basic signaling

Hand-Off to Industry:

- Adapter FMEA results provided to UL2252 and J3400/1 in 2024
- Recommended inclusion of reference inlet design in UL2252
- Sharing testing results with J3400, UL 2251/2252 committees

Side-load evaluation for parked vehicle "just in reach" of EVSE

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Communications Task Force

Goal: Identify and fix issues with EV/EVSE communication protocols to improve charging experience

Completed:

- Seamless Retry
  - Published recommended-practice report; updated report with improved features
- Streamlining Timeouts
  - Published recommended-practice report
- Additional Information Exchange
  - Defined messages for co-identification, adapter detection, ongoing current/power limits, error codes and demonstrated EVerest implementation of ISO 15118-200
  - Published code to GitHub
- Quantifying and Reducing Time to Start Charging Sessions
  - Published recommended-practice report
- Published update to Seamless Retry report

Remaining work:

- Continuing data collection in September for quantifying time

Hand-off to Industry:

- Shared lessons learned and recommended incorporation into relevant standards:
  - IEC 61851-23
  - SAE J1772
  - ISO 15118-2/-3/-202

Seamless Retry demonstrated by Electrify America, BTC Power, and Ford

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Diagnostics Task Force

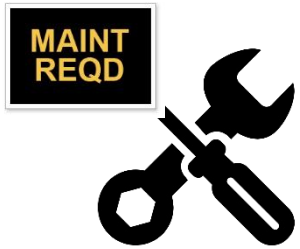
Goal: Institute common set of error codes and supporting diagnostic information across industry to accelerate problem resolution

Completed:

- Published charger-focused Minimum Required Error Codes (MRECs) and implementation instructions
- Published Minimum Required Diagnostic Information (MRDI) for diagnosing the root cause of faults communicated by MRECs
- Published recommendations for improving OCPI

Remaining Work:

- Potential for MREC, MRDI implementation pilot and field data collection to improve interop and certification testing



Hand-Off to Industry:

- MRECs implemented in EVerest for OCPP
- Codified in SAE J2953/3
- CharIN Error Code sub-group created for detailed error codes

MRECs demonstrated by EVgo

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Testing Task Force

Goal: Improve testing tools and procedures to improve industry's ability to scale EV/EVSE interoperability

Completed:

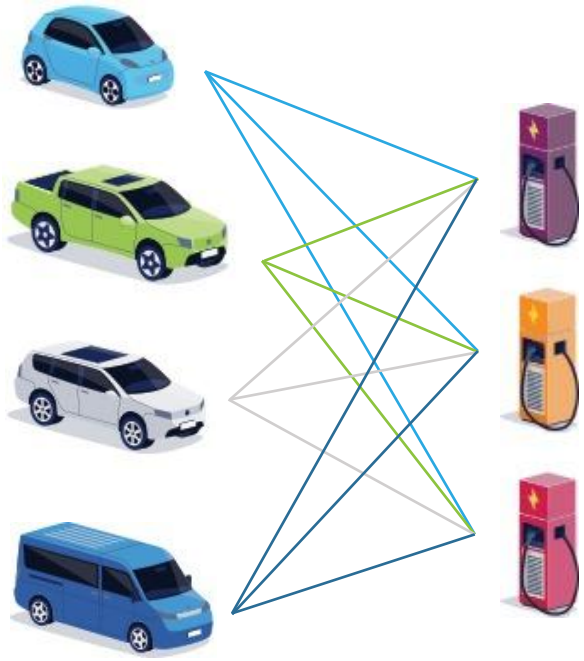
- Developed first-of-a-kind Remote Test Harness (RTH) to conduct remote interoperability testing between EVs and EVSE at separate locations
  - Produced minimum viable product
  - Released open-source code to GitHub
- Developed comprehensive EV-EVSE testing plan
  - Published EV-EVSE Interoperability Test Plan (EEITP) ver1 and ver2
- Executed prescribed testing at June, Nov 2024 CharIN Testivals and helped ACM host prescribed testing at May 2025 Testival

Remaining Work:

- Socialize RTH with industry, support tech transfer and pilot testing

Hand-Off to Industry:

- Completed and demonstrated minimum viable product using commercially available hardware
- Taught CharIN/ACM how to execute prescribed testing program
- Published EEITP



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Ensuring Smart Charging is Reliable

Vehicle/Grid Integration (VGI) projects

(conducted by labs outside of ChargeX Task Forces)

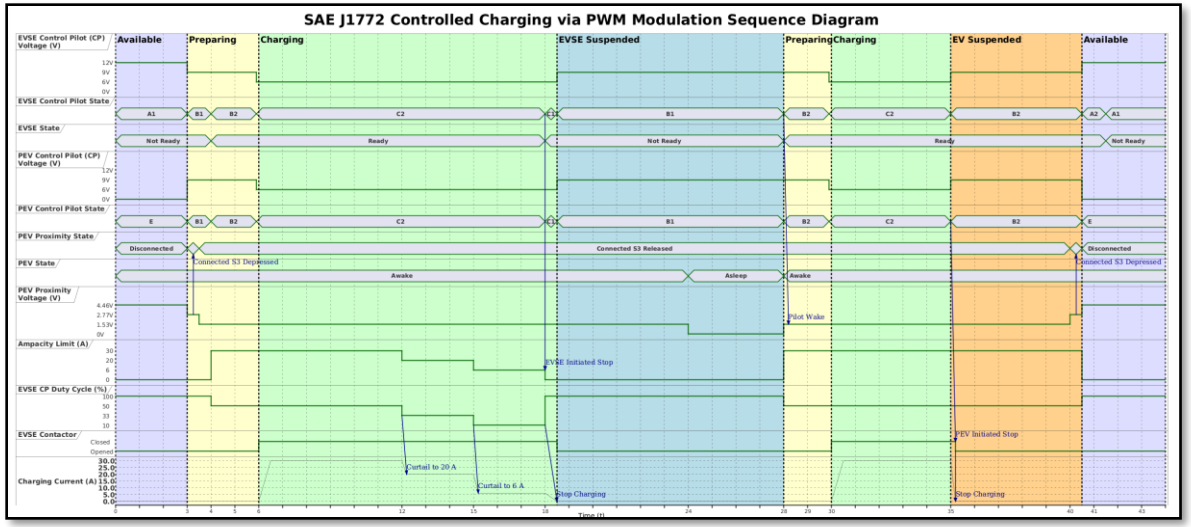
- VGI 1. Develop V1G state machine and sequence diagrams for EV, EVSE, and OCPP
- VGI 2. Develop performance metrics for AC Level 2 smart charge management
- VGI 3. Perform failure mode and effects analysis for smart-charging use cases
- VGI 4. Conduct V1G EV benchmarking for 80% of available U.S. makes/models

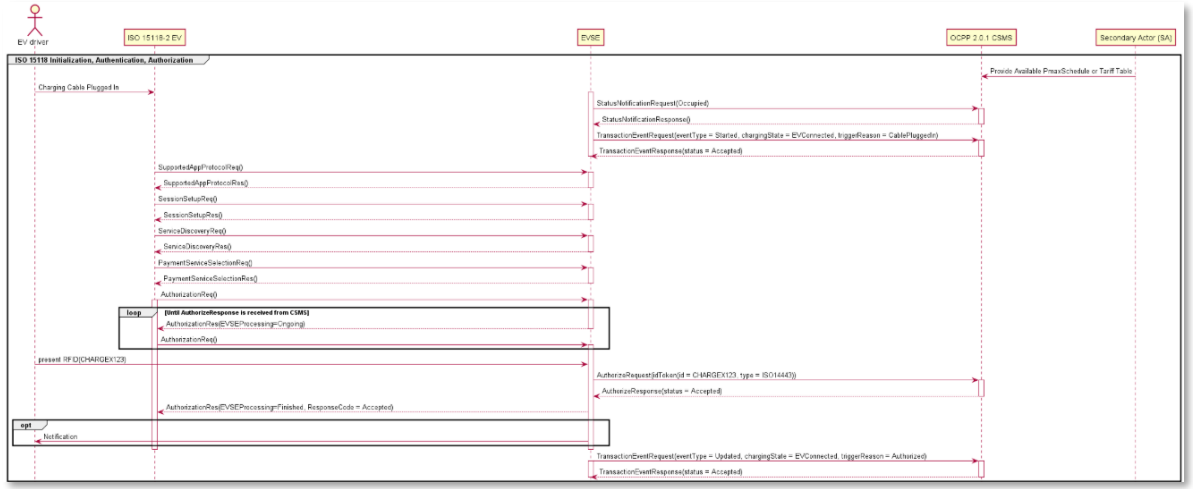
VGI Charging Sequence Diagrams

Goal: Develop state-machine and sequence diagrams for EV, EVSE, and OCPP for managed charging scenarios

Completed:

- **SAE J1772 PWM Charging (Control Pilot)**
  Focuses solely on the low-level, analog control pilot and proximity handshake between EVSE and EV to establish a charge session, modulate current and end a session.
- **SAE J1772 PWM Controlled Charging with OCPP 1.6J**
  Builds on the pure PWM sequence diagram by weaving in OCPP 1.6J messages between EVSE and CSMS for session management and grid-side coordination.
- **ISO 15118-2 Controlled Charging with OCPP 1.6J**
  Uses ISO 15118-2:2013 over HomePlug GreenPhy (HPGP) Powerline Communication (PLC) for EV ↔ EVSE and OCPP 1.6J for EVSE ↔ CSMS. The CSMS can push a charging profile to the EV, but there's no bidirectional negotiation to balance driver energy needs and departure times with grid constraints—vehicles simply follow the profile provided by the Secondary Actor via the CSMS.
- **ISO 15118-2 HLC Optimized Charge Scheduling with OCPP 2.0.1**
  Retains the ISO 15118-2 HLC flows but upgrades to OCPP 2.0.1's richer set of messages and adds true negotiation. EV, CSMS, and optionally a Secondary Actor exchange requirements and constraints so that the final schedule optimally meets both driver departure/energy needs and grid/operator limits.
- **SAE J1772 EVSE Control Pilot FSM**
  A finite-state machine view of the SAE J1772 control pilot, ideal for understanding basic pilot-voltage state transitions.





https://github.com/chargex-consortium/ev-charge-seq-state

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VGI Performance Metrics

Goal: Establish key performance indicators (KPIs) for AC Level 2 SCM that measure its performance and effectiveness from the perspective of different stakeholders for the SCM use cases/objective functions in VGI Tasks 1 and 3

Completed:

Developed and published 5 sets of KPIs (Reliability; Responsiveness; Participation; Energy; Interoperability) that cover 3 areas (Integrity; Availability; Durability).

Remaining Work:

- Select a key set of the KPIs recommended in this document for implementation.
- Identify the necessary data to calculate the key set of KPIs.
- Develop detailed instructions on how to implement the key set of KPIs.

Table 1. Reliability KPIs

Grouping	KPI Name	Stakeholder	Units	Description
Availability	Uptime of SCM Service	EVSE OEM / Utility	%	Percentage of time a resource is available to utility. This is the portion of operational time in which the EVSE can respond to a direct control signal. This encompasses the direct response compliance rate and data exchange success rate. Latency, communication standards compliance, and message parsing errors are covered by other KPIs.
Availability	Event Response Reliability	Utility	%	Percentage of event signals executed successfully (i.e., control signals executed as intended). This is different from opt-out rates because it encompasses communications and controls failures.
Integrity	Energy Delivery Reliability	Reliability Customer	kWh	Cumulative energy deficit (i.e., EV battery charging energy shortfall per period). Observed at the end of the dwell period when the driver expects to be able to depart and experienced by the EV owner over an interval of time. A cumulative score ensures both the case in which one session came up short by a large amount of energy (e.g., 100 kWh), which is one very bad incident, and cases in which many sessions came up short by a small amount of energy (many smaller incidents) are incorporated.
Availability	SCM Session Start Success	Utility / EV OEM / EVSE OEM	%	Percent of the time that the SCM command initializes control successfully. This does not come with a time limit, so any timeout would be considered unsuccessful.
Integrity	SCM Session End Success	EV Owner / Utility / EV OEM	%	Percent of the time that the SCM session ends successfully with power regulation returning to normal operations by releasing control back to the local EVSE or CSMS.

VGI Reliability

Goal: Understand reliability issues for two smart-charging use cases by performing process failure mode and effect analysis (**PFMEA**) and suggest mitigating strategies (recommended actions) in a report.

Completed:
- Wrote Communications Reliability for Vehicle Grid Integration report through NREL review process and DOE review

Remaining Work:
- Publish report (in final step with NREL scientific publishing committee
- Release source files on Github
- Potential to add data on likelihood of failure, also additional SCM use cases (e.g., transformer overload mitigation)

#	Name	Description	Protocols
1	Scheduled charging via telematics	Smart charging controlled by a telematics based SCM system	SAE J1772 (PWM) EV Telematics EV OEM APIs
2	Day-Ahead Pricing	Charging is scheduled to minimize costs per LMP (Locational Marginal Pricing)	ISO 15118-02 AC OCPP 2.0.1 IEEE 2030.5 (Tariffs)

EV Benchmarking

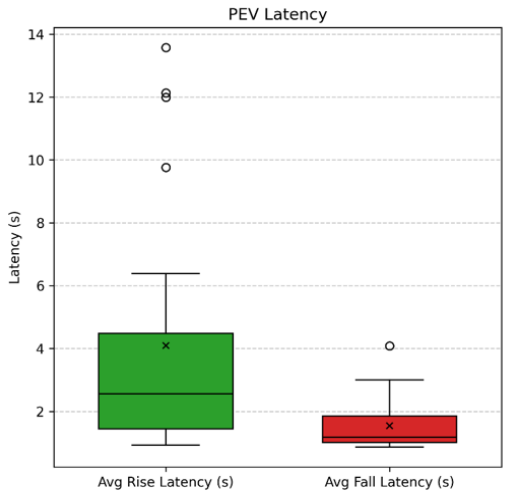
Goal: Benchmark large fraction of US available EV makes to understand charge control capabilities via SAE J1772 PWM modulation as well as pilot wake transitions.

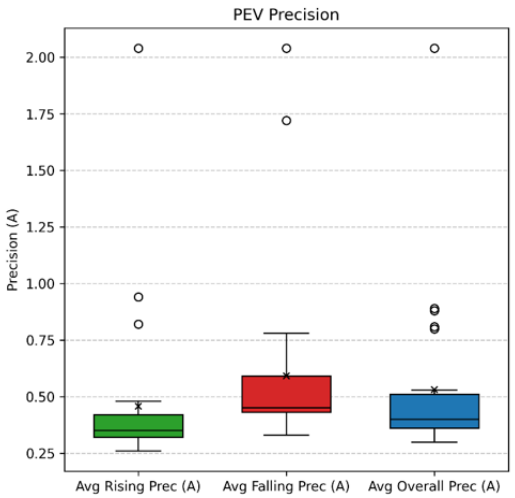
Completed:

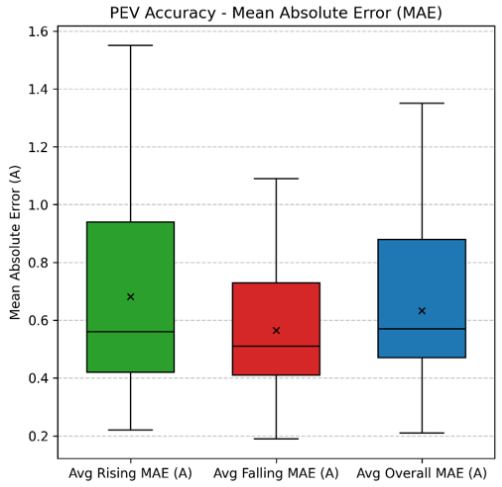
- Test Plans Completed
- Automation Test Scripts Developed
  - Charge control accuracy and precision, latency, and resolution
  - PWM-based charge control response: PJM RegD response score
  - EV Pilot Wake response – timeout tests
- Testing Completed on 25 Makes

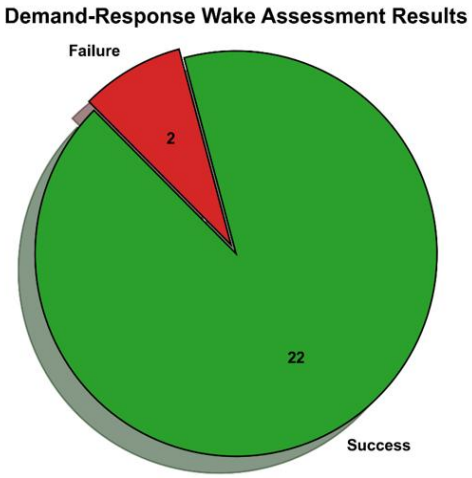
Remaining Work:

- Finalizing Final Report









Reports published to:

chargex.inl.gov

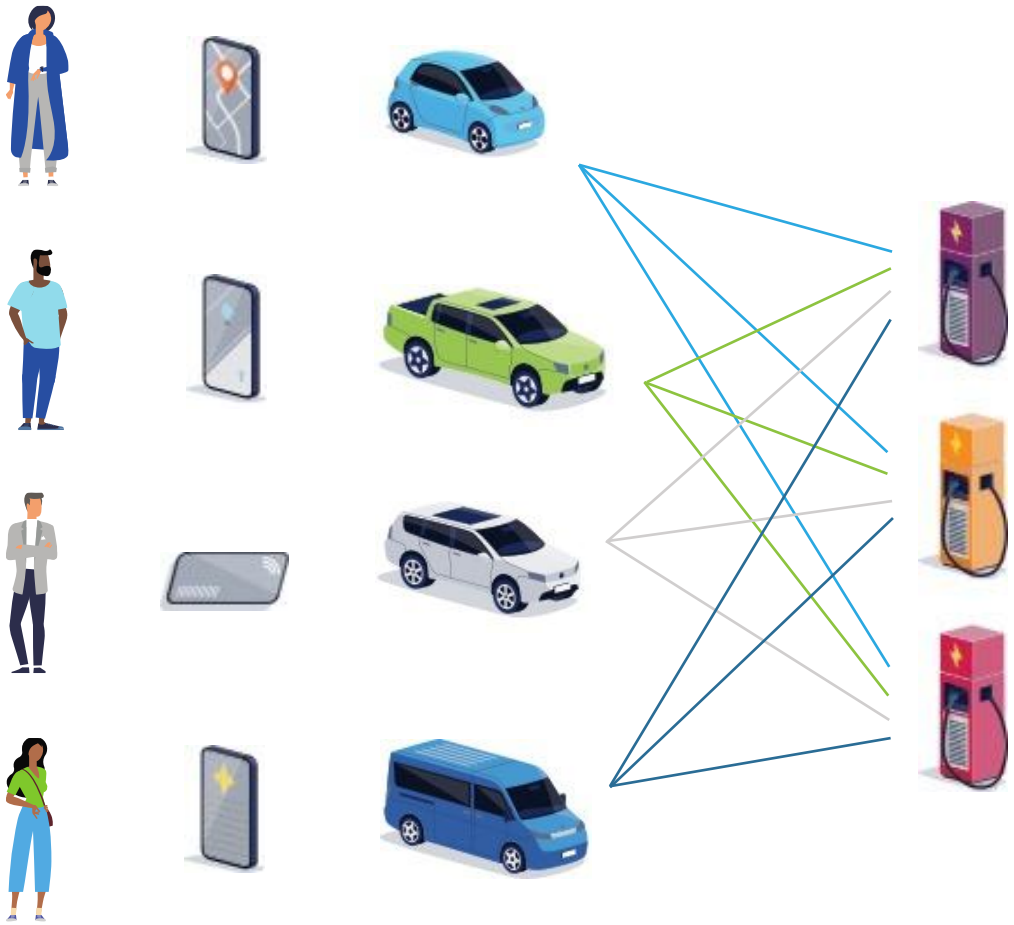
osti.gov

Code published to:

https://github.com/orgs/chargex-consortium/repositories

https://github.com/doecode

Any Driver, Any EV, Any Charger



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