2019 DOE VEHICLE TECHNOLOGIES
ANNUAL MERIT REVIEW

CHARGING INFRASTRUCTURE TECHNOLOGIES: SMART VEHICLE-GRID INTEGRATION (VGI)

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12 June 2019
Washington, DC

Project ID: elt201

SMART VGI PROJECT

Develop communication/control requirements, control strategies and enabling technologies to integrate vehicles and grid-connected devices in a manner that meets the needs of the customer and the grid

- Smart energy management – EV charging, renewables, building systems and battery storage
- Lab demo in 2-3 years; public pilot in 4-5 years
- Contributors/advisors:
  - Global Grid Integration Program, Thor Trucks
  - Idaho National Lab
  - California Energy Commission
  - SMEs

OVERVIEW

Timeline

- Agreement to establish interoperability centers in US and Europe - Q1, FY 2012
- Argonne IOC launch - Q4, FY 2013
- EC-JRC IOC launch – Q1, FY 2016
- Smart Energy Plaza Ø1 – Q4, FY 2015
- Smart Energy Plaza Ø2 – Q3, FY 2017
- 3-yr Lab Call project 3D began FY 2019

Barriers/Challenges

- Lack of consensus on vehicle-to-charging infrastructure-to-grid communication protocols and devices with ‘smart’ non-proprietary interfaces
- Vehicles/charging infrastructure’s ability to respond adequately to support grid services
- Smart, interoperable connectivity and diagnostic tools for grid integration

Budget

- FY2016 - $2824K
- FY2017 - $2485K
- FY2018 – $3300K
- FY2019 – $3100K

Collaborators

- US and European vehicle and electric vehicle supply equipment (EVSE) manufacturers, utilities, research organizations
- Idaho National Laboratory

RELEVANCE

Objective:

Increased energy efficiency and grid resiliency via management of the charging infrastructure in a 'grid of things' (managed energy flow in a network of grid-connected devices)

- Maximize the benefits of VGI on the customer-side of the meter
- Respond to grid conditions/signals with minimal impact on local operations
- Identify benefits and impacts of EVs @ scale (controlled v. uncontrolled charging)
- Develop monetization scenarios of VGI for owners, utilities and aggregators

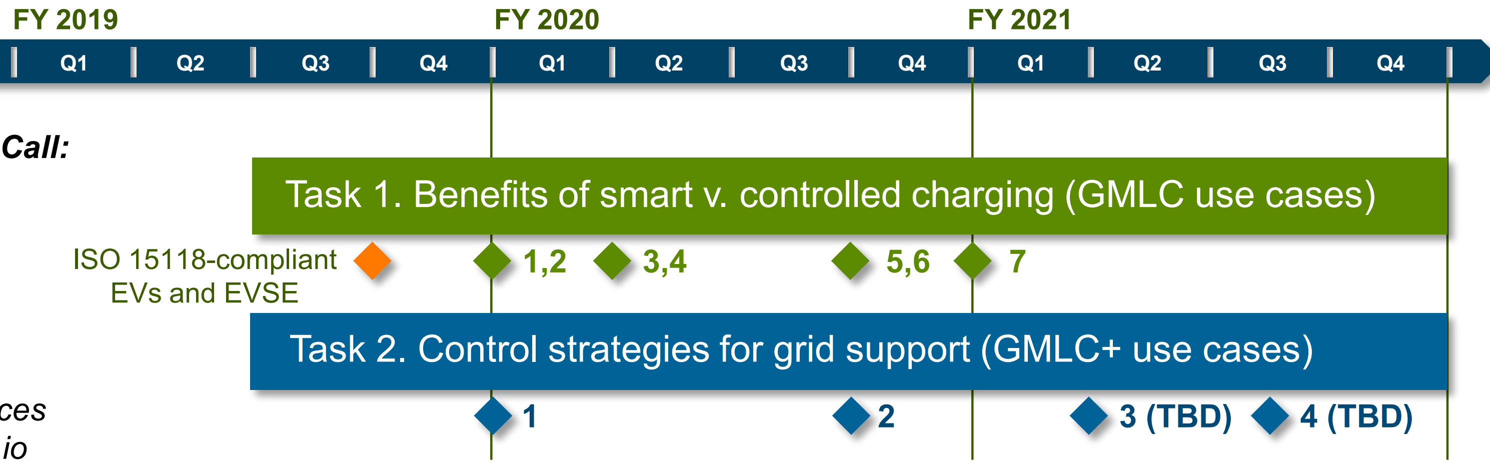
Technical achievements:

- Open source communication platform with High-Level Communication (HLC) to enable 'smart' charging
- Strategies that balance needs on the customer-side of the meter with grid conditions
- Enabling technologies (i.e., 'smart' interfaces, digital communication, sub-metering, tools to verify interoperability and perform diagnostics).

Partnership with Global Grid Integration Program:

US and European automotive industry, utilities, research organizations and equipment manufacturers

MILESTONES: SMART CHARGING & GRID SUPPORT



From previous Lab Call:

- *GMLC use cases demonstrated for controlled and emulated smart charging (✓)*
- *Energy Plaza devices networked via CIP.io*

Task 1 Milestones

GMLC use cases (w/ISO 15118)

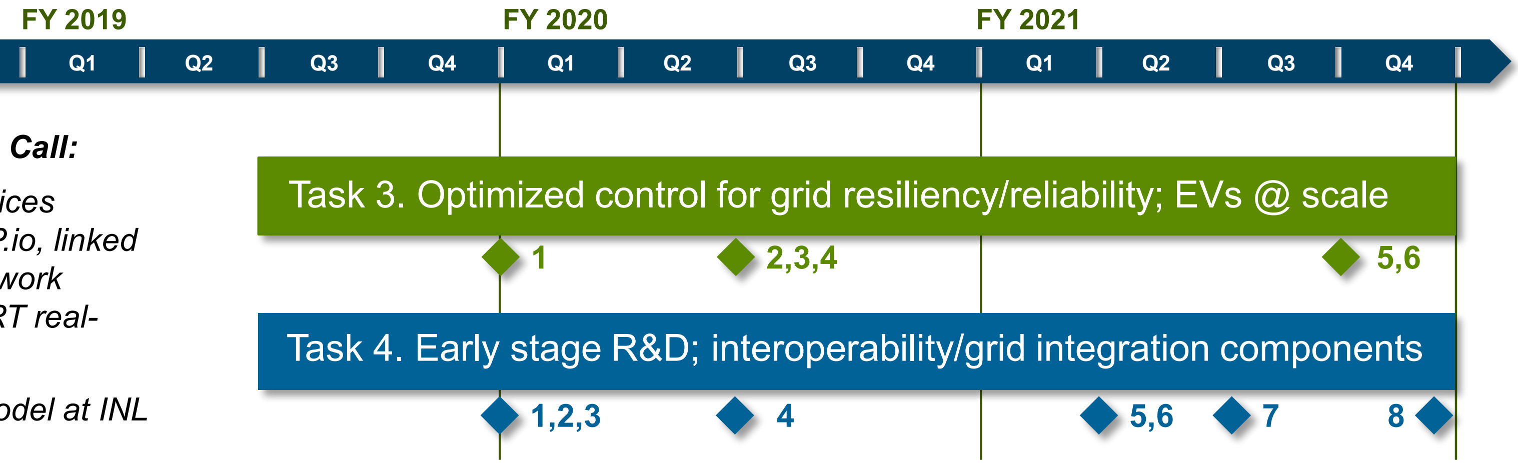
✓ 1. Demand response
✓ 2. Demand charge mitigation
✓ 3. Frequency regulation
✓ 4. Charging capacity deferral
✓ 5. Transactive energy/charging
✓ 6. Maximize use/value of local renewables
7. Utility price signals

Task 2 Milestones

GMLC+ use cases (w/ISO 15118)

1. Plug’n Charge (PnC)
2. Smart charging to balance PV
3. V2X/emergency power
4. Wireless charging

MILESTONES:
GRID RESILIENCE & ENABLING TECHNOLOGIES



From previous Lab Call:

- *Energy Plaza devices networked via CIP.io, linked to Distributed Network Model and Opal-RT real-time simulator*
- *DTRS and grid model at INL*

Task 3 Milestones

1. HIL methodology, design of experiments, grid operational scenarios
2. Ability to respond to grid signals (EV/EVSE & customer side-of-the-meter network)
3. Translate network response behavior to Distributed Network Model
4. Integrate with grid model; assess impact of EVs
5. Demo uncontrolled v. controlled charging at ANL
6. Test uncontrolled v. controlled charging w/EVs @ scale using DTRS @ INL

Task 4 Milestones

1. Demo multi-unit sub-metering
2. Demo beta DEVA with CIP.io
3. Demo beta SpEC2 module
4. HLC via PLC integration in DEVA
5. EUMD TCF – supply chain developed; prototype production
6. SCA/DEVA TCF – Supply chain developed, pilot production
7. Beta smart inlet w/CIP.io
8. Refinements for field testing

APPROACH - TECHNICAL

Image: Innogy.com

Task 1. Quantify benefits of smart charging (w/GMLC use cases)

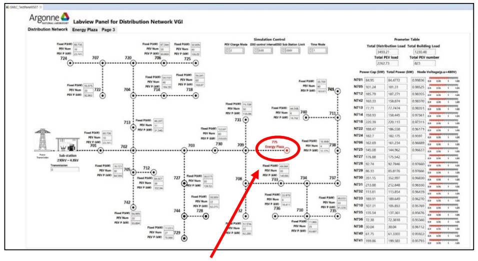
- **Barriers:** Lack of consensus on EV/EVSE VGI protocol; Use cases implemented without HLC; lack of HLC-compliant EVs and EVSE.
- **Solution:** Enhance CIP.io with ISO 15118 and SEP2.0; add compliant EVs and EVSE when available; Reassess GMLC use cases

Task 2. Demonstrate control strategies for grid integration (GMLC+)

- **Barrier:** GMLC use cases did not address all utility grid support issues
- **Solution:** Expand uses cases beyond GMLC; develop strategies for grid services

Task 3. Optimized control for grid resiliency/reliability; Impact of EVs @ scale

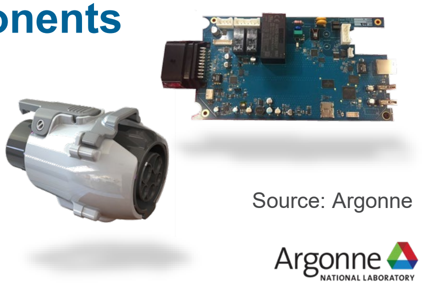
- **Barriers:** Responses of smart charging/networks not quantified; energy management strategies that consider customer and grid; unknown grid impacts of high volume EV charging
- **Solution:** Characterize EV/EVSE and integrated Energy Plaza; utilize ANL Distributed Network Model and INL grid simulation to assess controlled v. uncontrolled charging at local and grid levels



Energy Plaza linked via OPAL-RT

Task 4. Early-stage R&D; Interoperability/grid integration components

- **Barriers:** Verification of interoperability and diagnostics; VGI solution for vehicles; sub-meters for multi-EVSE installations; communication controllers
- **Solutions:** Diagnostic device; smart Inlet; low-cost sub-meter systems



Source: Argonne

APPROACH - PROGRAMMATIC

Collaborate with US & EU industry, government and research organizations to integrate vehicles in the ‘Grid of Things’

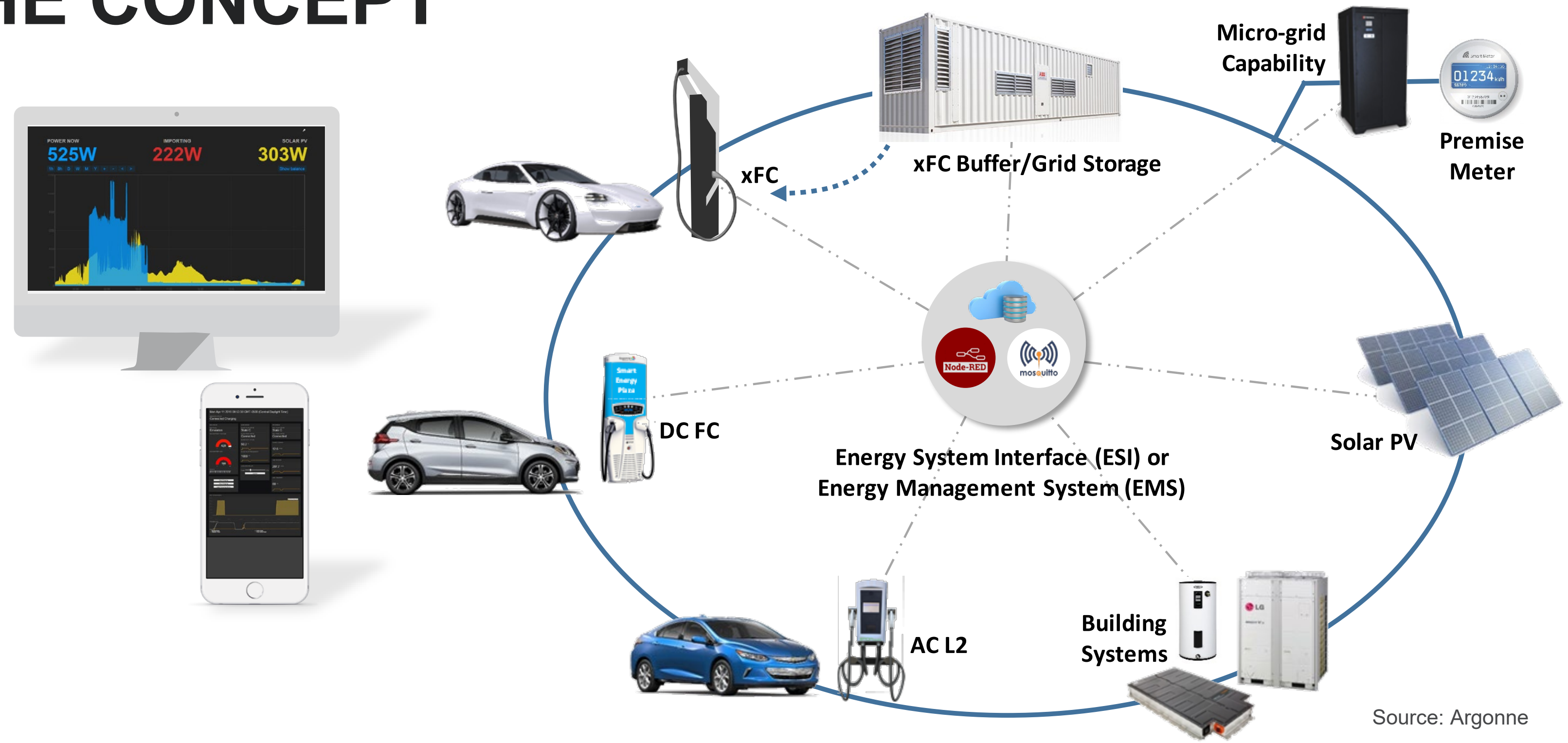
Source: PG&E

‘The always on, always there platform that enables all the products and services customers need to engage with and use energy’

Global Grid Integration Program:

Argonne National Laboratory | European Commission | Elaadnl | Audi | BMW | FCA Fiat Chrysler Automobiles | Ford | GM | IoTecha | PG&E | Porsche | Shell | VW

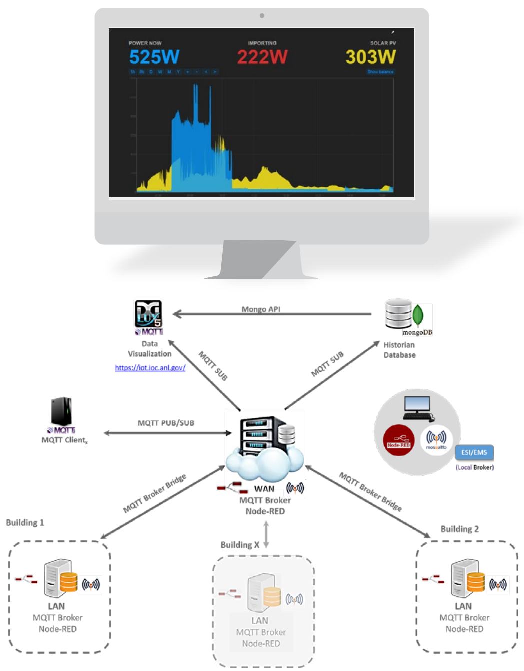
THE CONCEPT

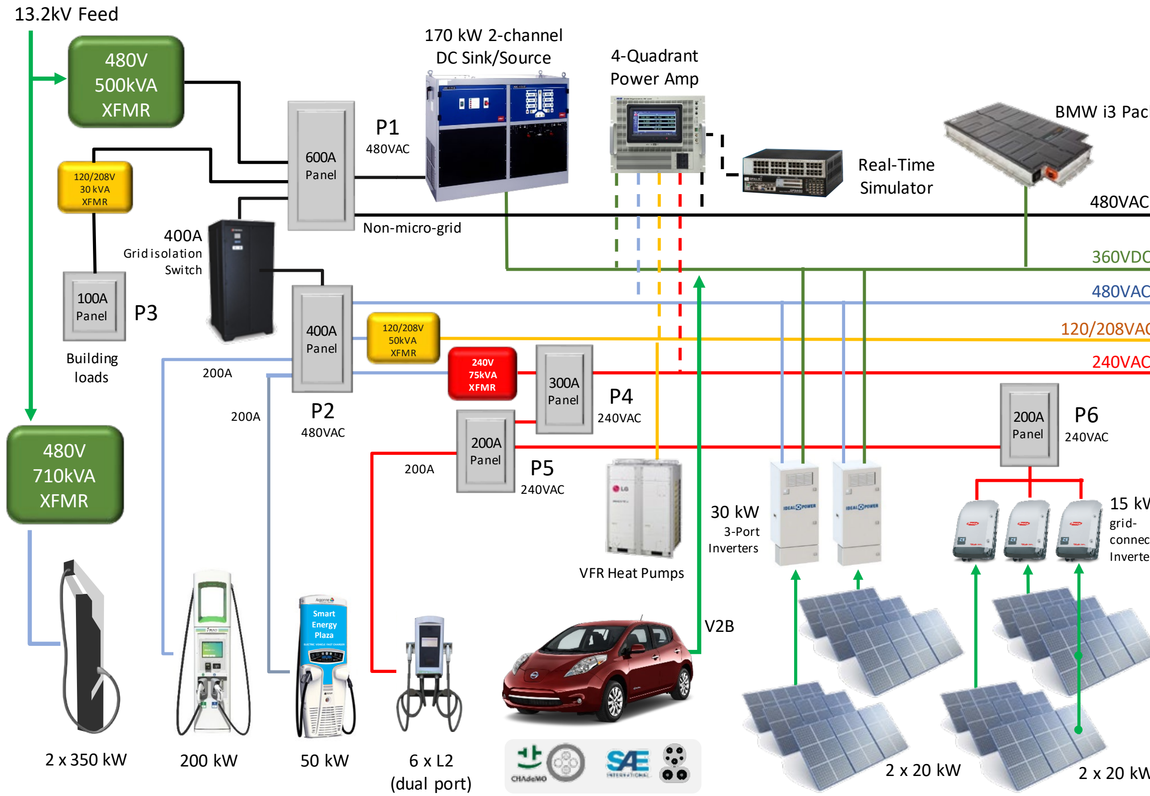


Source: Argonne

- **Customers would be enabled to develop apps** that integrate smart charging with devices in their homes or workplaces
- **Utilities/distribution system operators communicate** with the ESI/EMS or smart meter
- **EV charging and networked devices would be optimally controlled** depending on local demands and grid conditions

IN PRACTICE





Source: Argonne

- **Multiple AC and DC voltages, sources and power levels**
- **Incompatible interfaces**, standards and protocols
- **Latency** in communication and processing
- **Variety of use cases**, i.e., operational scenarios and control strategies
- **Cybersecurity concerns**: accessibility, vulnerabilities and consequences

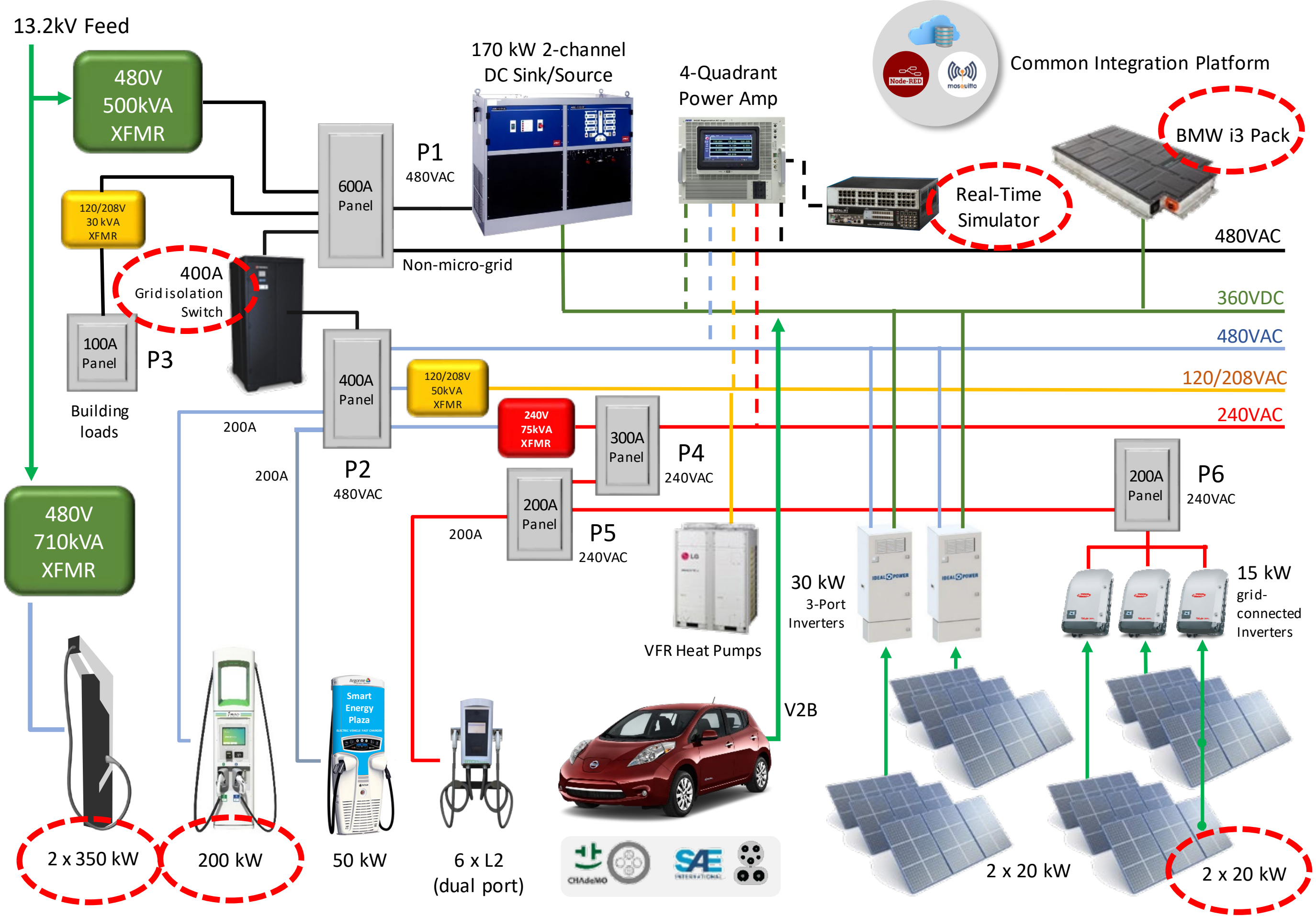
ACCOMPLISHMENTS AND PROGRESS … TO SUPPORT VGI PROJECT

- Energy Plaza – Additional devices
- CIP.io – Additional communication protocols
- GMLC use cases for controlled and emulated smart charging
- Distributed Network Model – Linked to Energy Plaza via OPAL-RT
- Enabling technologies and tools

ENERGY PLAZA

Integrated additional devices

- 40 kW PV
- Second-use vehicle battery
- Real-time simulator
- Grid isolation switch
- 200 kW DC xFC
- 2x350 kW DC xFC (in process)

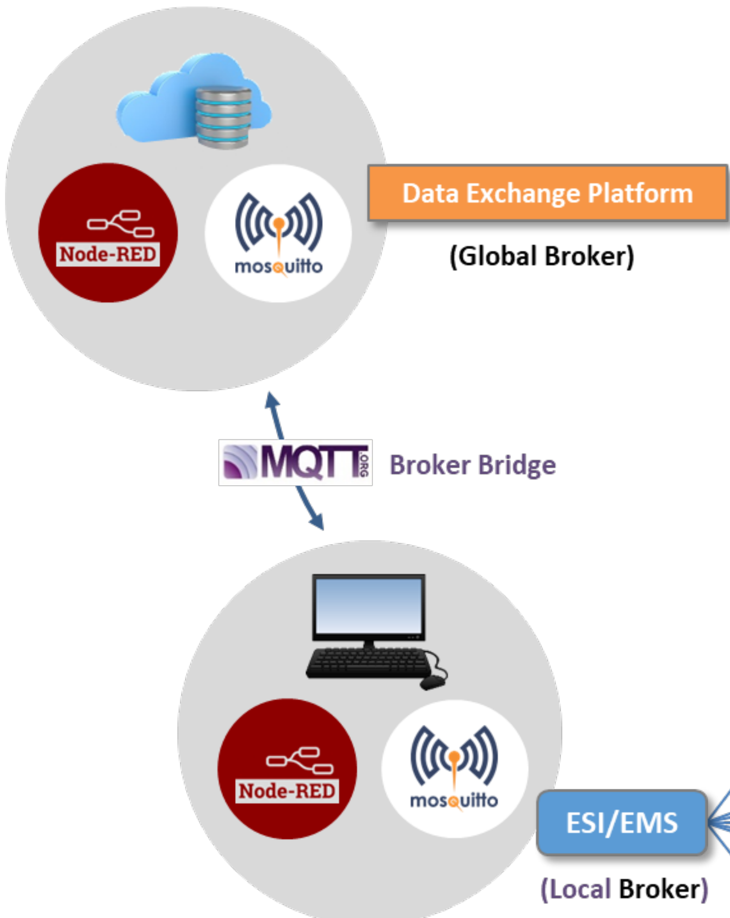


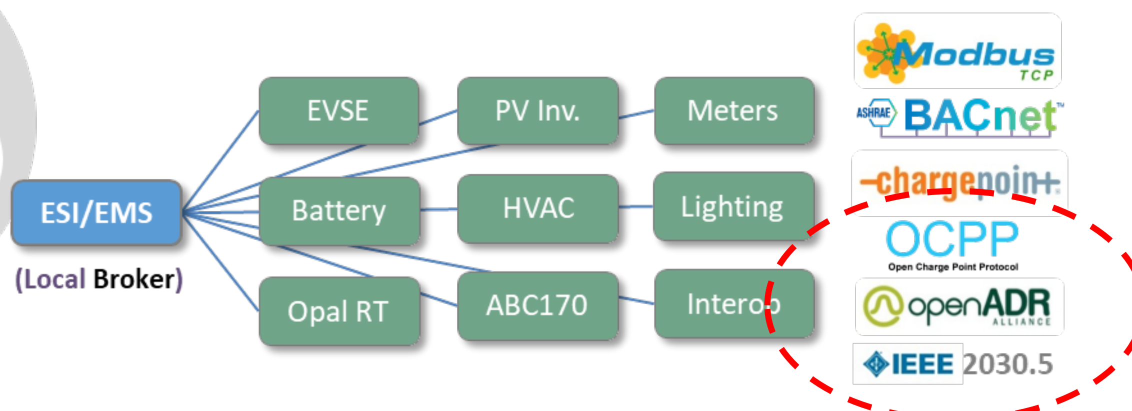
Source: Argonne

COMMON INTEGRATION PLATFORM CIP.io

Incorporated additional communication protocols

- Controls the network of grid-connected devices locally (i.e., the Energy Plaza) and/or globally (e.g., multi-lab demand response demonstration)
- Implemented GMLC use cases for controlled and emulated smart charging
- Protocols for communication with EVSE, DERs, battery storage and building systems

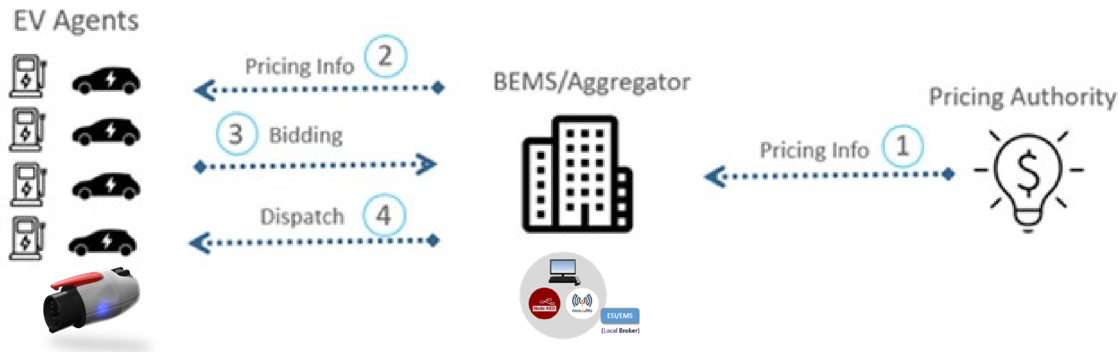


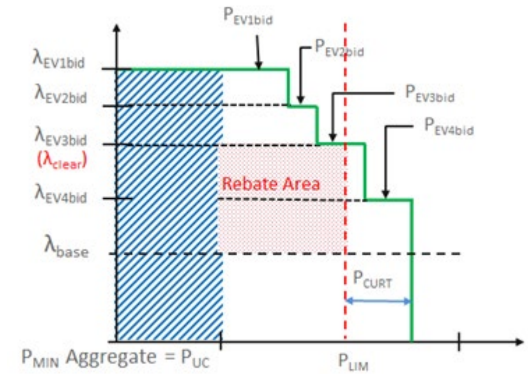


Source: Argonne

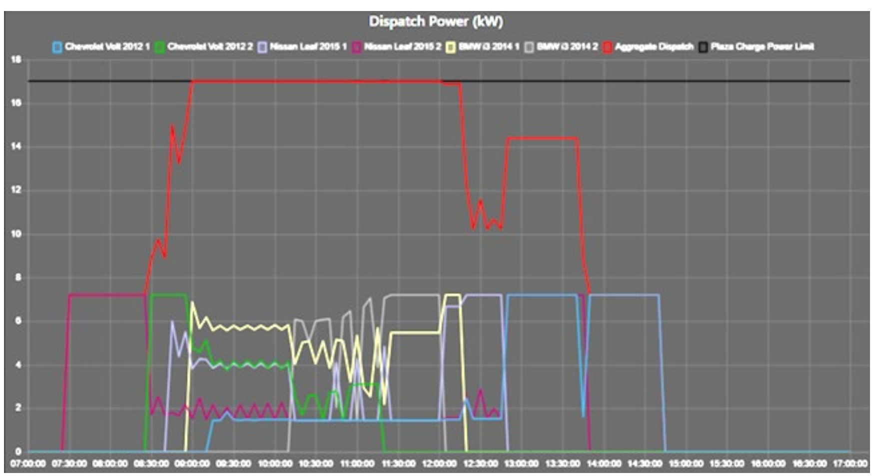
GMLC USE CASES

e.g., Transactive coordination framework (energy trading)





- Coordinate and fairly dispatch charging limits during time of congestion.
- Maintains system revenue neutrality; includes rebate system to incentivize driver flexibility.
- Leveraged Argonne's SCAs and EVs/EVSE to demonstrate real transactive sessions.

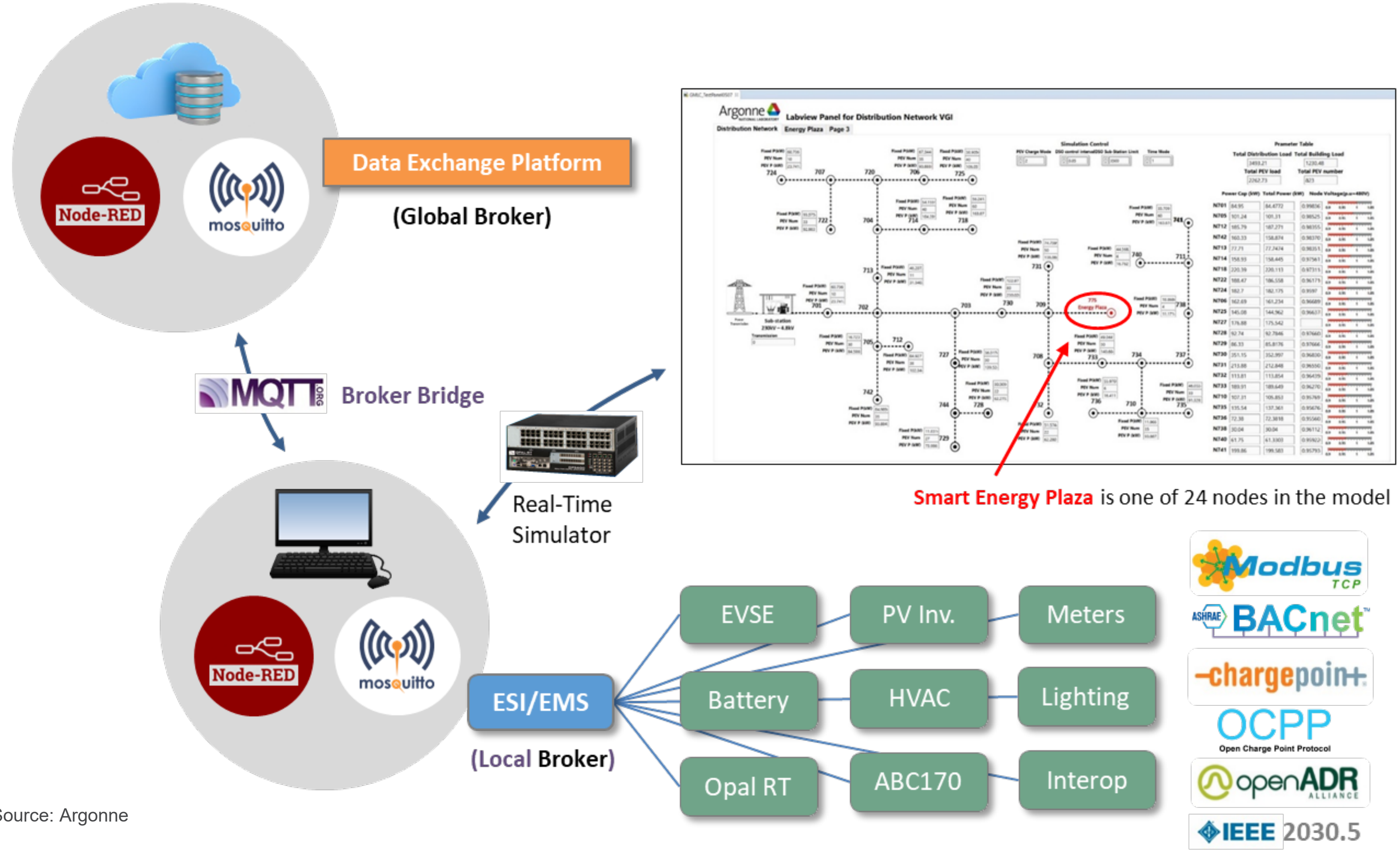


PEV	Energy Cost	Rebates	Total	Avg. Rate
Chevrolet Volt 2012 1	0.291 (USD)	0.001 (USD)	0.29 (USD)	0.026 ($/kWh)
Chevrolet Volt 2012 2	0.258 (USD)	0.002 (USD)	0.256 (USD)	0.031 ($/kWh)
Nissan Leaf 2015 1	0.436 (USD)	0.258 (USD)	0.178 (USD)	0.012 ($/kWh)
Nissan Leaf 2015 2	0.542 (USD)	0.006 (USD)	0.537 (USD)	0.028 ($/kWh)
BMW i3 2014 1	0.652 (USD)	0.092 (USD)	0.559 (USD)	0.032 ($/kWh)
BMW i3 2014 2	0.497 (USD)	0.011 (USD)	0.486 (USD)	0.044 ($/kWh)

Source: Argonne

DISTRIBUTED NETWORK MODEL

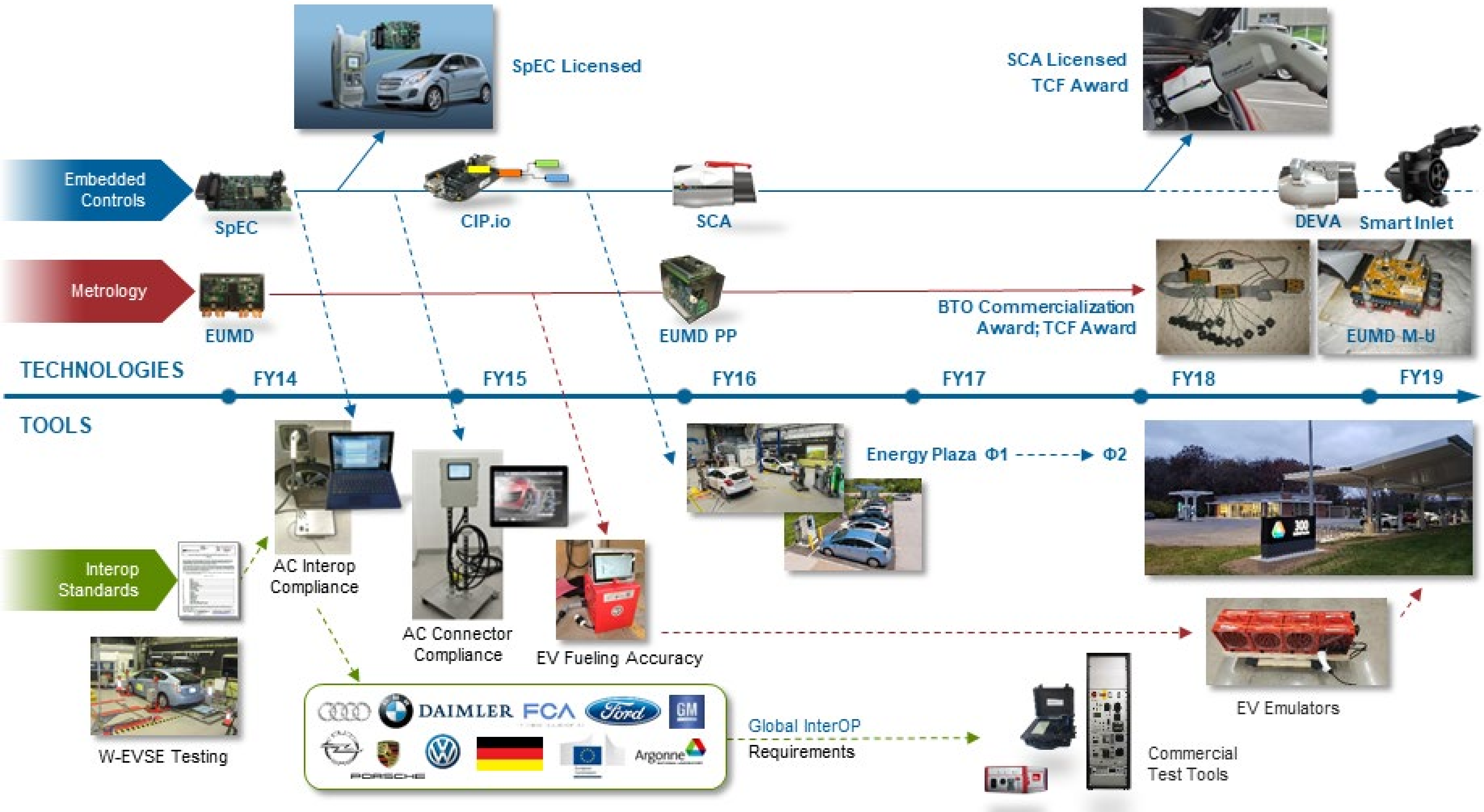
Linked to Energy Plaza via OPAL-RT real-time simulator



Source: Argonne

ENABLING TECHNOLOGIES AND TOOLS

Transition from EV interoperability to grid integration



ENABLING TECHNOLOGIES

Connectivity, communication and diagnostics

Smart Charge Adaptor (SCA): 30 alpha prototypes GMLC research and project partner; alpha gap analysis; beta design

- TCF award: CRADA partners Qmulus LLC and Zen Ecosystems
  - Commercial design; supply chain development
  - Cloud platform and web application
  - ANL and CA pilot programs

Diagnostic Electric Vehicle Adaptor (DEVA) w/PLC: Leveraged alpha SCA to beta SCA/DEVA

- HomePlug Green PHY™ (HPGP) chipset: sniffer mode, Supply Equipment Communication Controller (SECC) emulation, Internet protocol (IP) communication over power lines
- Oscilloscope mode: high speed sampling of pilot/prox
- Manual operation/manipulation of EV/EVSE pilot/prox
- Mechanical hardening

Smart Charging Inlet (SCI) – Leverages SCA/EVA design to fit the inlet space of an EV and withstand the vehicle environment.

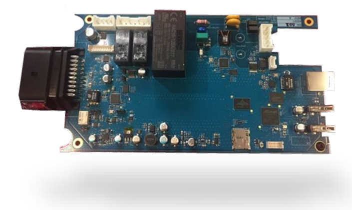
Source: Argonne

ENABLING TECHNOLOGIES

Communication and sub-metering

Communication control module (SpEC2) – Can be configured as an SECC or Electric Vehicle Communication Controller (EVCC)

- Features of original SpEC module *plus*
  - sub-metering (AC or DC)
  - AC coupled HPGP circuit for communication over power lines
  - SAE J2411 (CAN) communication.



Sub-metering for multi-EVSE installations – Power panel design can monitor and report 15 EVSE plus PV/battery inverter buffer and net load on the main feed; AC or DC; single or multiple deployments

- TCF award: CRADA partners BTCPower and Amzur Technologies
  - Supply chain development
  - Software/customer support tools
  - Process for calibration/configuration/quality assurance procedure implementation

Source: Argonne

Argonne NATIONAL LABORATORY

COLLABORATION AND COORDINATION

Team Members	Roles	Responsibilities
ANL	Lead lab	Management, development, integration and testing
INL	Contributor	Grid modeling
European Commission -Joint Research Center (EC-JRC)	Collaborator	US-EU coordination: Interoperability and smart home coordination, CIP.io/Smappee implementation
Automotive: Audi, BMW, FCA, Ford, GM, Porsche, VW	Tech. advisors, contributors	V2H/VGI opportunities/technical implications and gaps; ISO-compliant vehicles/EVSE; plan for 'public' demo; Vehicle interfaces and comm. requirements
Truck: Thor		MD/HD VGI opportunities, interfaces and gaps
EVSE – BTC Power, IoTecha, Innogy	Suppliers	EVSE, communication and control interfaces
Utility/Energy: PG&E, Shell, CA Energy Commission	Tech. advisors	Grid interface expectations, requirements, standards, gaps, opportunities/technical implications and gaps; plan for 'public' demo
ELAAD NL (DSO R&D)	Contributor	CIP.io/Smappee implementation
SMEs: 2G Engineering, Amzur, CSS, Atrius	Collaborators/Suppliers	Hardware/software development and support
TCF (SCA)– Qmulus LLC, Zen Ecosystems **TCF (sub-metering) – Amzur Technologies, BTCPower**	CRADA partners	Hardware and software refinements for commercialization; supply chain development

REMAINING CHALLENGES AND BARRIERS

Lack of consensus on vehicle-to-EVSE-to-grid communication protocols and devices with 'smart' non-proprietary interfaces

- Developing charge point operator (CPO) market has led to proprietary communication which limits integration with grid-connected devices
- Few EVs and EVSE available with ISO 15118 standard protocol

Vehicle/charging infrastructure's ability to respond adequately to support grid services/emergencies yet to be determined

- Response times/latencies of EV-EVSE combinations vary; ability of a network of grid-connected devices will depend on the implementation as well as availability (i.e., hardware and energy), local demands, etc.

Smart, interoperable connectivity and diagnostic tools for grid integration

- Emerging market is supporting high-cost instrumentation in the near-term; substantial cost reduction is required for widespread availability

Utilization and cost of high power xFC

- Integrating DC systems to increase utilization of assets and add value

PROPOSED FUTURE RESEARCH AND (MAINTAIN) COLLABORATION

Benefits of smart charging

- Enhance CIP.io with ISO 15118; acquire compliant EVs and EVSE when available
- Assess GMLC and GMLC+ use cases with compliant protocols, EVs and EVSE; compare controlled versus uncontrolled charging

Ability of EV charging infrastructure to provide grid services

- Charge management strategies to supply grid services while meeting local demands

Control for grid resiliency/reliability and impact of EVs @ scale

- Characterize communication latency and response times
- Integrate in distribution system and grids model to assess benefits and impacts of controlled versus uncontrolled charging locally and with EVs @ scale.

Enabling Technologies

- Beta development, support commercialization studies and technology transfer

US-Europe harmonization to facilitate grid integration

- Implement CIP.io and use cases in commercial platform partner

Integrating high power DC effectively

- Combining xFC, stationary storage and DC as a Service (DCaaS) to provide peak power mitigation and grid services – control and implementation issues

Any proposed future work is subject to change based on funding levels.

SUMMARY

- **Relevance**
  Directly supporting VTO objectives of increasing energy efficiency and vehicle-grid integration to support resiliency/reliability (local/grid levels); developing key enabling technologies; working with multi-national manufacturers to facilitate tech transfer
- **Approach**
  Quantifying the benefits of smart charging and determining the ability to support grid services/emergency operations; combining physical assets and modeling to assess the benefits and impacts of EVs @ scale
- **Technical accomplishments and progress**
  Previous investments and recent developments in the research facility, tools and technology provide key resources to accomplish Smart VGI Project. Key component and software developments are progressing toward implementation with industry partners.
- **Collaboration**
  Strategic alignments aid technology transfer and global harmonization
- **Future work**
  Proposed in cooperation with key players; aligned with DOE grid modernization and integration efforts