Project ID # ELT202

Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)

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June 12, 2019

DOE Vehicle Technologies Program
2019 Annual Merit Review and Peer Evaluation Meeting

Overview

Timeline

- Project start date: 10/01/2018
- Project end date: 9/30/2021 (3 years)
- Percent complete: 15%

Budget

Total project funding: $2.0M
DOE share: $2.0
Contractor share: $0
Funding for Fiscal Year (FY) 2018: $0
Funding for FY 2019: $2M

Barriers

- Barriers addressed:
  - A Need for Managed Vehicle Charging Loads Consistent with Smart Grid Operations
  - A Need to Develop and Enable Reduced Costs for Electric Charging Infrastructure
  - A Need to Develop New Control Analytics for PEV Charge Control

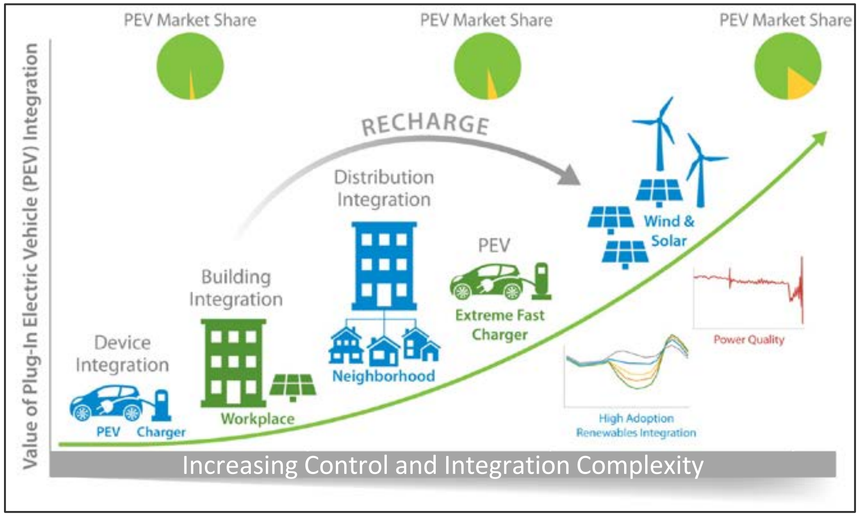
Partners

- Idaho National Lab (INL)
- Sandia National Labs (SNL)
- National Renewable Energy Lab (NREL)
- Xcel Energy
- Southern Company
- INRIX

Relevance

This project will:

1) Determine how plug-in electric vehicles (PEVs) **charging at scale** in two cities should be managed to **avoid negative grid impacts**
2) Allow critical strategies and technologies to be developed
3) **Increase the value for PEV owners, building managers,** charge network operators, grid services aggregators, and **utilities**.



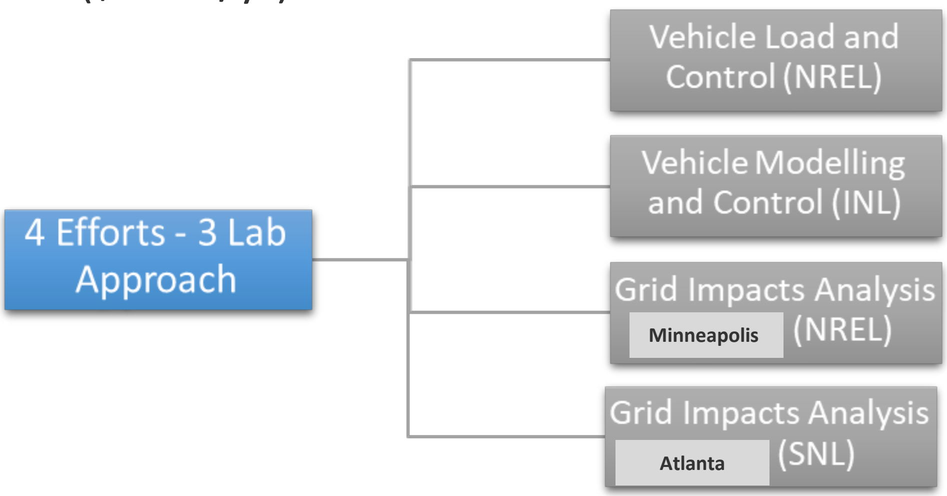
Specifically, this project will accomplish the following objectives:

1) Quantify the effects of uncontrolled charging to understand how increased PEV adoption may negatively impact the grid
2) Analyze the effectiveness of multiple control strategies in mitigating negative grid impacts introduced by PEVs at scale
3) Rank the benefits and costs of the control strategies in avoiding grid upgrades, providing grid services, and improving resiliency
4) Overcome technical barriers to implementing high-value control strategies.

Resources

Total Funding: $6M over 3 years ($2M/yr)

NREL: $3M ($1M/yr)
INL: $1.5M ($0.5M/yr)
SNL: $1.5M ($0.5M/yr)



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Milestones: All Labs

Milestone Name/Description	Deadline	Milestone Type
Identify regions and establish utility partners for distribution system and PEVs at scale impact analysis.	12/31/2018	Quarterly Progress
Develop PEV charging load dataset for at least one of the two regions	3/31/2019	Quarterly Progress
OpenDSS-based Python tools for integrating PEVs into distribution feeder models	6/30/2019	Quarterly Progress
Conversion of electric vehicle (EV) charging stations at the NREL garage	9/29/2019	Quarterly Progress
Hosting capacity analysis quantifying uncontrolled charger capacity and infrastructure limitations at all nodes on 10 real distribution grid feeders	9/29/2019	Go/No-Go Milestone
Support hosting capacity analysis with aggregator model development for python toolkit.	9/29/2019	Go/No-Go Milestone
Develop the aggregator model developed from GM0085 in Python toolkit and integrate Electric Vehicle Infrastructure Projection Tool (EVI-Pro) dataset	12/31/2019	Quarterly Progress
Implementation of building load model into NREL garage control system to include building load forecasting in smart control	3/31/2020	Quarterly Progress
Distribution impact analysis including hosting capacity, distribution system upgrades, and costs performed for the smart control strategies identified	6/30/2020	Quarterly Progress
Quantify implementation costs of multiple smart charge management approaches	9/29/2020	Quarterly Progress
Impact of smart charging control strategies at smoothing temporal voltage and power draw profiles and reducing limits on hosting capacity demonstrated	9/29/2020	Go/No-Go Milestone
Transmission-level analysis showing EV charger impact to net load profiles and resulting modifications	12/31/2020	Quarterly Progress
Demonstration of the value of smart charging integration with other DER (photovoltaic (PV), storage)) to minimize cost and grid impacts	3/31/2021	Quarterly Progress
Incorporate building control and load prediction tools into commercial product	6/30/2021	Quarterly Progress
Resiliency analysis of smart charging control and value during extreme events which stress the grid	9/29/2021	Quarterly Progress

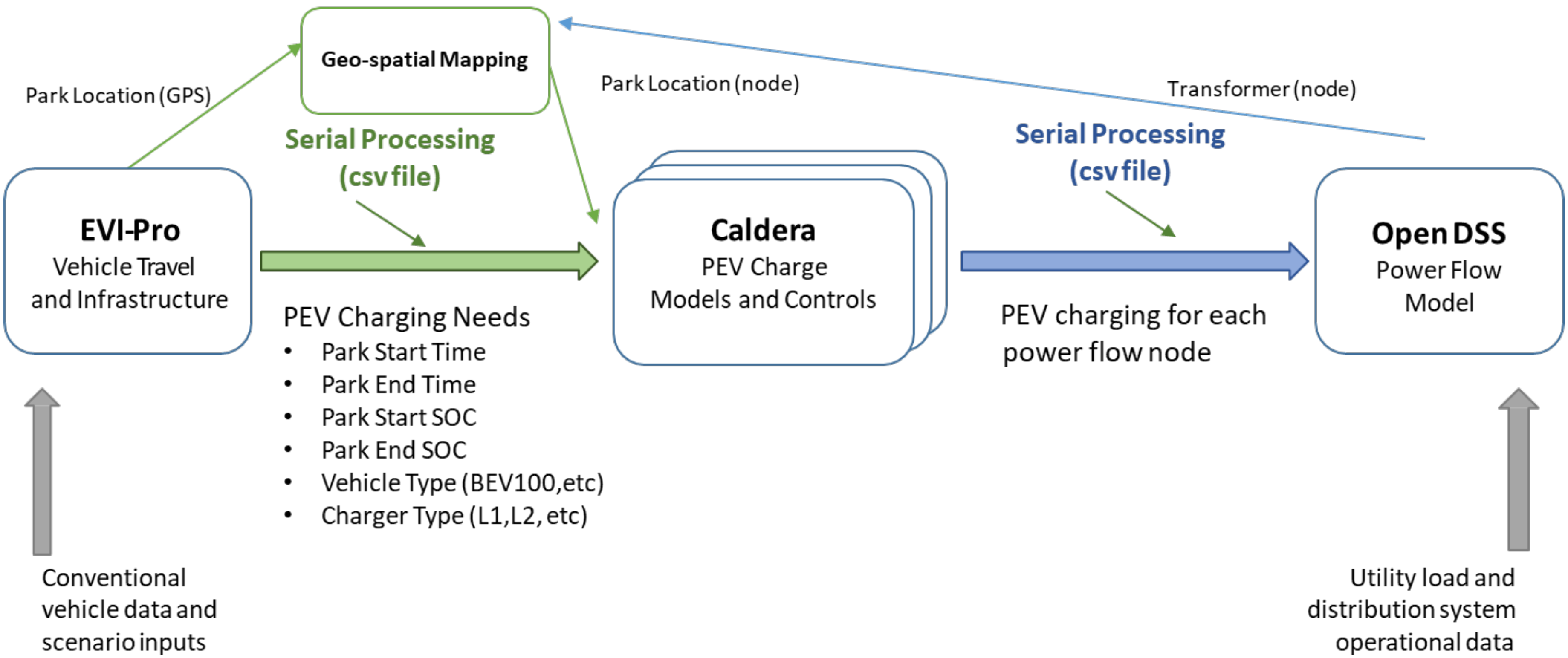
Year 1 milestones will show:

1) **Development of initial PEV loads for two cities (Minneapolis and Atlanta)**
2) **Development of OpenDSS utility models for two cities**
3) **Development of aggregator/control**
4) **Buildout of EVSE hardware for controlled experiments**
5) **Analysis of hosting capacity on 10 distribution feeders**

Approach: First, Understand PEVs at Scale with Unmanaged Charging

- No charge control flexibility

PEVs @ Scale Modeling and Analysis in Two Regions:
Atlanta: warm climate
Minneapolis: cold climate



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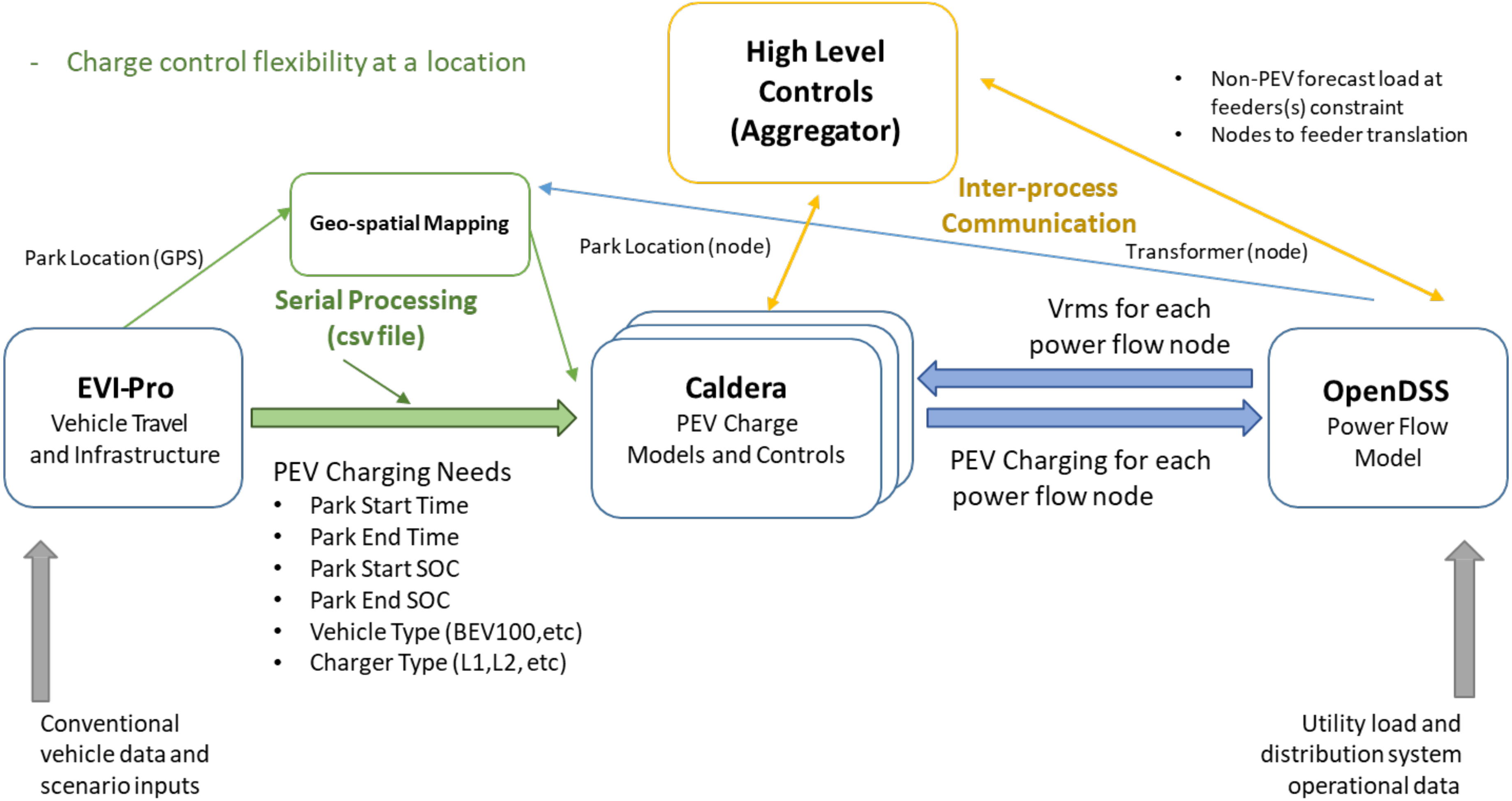
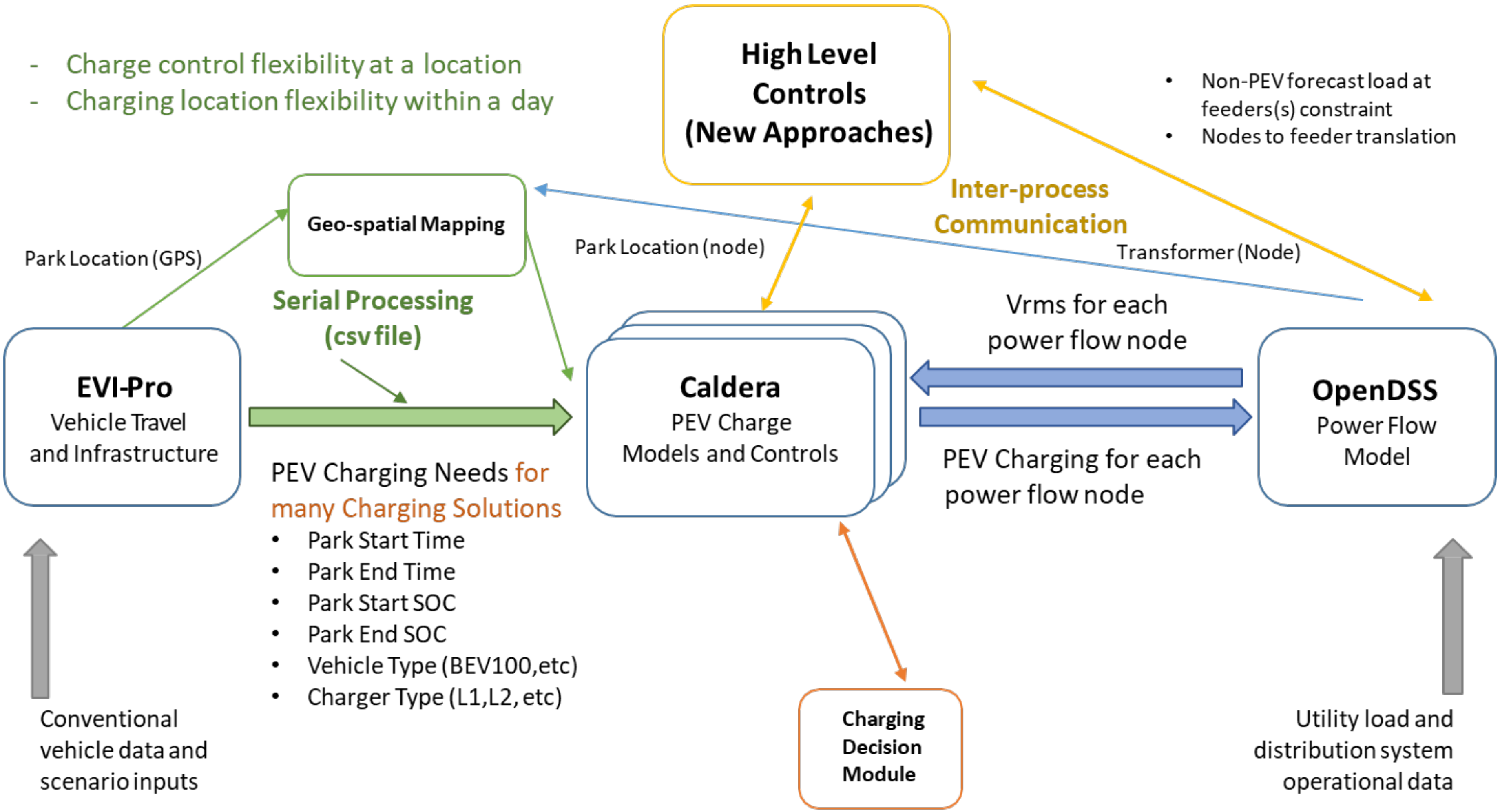
Approach: Next, Look at Managed Charging with Co-Simulation of PEV and Grid in Two Regions



Approach: Finally, Look at Advanced Charge Controls with Co-Simulation of PEV and Grid in Two Regions

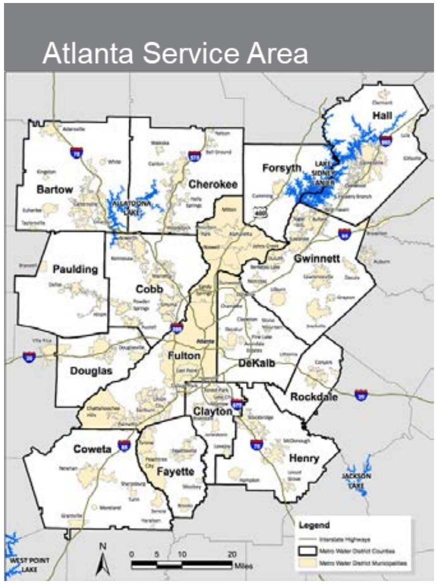


Approach: Multi-Task, Multi-Year

Task	Year 1	Year 2	Year 3
1: Scoping, Requirements, and Industry Engagement			
2: Develop PEV Charging Requirements			
3: PEV Charging and Distribution System Modeling			
4: Quantify the Impact of Uncontrolled Charging			
5: Refine Smart Charge Control Strategies (Caldera)			
6: Quantify Value of Smart Charging			
7: Investigate "Resiliency" Scenario			
8: Develop Advanced Charge Decision Model (Caldera)			
9: Integration of Smart Charging with Building Loads			
10: Integration of DER with Smart Extreme Fast Charging (XFC)			

Technical Accomplishments and Progress Task One: Scoping, Data Requirements, and Engagement with Utilities

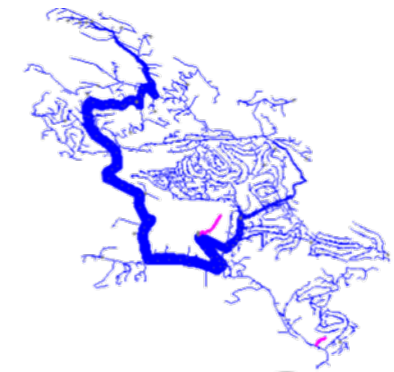
- Completed nondisclosure agreement (NDA) with Xcel Energy, Minnesota, and data received
- Priority feeder locations have been identified by Xcel Energy team based on current EV adoption
- NREL and Xcel Energy team are reconciling selection of specific areas for study
- Data are now available from Xcel for use at NREL
- NDA execution in progress with Southern Company

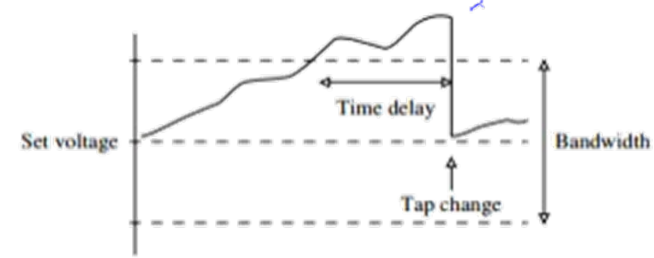


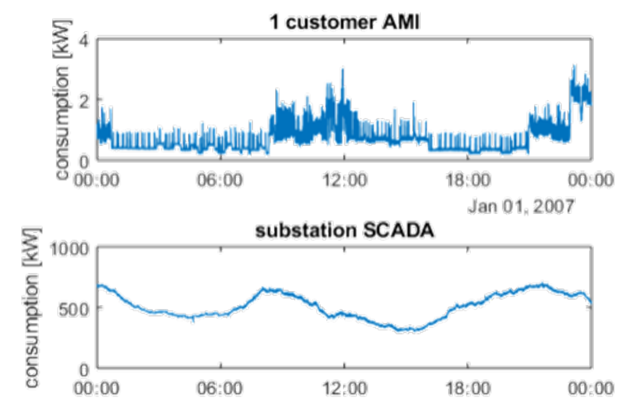
Technical Accomplishments and Progress Task One: Scoping, Data Requirements, and Engagement with Utilities

Data request

- Distribution grid load flow models in CYME/GIS for feeders in metro areas
- Additional details not always included in CYME/GIS model [voltage regulation equipment settings, distributed generation (PV, storage, etc.) and special customers (e.g., HVAC demand response)]
- Time series information: Supervisory Controls And Data Acquisition (SCADA) data, available voltage/power/current measurements, including customer advanced metering infrastructure, PV generation, etc.
- Meta-data for other feeders—feeder length, load type (residential, commercial, industrial), peak load, number of customers, feeder type (rural, urban), older/newer areas.







Technical Accomplishments and Progress Task Two: Develop PEV Charging Load Profiles

79,700 PEVs are allocated to specific locations within the study region: We estimated 3% of veh population in 2025 @ 8% of sales

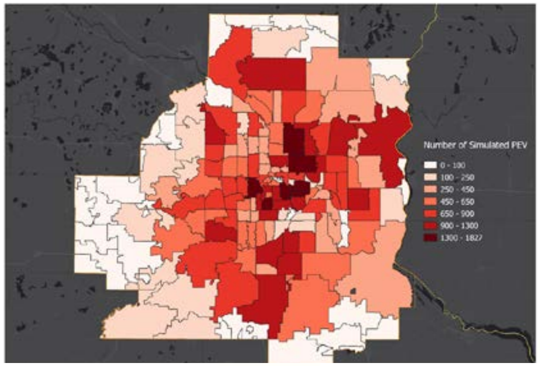
Only residential charging is considered in this update

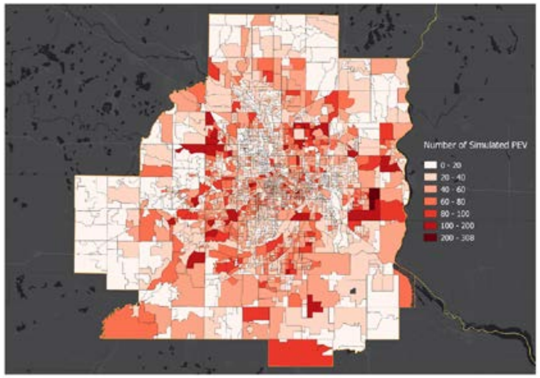
PEVs are located using 3-layer spatial disaggregation considering:

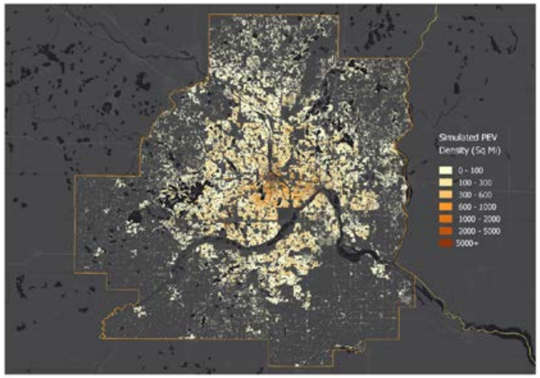
Hybrid electric vehicle (HEV) registrations (by ZIP Code)

Population (by Census block group)
Residential neighborhoods (by land use feature)

79,700 PEVs across 57,310 features
Avg 1.4 PEVs / feature
One feature with 150 PEVs
Median feature area = 1 acre







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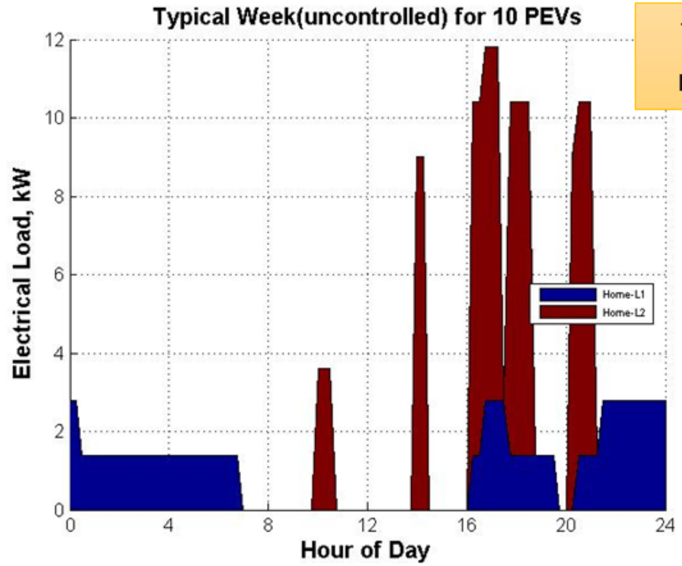
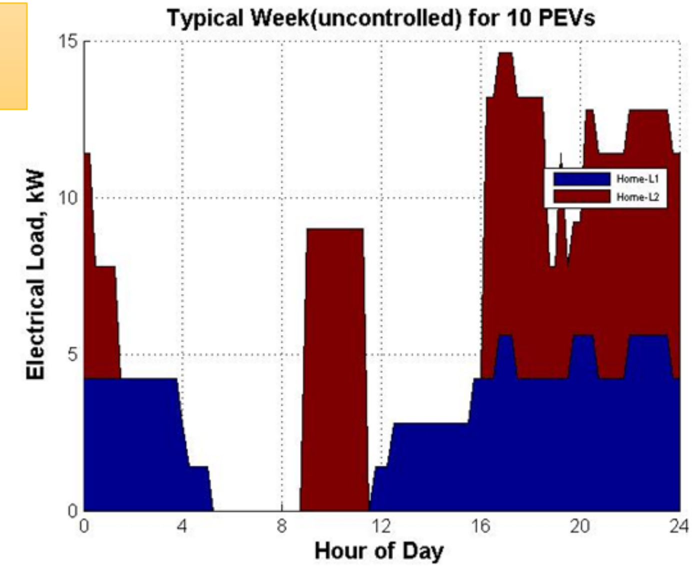
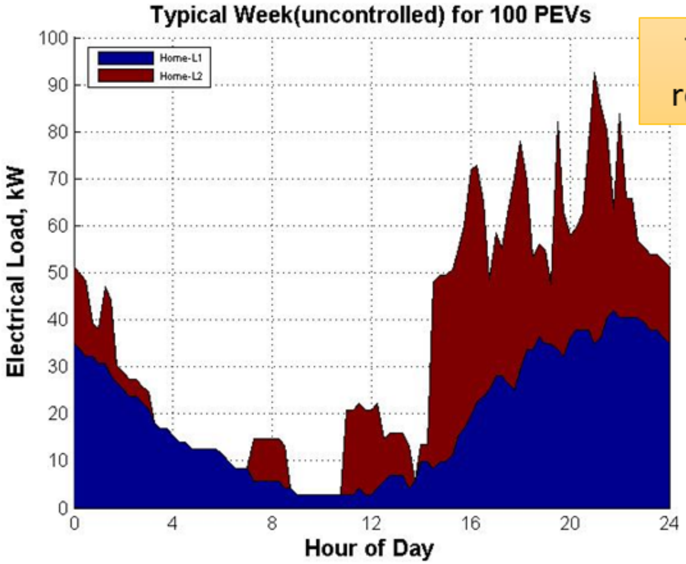
Technical Accomplishments and Progress Task Two: Develop PEV Charging Load Profiles

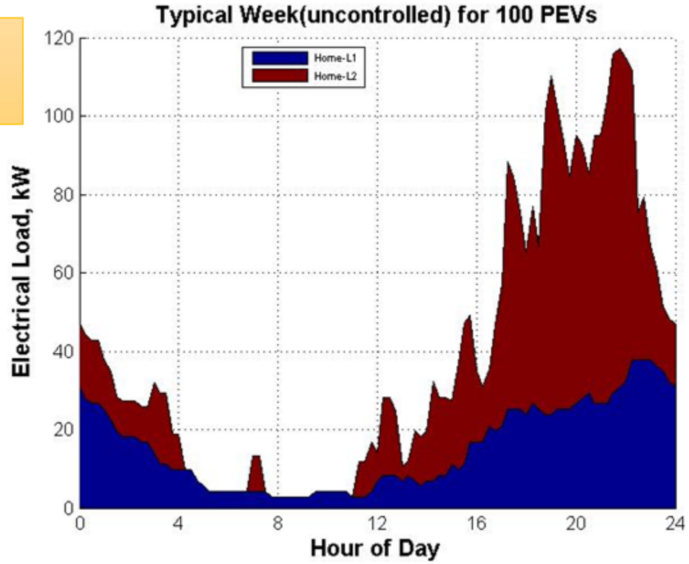


Two random aggregations of residential load from 10 PEVs





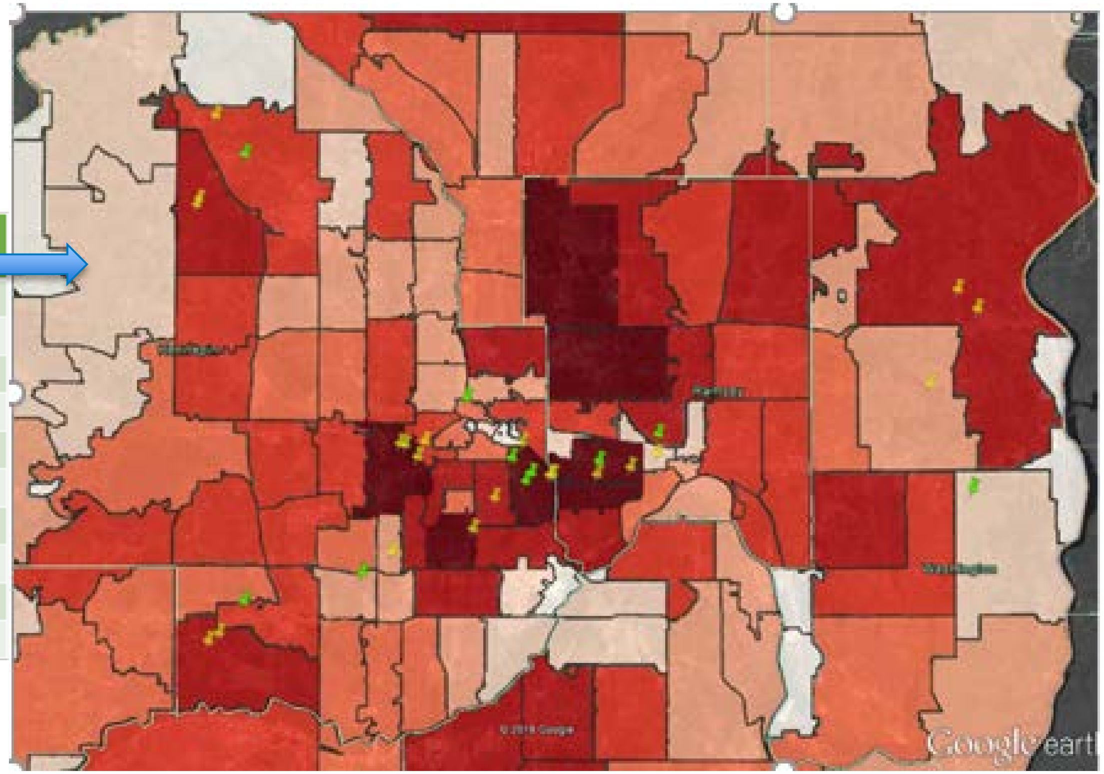
Two random aggregations of residential load from 100 PEVs



Technical Accomplishments and Progress Task Three: PEV and Distribution System Modeling

Feeders have been identified by Xcel Energy in Minnesota for the EV integration study and mapped:

Feeder#	Area	Feeder voltage (kV)	# of customers
Feeder1	White Bear Lake	34.5	4927
Feeder2	Minneapolis	13.8	2975
Feeder3	Maple Grove	34.5	4376
Feeder4	Edina	13.8	2746
Feeder5	Minneapolis	13.8	2649
Feeder6	St. Paul	13.8	3564
Feeder7	Minneapolis	13.8	3349
Feeder8	Minneapolis	13.8	2891
Feeder9	St. Paul	13.8	2194
Feeder10	Minnetonka	13.8	1588



Methodology to map vehicle charging locations and substation locations being developed–will use EV charge data (time, location) from Task Two.

Technical Accomplishments and Progress Task Three: PEV and Distribution System Modeling

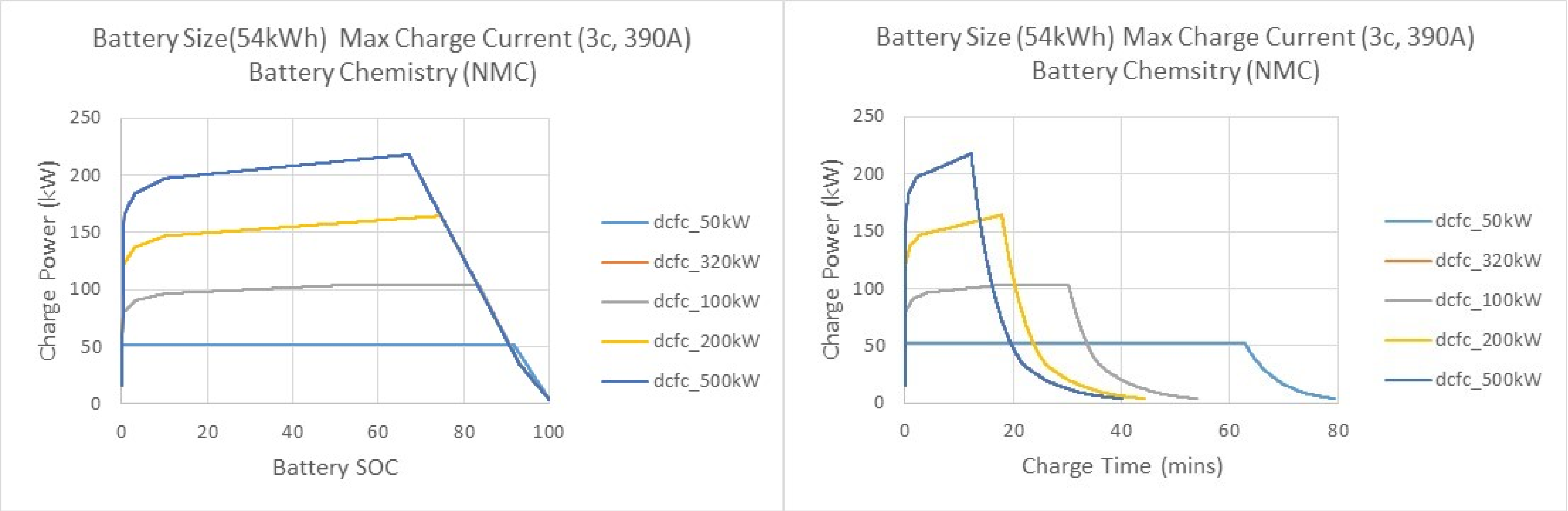
- OpenDSS model development underway
  - Data request in progress
- Python-based toolkit
  - Task intent
    - Create control interface
    - Create visualization tools to monitor results
  - Leverage existing Python packages
    - dss_python
    - OpenDSSdirect
  - Current progress
    - Dynamic input control interface
    - Circuit Map
      - Topology map
      - Dynamic print out of line information from plot

Technical Accomplishments and Progress Task Three: Add High-Fidelity PEV Charging Models to Caldera

High-fidelity PEV charging models developed and validated against lab testing results of actual equipment

Progress to date

- Level 2 PEV charging models integrated into Caldera
- Direct-current Fast Charging (DCFC) and XFC PEV charging profiles developed from battery test data
- Began integrating DCFC and XFC charging models into Caldera



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Technical Accomplishments and Progress Task Four: Run OpenDSS Models and Assess Impacts

Progress:

- Identified Python-based tools that were used for prior studies on hosting capacities
- Developed metrics for evaluating grid performance for hosting capacity analysis
- Jointly developing and prioritizing grid performance metrics for hosting capacity analysis:
  - **Voltage Violation Magnitude Index:** Quantifies the average voltage violation with respect to a predefined lower threshold
  - **Voltage Violation Frequency Index:** Quantifies the spread of violations across the system by the ratio of the number of nodes violating the lower voltage limit to the total number of nodes, for the given time window
  - **Voltage Unbalance Index:** Ratio of maximum deviation from average to average voltage (of three phase)
  - **Voltage deviation:** Average deviation from nominal values (nominal values are considered from the scenario when EV charging did not take place)
  - **Losses**: Total losses occurred in the distribution feeder
  - **Operation of control devices:** Number of tap change counts and capacitor bank switching operations within a given time window

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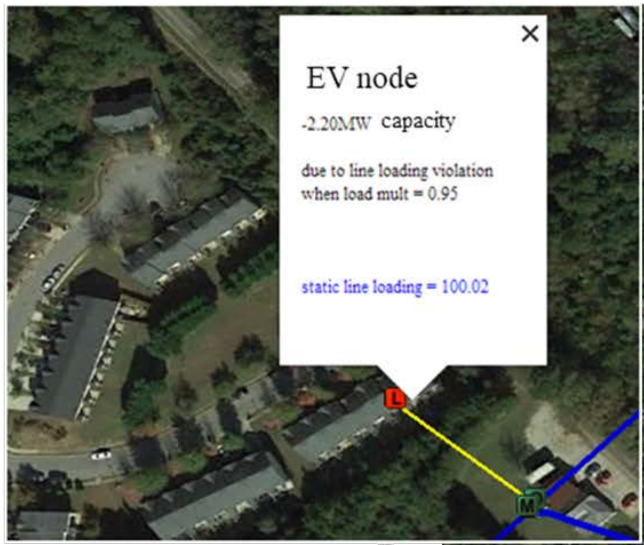
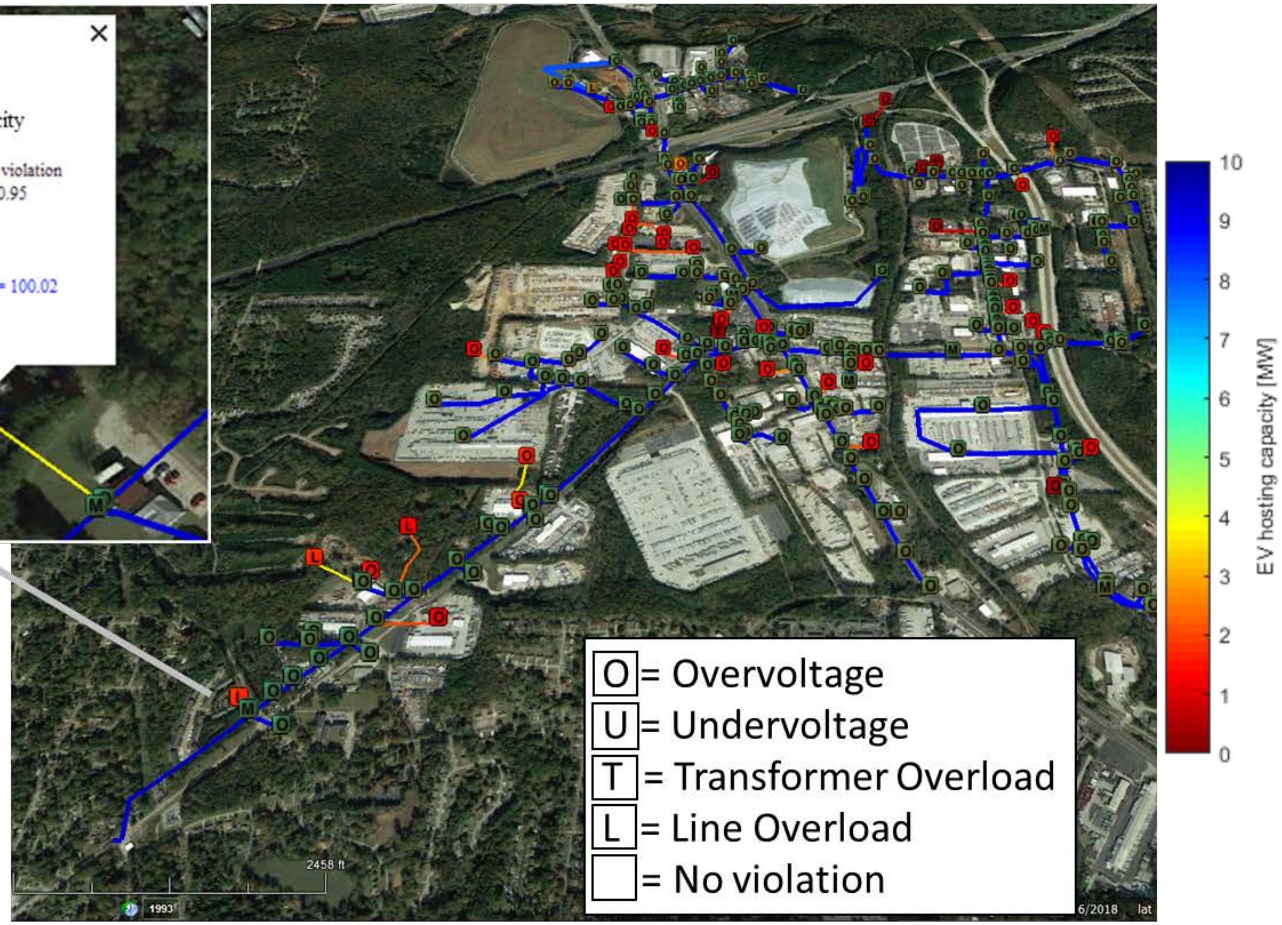
Technical Accomplishments and Progress Task Four: Run OpenDSS Models and Assess Impacts

Progress: Creating framework to run simulation to assess hosting capacity

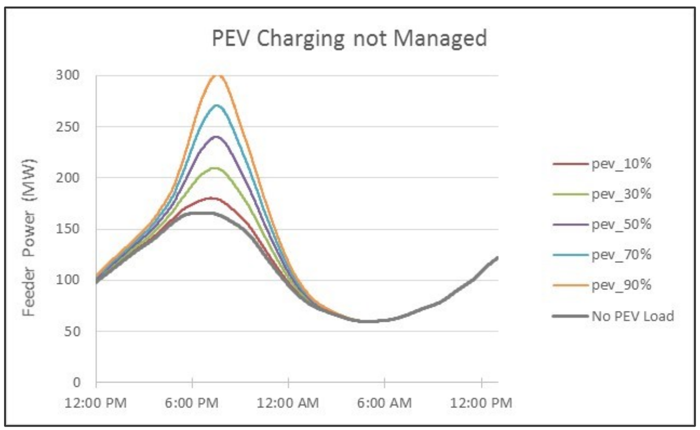


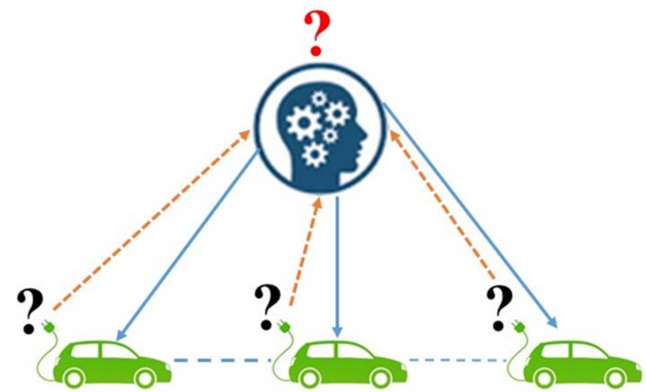
At this node, a 2.2MW EV charging load would lead to a line loading violation (too much current through line).

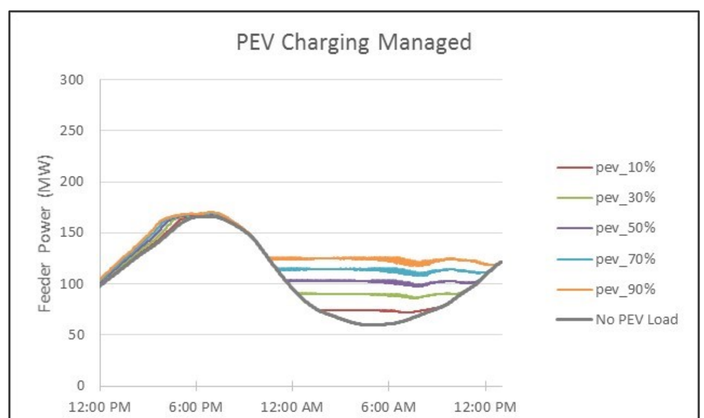


Technical Accomplishments and Progress Task Five: Develop PEV Charging Control Strategies

- Progress to date:
  – Began integrating into Caldera the centralized PEV charging control strategy developed in the GMLC GM0085 project
  – Began literature review for distributed PEV charge control beyond centralized aggregator control
  – Started investigating the potential distributed control structures that are feasible for PEV charging at scale.







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Responses to Previous Year Reviewers' Comments

- This project is a new project and was not reviewed last year.

Collaboration and Coordination: Multi-Lab Approach with Multiple Industry Partners

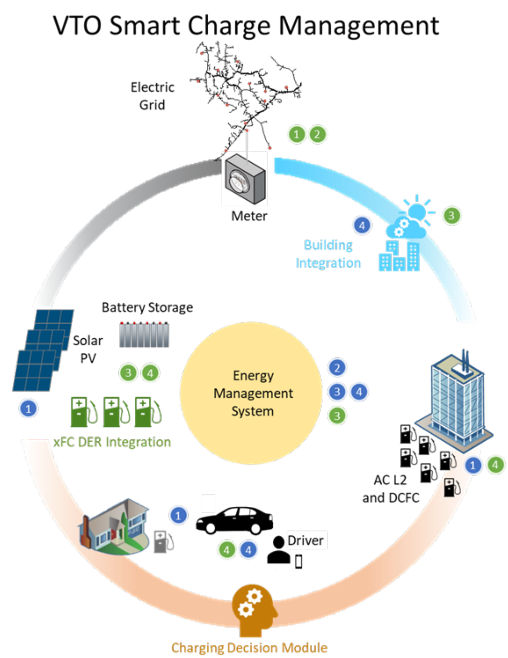
- **National Renewable Energy Laboratory:** Leading the project and developing PEV load profiles, as well as MN OpenDSS model
- **Idaho National Lab:** Co-funded sub to the project, responsible for developing aggregator model
- **Sandia National Labs:** Co-funded sub to the project, responsible for developing Atlanta OpenDSS model
- **Xcel Energy:** Providing data from Minneapolis distribution grid to assess loads and hosting capacity
- **Southern Company:** Providing data from Atlanta distribution grid to assess loads and hosting capacity
- **INRIX:** Subcontractor providing Minneapolis and Atlanta travel/vehicle data to assess PEV spatial and temporal charging loads

Also - coordination with other Smart Charge Management Projects

Smart Vehicle-Grid Integration

1. Vehicle role for home and workplace energy management
2. Controls for grid integration (GMLC use cases)
3. Optimal control on customer side for grid resilience and stability
4. Enabling technologies and tools development

TIMESTEP
Sub-second to hours



Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)

1. Simulation and controls development to minimize distribution impacts
2. Regional modeling for distribution operations & capacity planning
3. Forecasting-enhanced charging integration with buildings and DER
4. Predictive and interactive charge decision making

TIMESTEP
Minutes to weeks

Remaining Challenges and Barriers

- PEV loads: initial estimates are complete using surrogate data from other studies, but creation of actual PEV loads using INRIX data for both regions is still needed
- Utility mapping: utility engagement for both regions and key data to identify and analyze priority distribution feeders
- Overlay of PEV loads and utility data at a high resolution spatially and temporally is key to project
- Aggregator controls need to be developed, hardware demonstration of controllable devices will be needed in future years.

Proposed Future Research: Remainder of FY 19

- Project, as proposed and funded, is a 3-year project.
- Significant efforts in years 2 and 3 will drive success of project: assess impacts of high penetration, uncontrolled charging, and control strategies to mitigate impacts to grid or PEV owners.
- Remainder of FY 19:
    - Integration of controls with new commercial charging systems
    - Hosting capacity analysis for ten distribution feeders
    - Aggregator development for hosting capacity

OpenDSS-based Python tools for integrating PEVs into distribution feeder models	**3.1.1** **3.1.2**	**6/30/2019**	**Quarterly Progress**
Conversion of EV charging stations at the NREL garage	9.1.1	9/29/2019	Quarterly Progress
Hosting capacity analysis quantifying uncontrolled charger capacity and infrastructure limitations at all nodes on ten real distribution grid feeders	4.1.1	9/29/2019	Go/No-Go Milestone
Support hosting capacity analysis with aggregator model development for python toolkit.	5.1.1	9/29/2019	Go/No-Go Milestone

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

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Proposed Future Research: FY 20 and FY 21

Task#	Description	Lead	Funding	Q1	Q2	Q3	Q4
Year 2 (FY 2020)			k				
1.2	Dissemination of results and learnings to utility partners to maintain engagement and ensure project objectives are aligned with industry objectives.	NREL	$ 25				
		SNL	$ 25				
		INL	$ 25				
5.2.1	Implement and calibrate non-aggregator control strategies in OpenDSS platform (follows task 5.1.2)	INL	$ 185				
		NREL	$ 250				
		SNL	$ 125				
5.2.2	Modify the high-fidelity PEVcharging models to accommodate new control methods developed in Task 5.1.1; incorporate advanced inverter functionality	INL	$ 135				
6.2.1	Assess distribution impacts/value of smart charging: existing hosting capacity, determine required upgrades; repeat simulation and analysis with new control	NREL	$ 225				
		SNL	$ 200				
6.2.2	Assess transmission impacts/value: generation requirements; repeat simulation and analysis with new smart charging control	SNL	$ 150				
6.2.3	Quantify implementation costs of multiple smart charge management approaches and produce value (i.e., cost vs. benefit) assessment	INL	$ 155				
		NREL	$ 100				
9.2.1	Integrate the building model into the smart control system	NREL	$ 200				
9.2.2	Implement and calibrate building model for the NREL campus	NREL	$ 200				
	Totals		$ 2,000.00				

Task#	Description	Lead	Funding	Q1	Q2	Q3	Q4
Year 3 (FY 2021)			k				
1.3	Dissemination of results and learnings to utility partners to maintain engagement and ensure project objectives are aligned with industry objectives.	NREL	$ 25				
		SNL	$ 25				
		INL	$ 25				
8.3.1	Develop CDM	INL	$ 150				
8.3.2	Incorporate vehicle CDM into load forecasting methodology used in high-value control strategy from Tasks 5.2.1 and 6.2.1	INL	$ 75				
		NREL	$ 200				
10.3.1	Develop xFC site model in OpenDSS and agent-based optimization routine in Python toolit	INL	$ 125				
		NREL	$ 225				
		SNL	$ 100				
10.3.2	Run simulation and assess distribution impacts: existing hosting capacity, determine required upgrades (repeat analysis with new xFC and control)	NREL	$ 150				
		SNL	$ 100				
7.3.1	Resiliency Analysis - Assess the ability of and develop strategies for smart charging during resiliency events which stress the grid	SNL	$ 275				
9.3.1	Implement high-value control strategy, demonstrate, and validate building control strategy with enhanced load forecasting methodology in NREL paring garage	INL	$ 125				
		NREL	$ 250				
9.3.2	Incorporate building control and load prediction tools into commercial product	NREL	$ 150				
	Totals		$ 2,000.00				

Years 2 and 3:

- Build out and analyze new scenarios (workplace, public, XFC, etc.)
- Develop "base" and "advanced" control strategies to mitigate impacts
- Develop load forecasting information
- Resiliency analysis
- Integration and development into final tools

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

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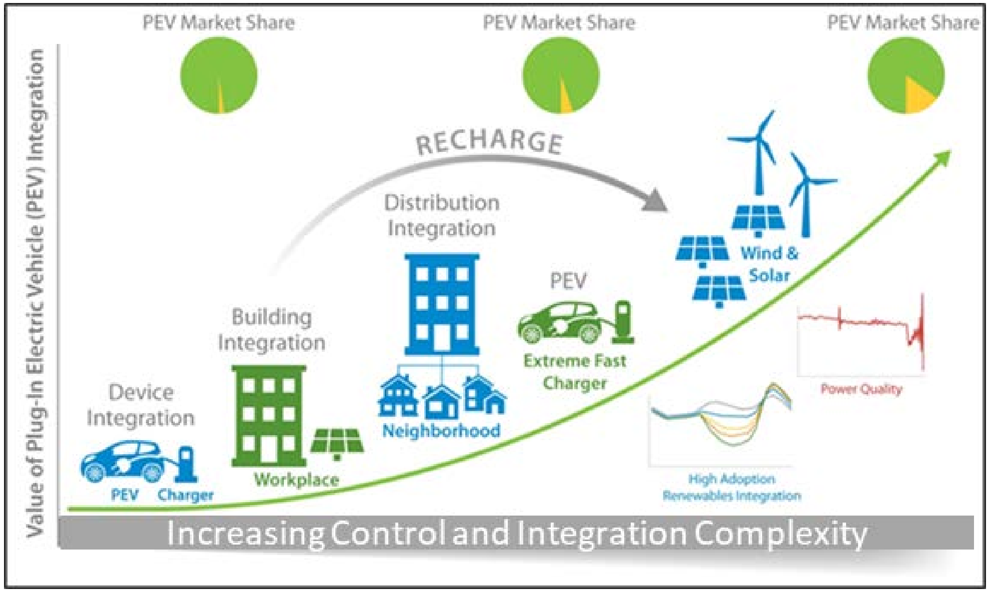
Summary

This project will:

- Determine how **PEV charging at scale** in two cities could be managed to avoid potential negative grid impacts
- Allow for critical strategies and technologies to be developed
- **Provide solutions to increase the value for PEV owners, building managers,** charge network operators, grid services aggregators, and **utilities**.



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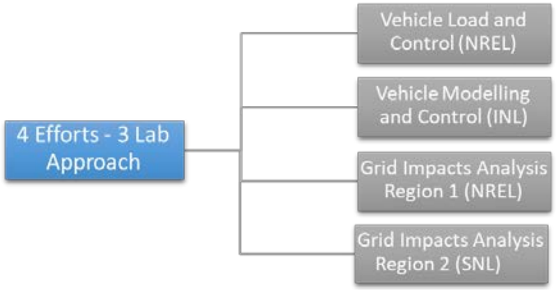

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Thank You
The RECHARGE Team

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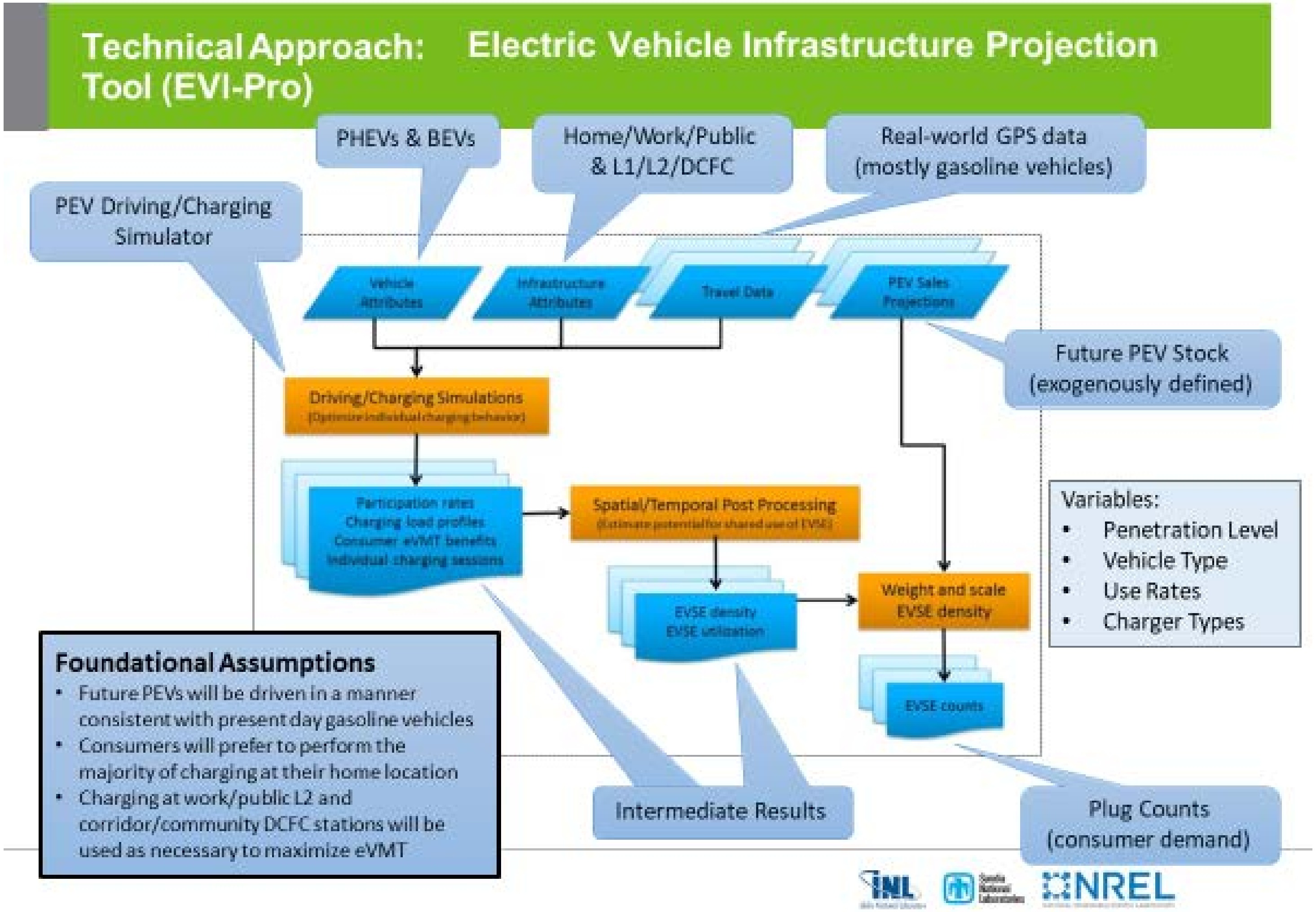
Technical Back-Up Slides

Technical Back-Up Slides



Technical Back-Up Slides

Simulation City	Minneapolis
Simulation Year	2025
PEV Sales %	8.3%
PEV Stock %	3.1%
PHEV20 share	12.5%
PHEV50 share	15.3%
BEV100 share	12.9%
BEV250 share	59.2%
Share of BEV250s as XFC capable	50.0%
PEV Sedan %	83.4%
PEVs by residence type	Single Family Dominant
PEVs by zip code	Proportional to 2017 HEVs
PEVs by block group	Proportional to population
Home EVSE distribution	Per UC Davis Survey
Charging Behavior	Home Dominant
Work EVSE Availability	10%
DCFC Power	150 kW

Near term PEV adoption scenario consistent with Energy Information Administration projections

Equal to approximately 79,700 LDVs as PEVs (out of 2.6M LDVs in 7-county area)

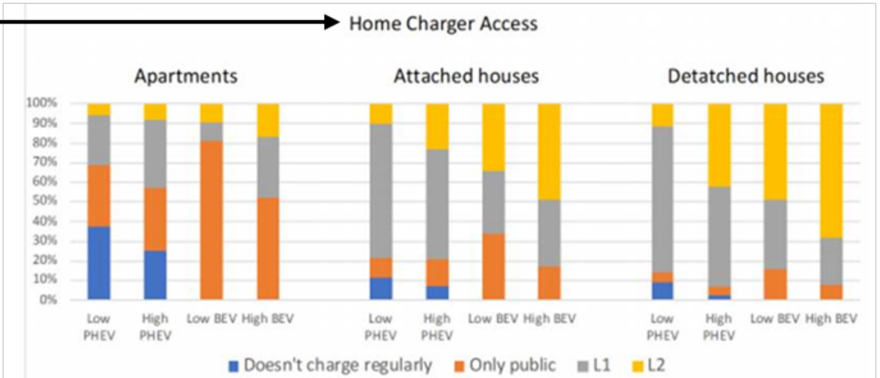


Figure 1 Home charging access by dwelling type and vehicle type

This scenario is not intended to be a forecast of the future!
Seeking feedback from VTO to inform additional scenarios within RECHARGE.

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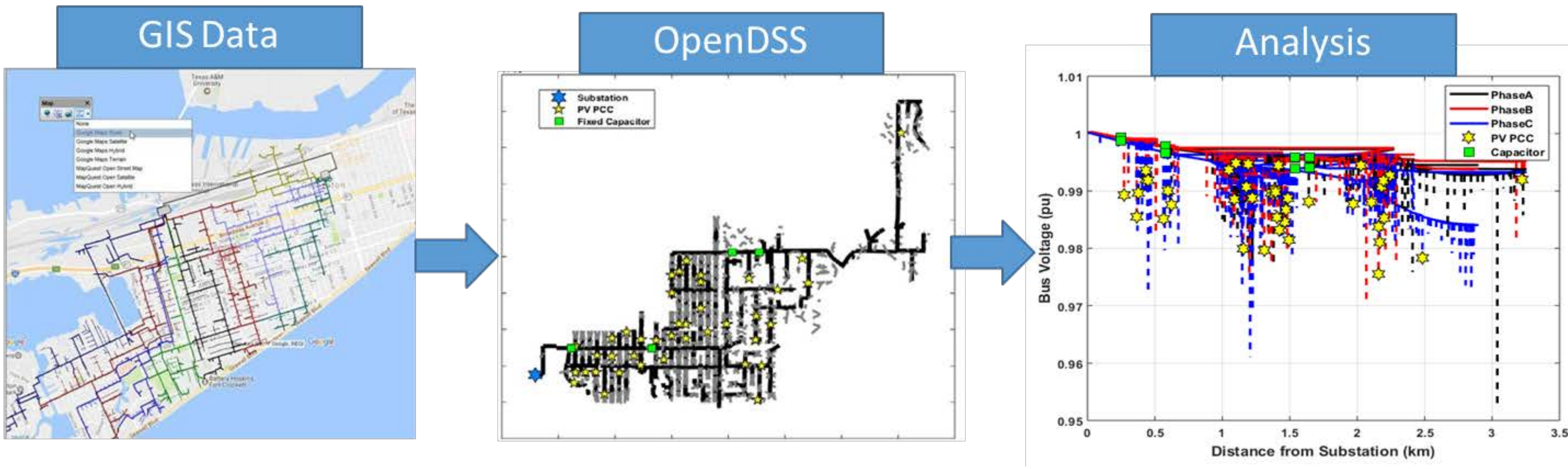
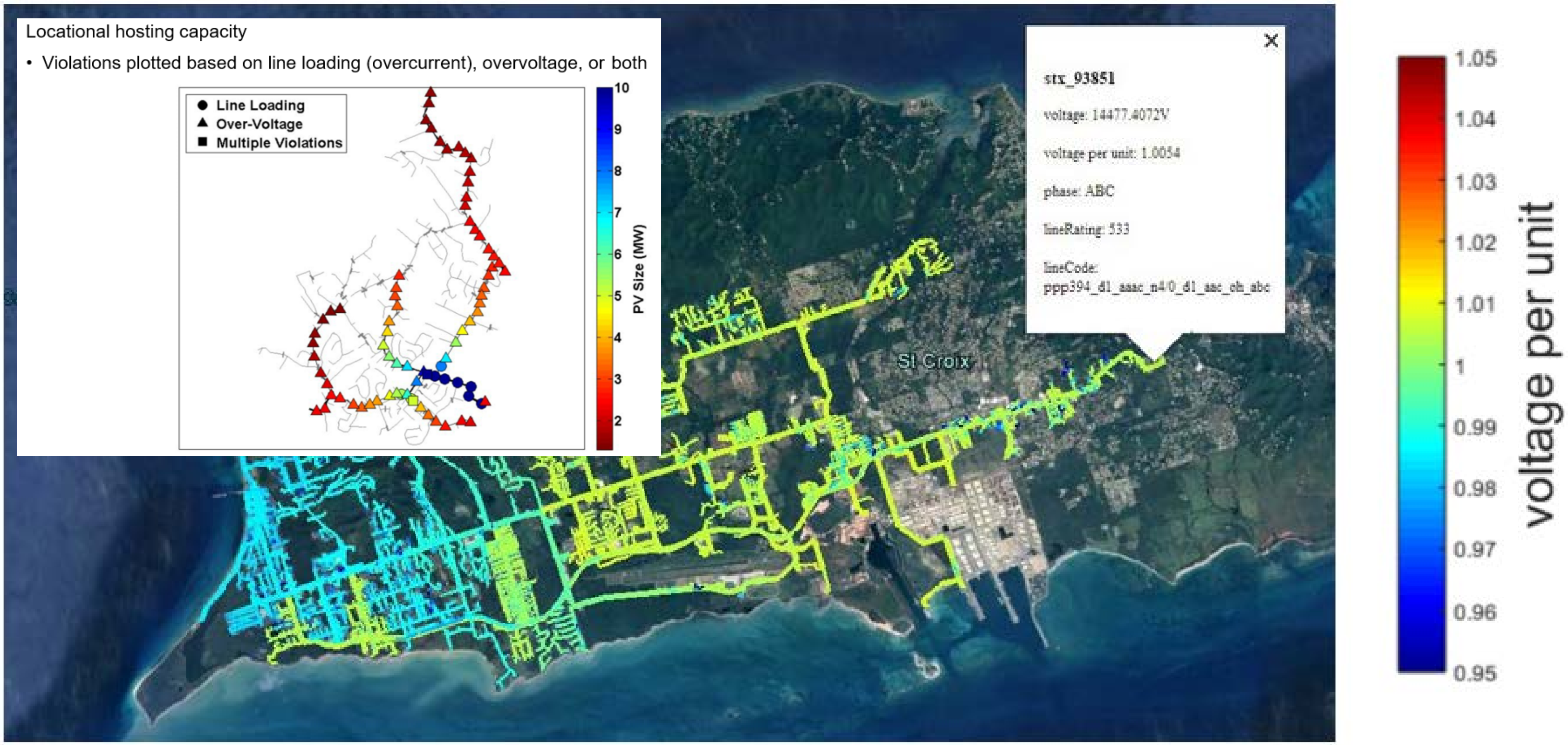
Technical Back-Up Slides

- Utility data is a repository of data from multiple databases – utility asset locations, conductor and transformer sizing, customer load profiles, etc.
- The entirety of this data is used to develop an OpenDSS model that represents the electrical properties of the grid
- OpenDSS model used for further analysis



Technical Back-Up Slides

When successfully converged, OpenDSS outputs modeled voltage, current, and power flow at each node on the feeder



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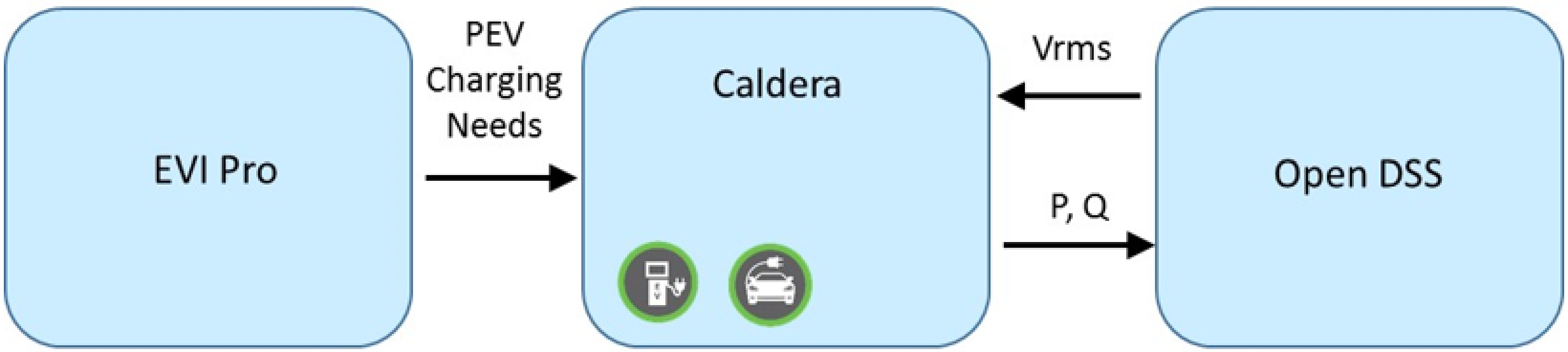
Technical Back-Up Slides

- Task Plan:
  - Integrate into Caldera L2 charging models from GM0085
  - Develop and integrate into Caldera 50 kW DCFC and 350 kW XFC charging models.



PEV Charging Needs
- PEV Make/Model
- Arrival & Departure Time
- Arrival & Departure SOC
- …

DCFC & XFC charging models

Level 2 PEV charging models