



EV Charging Load Forecasting Simulation Platform

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ESIG Workshop - 13 June 2023



Caldera™

An Idaho National Laboratory Tool for Modeling
Electric Vehicle, Grid, and Distributed Energy Resource
Interactions

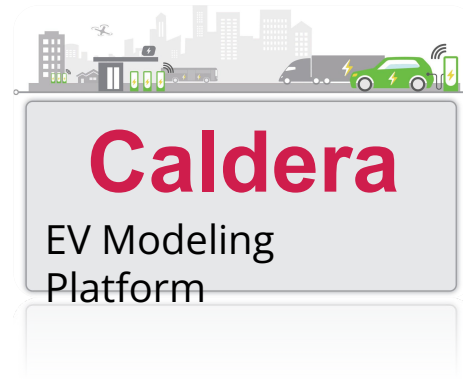
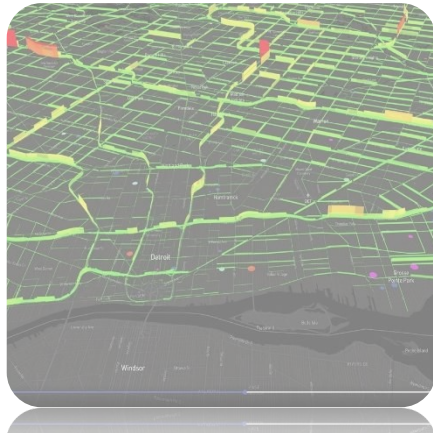
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy



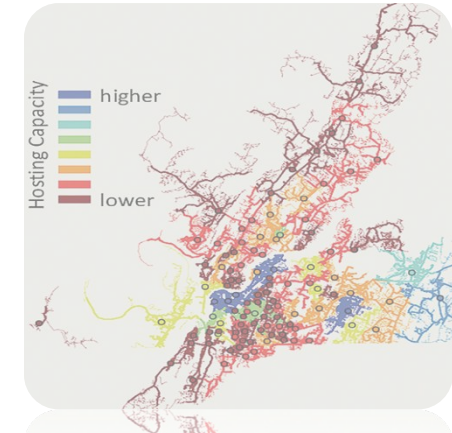
Why Caldera?

Caldera is the “**Missing Link**” to understanding EV charging demand and providing solutions to satisfy energy needs

Transportation Models



Energy System Models



Simulating mobility

Existing tools lack understanding of grid topology, power availability, charging cost information, detailed charge profiles

Linking Transportation and Grid Tools

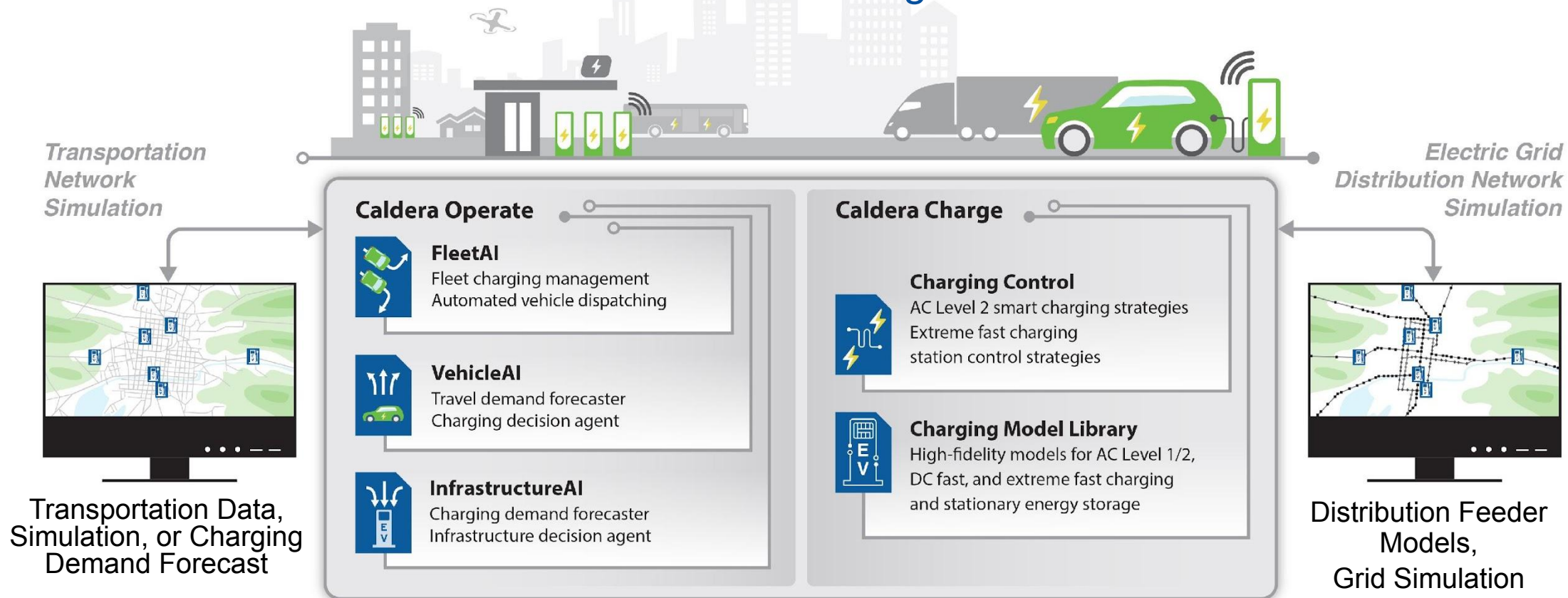
Demonstrates EV charging effects and illustrates system optimization by co-simulating both grid and driving conditions

Simulating distribution and traditional loads

Existing tools lack understanding of when and where EVs will charge, detailed load profiles, effects of control strategies

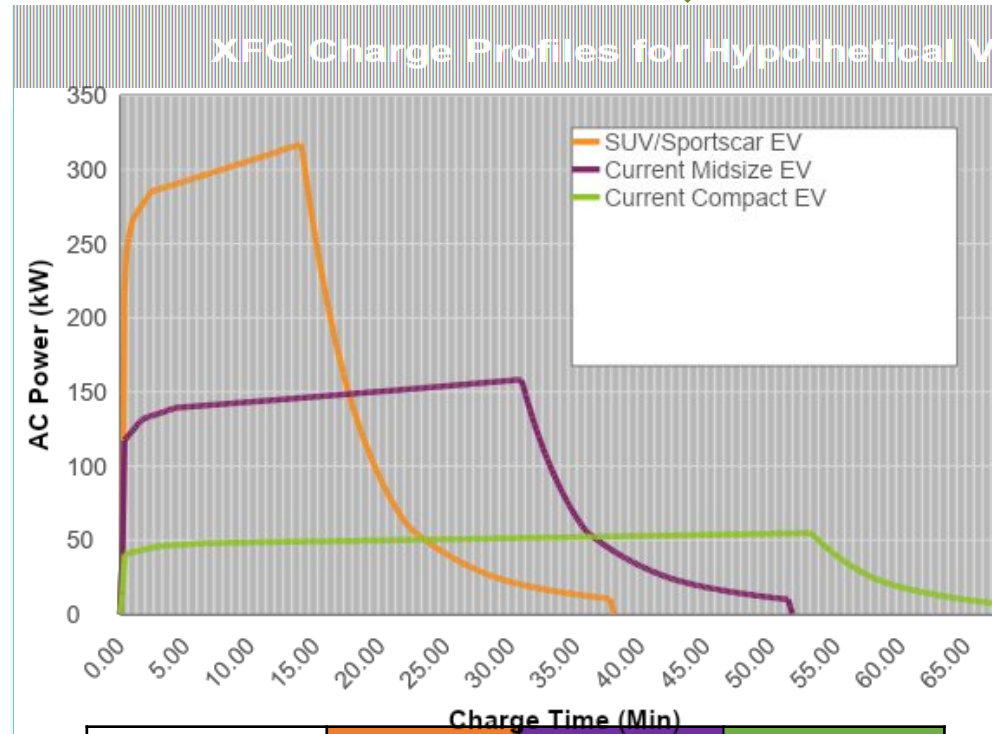
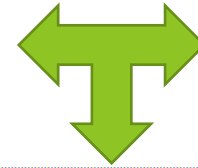
Caldera

Electric Vehicle & Infrastructure Decision Management Simulation Platform



Caldera is an agent-based modeling platform for predicting detailed system impacts and demonstrating intelligent management strategies.

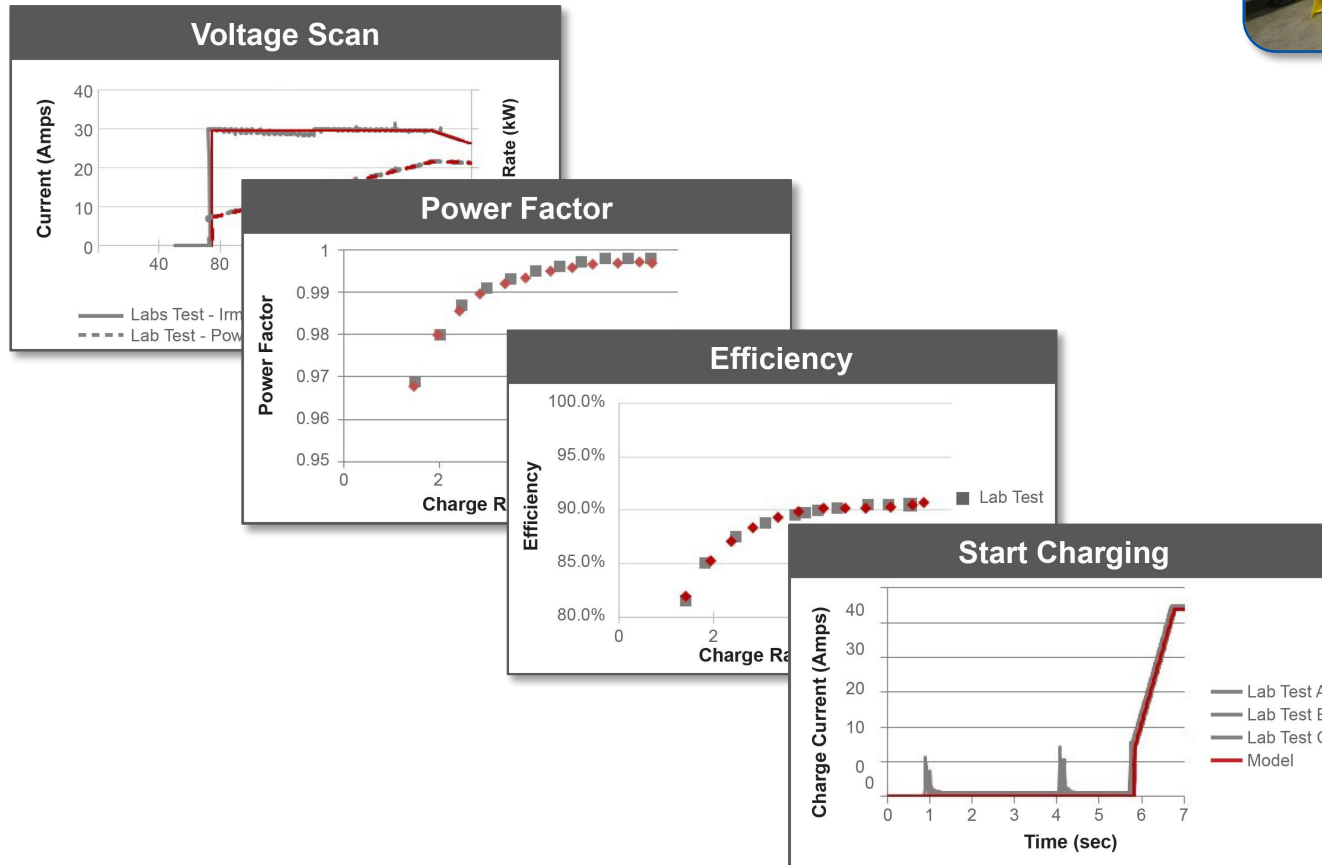
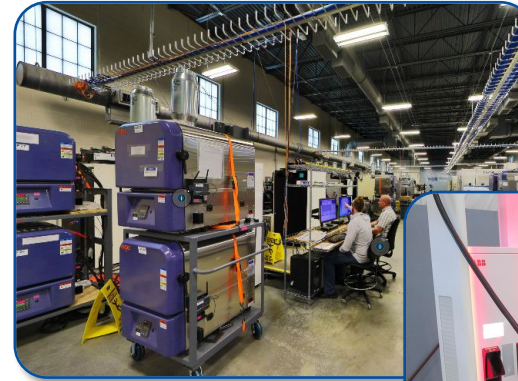
Unique Charge Profiles Based on EV and EVSE Models



	SUV/ Sportscar EV	Current Midsize EV	Current Compact EV
Max Charge Rate (kW)	300	150	50
Vehicle Range (Miles)	250	275	150
Vehicle Resembles	Porsche Taycan	Tesla Model 3	Nissan Leaf

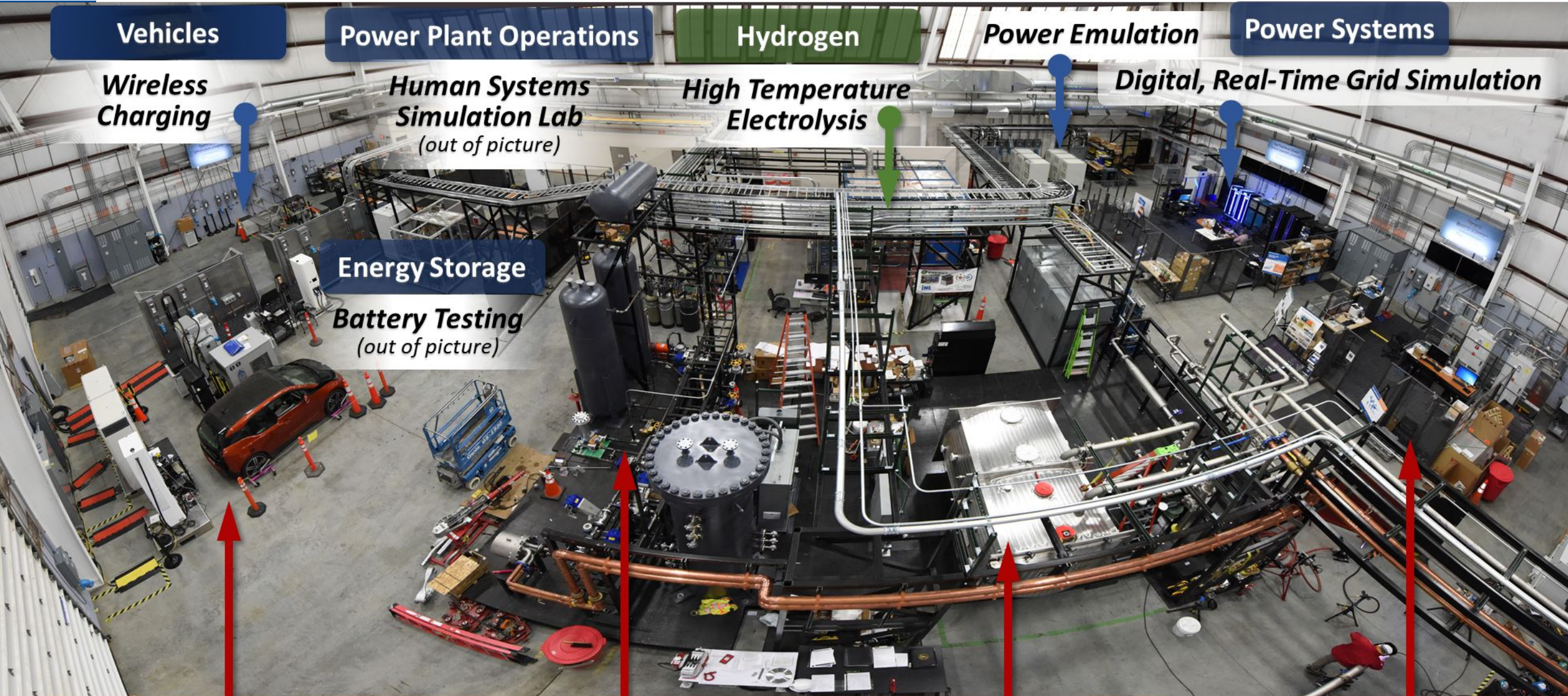
High Fidelity EV / EVSE Charging Model library

- In Caldera EVs and EVSEs are modeled **individually** using high-fidelity models. Aggregate or composite models are **not** used.
- These high-fidelity models are based on results from testing real EVs, EVSE, and batteries in the laboratory.



- The testing is done in INL's BTC and EVIL labs.
- Each of these graphs compares lab test results to outputs from one of INL's high fidelity EV charging models.

INL's Integrated Energy Systems Laboratory



Vehicles

Wireless Charging

Power Plant Operations

Human Systems Simulation Lab
(out of picture)

Hydrogen

High Temperature Electrolysis

Power Emulation

Power Systems

Digital, Real-Time Grid Simulation

Energy Storage

Battery Testing
(out of picture)

Fast Charging

Thermal Energy Delivery System
Includes Thermal Energy Storage

MAGNET
"Microreactor Agile Nonnuclear Experiment Testbed"

Distributed Energy & Microgrid

EVIL: XFC Test and Demonstrations

Emulated EV Charging
>350kW

XFC

CCS 350kW EV
Emulator

XFC electrical
data display

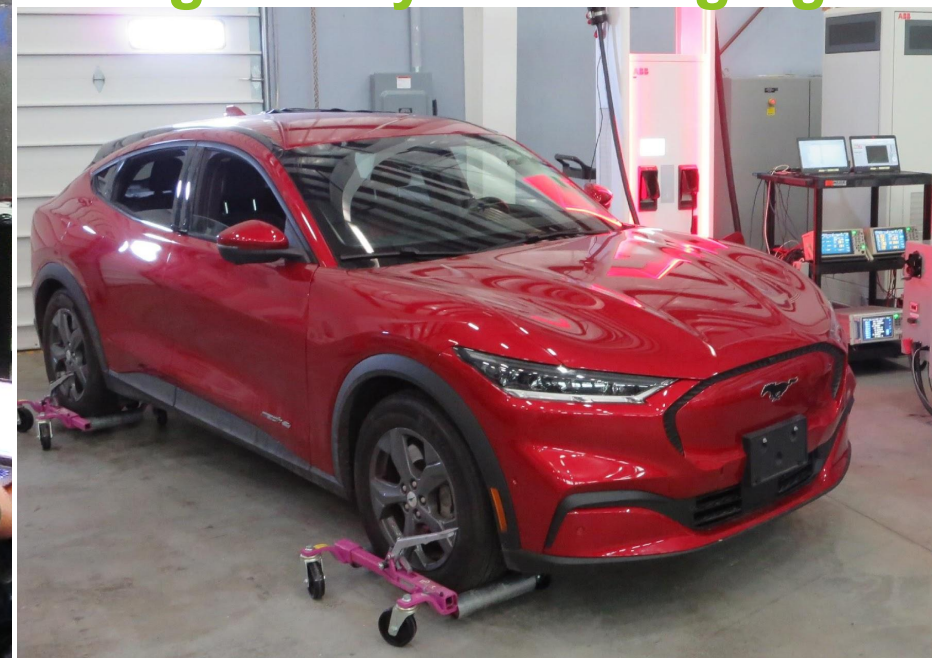
Nissan LEAF
(CHAdeMO)

OCPP
server

Heavy Duty EV Charging



Light Duty EV Charging

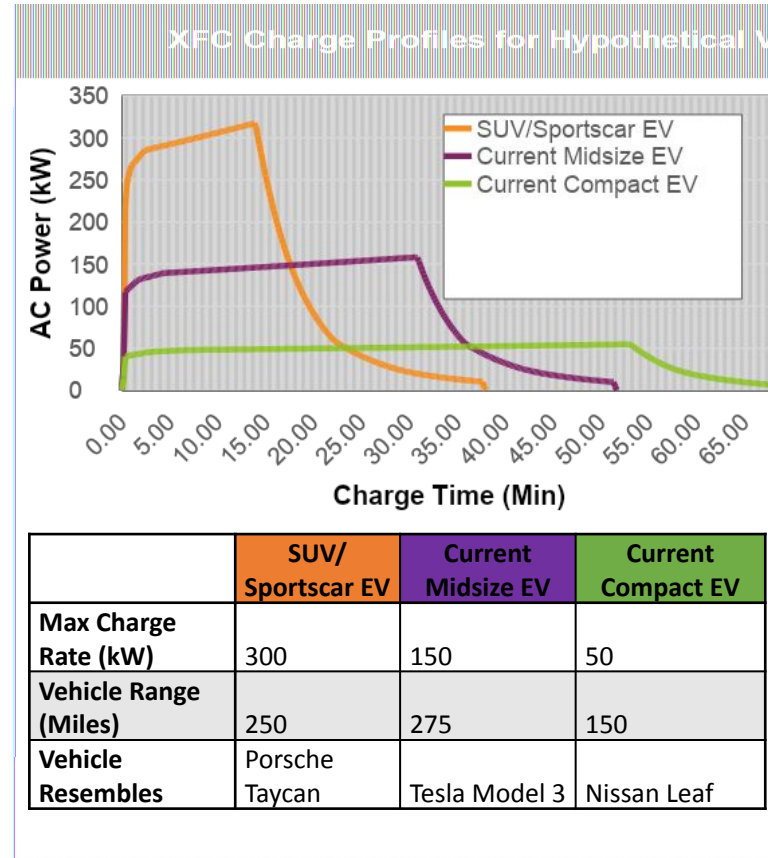


Characteristics of an XFC Station

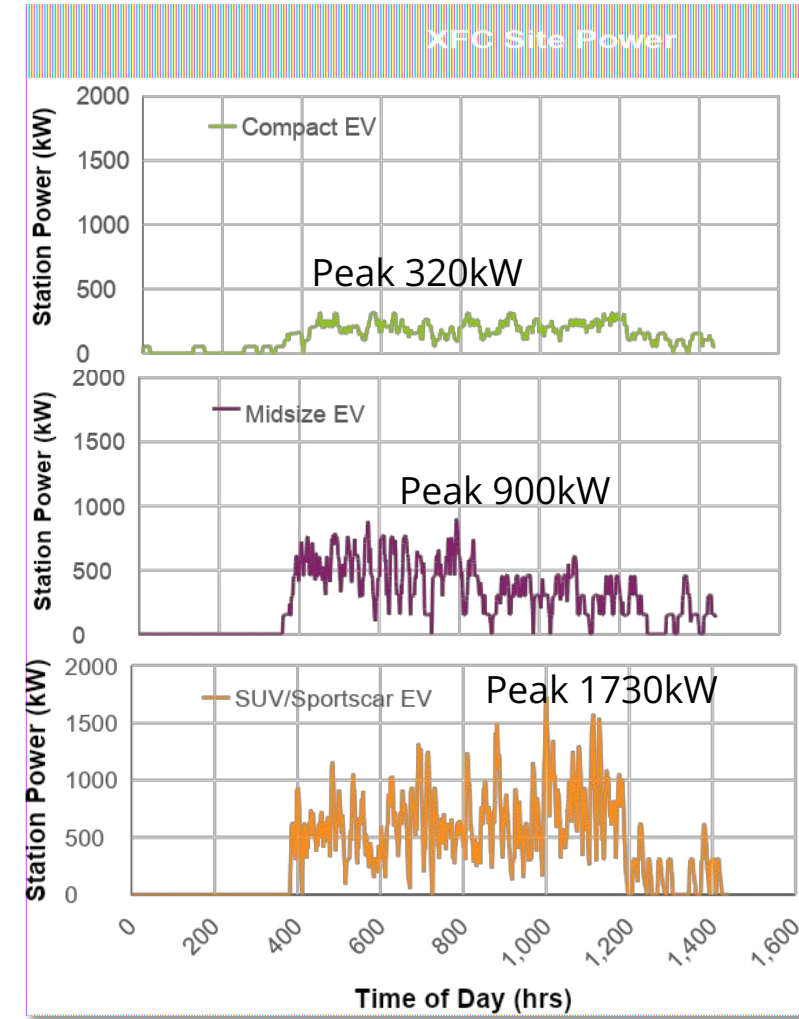


Caldera Simulation of XFC Station:

- 6 x 350 kW chargers collocated
- Vehicles are detailed agents representing classes in SCM projects
- Vehicle use based on actual EVgo station data, bounded by busy gas station data (46% utilization)
- Note abrupt ramping and high peaks for high charge power vehicles
- Demand charges impact the station operator. Electrify America has said “up to 80% of a station

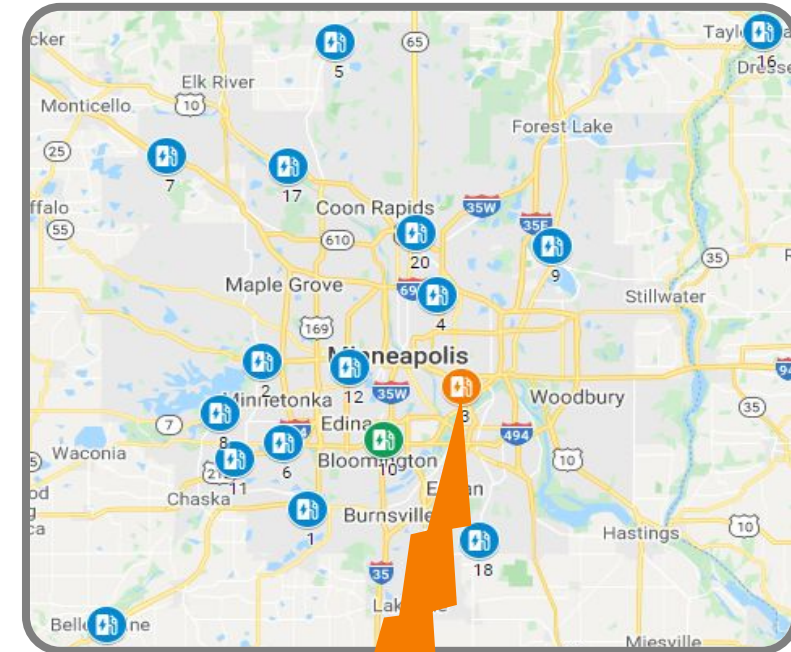
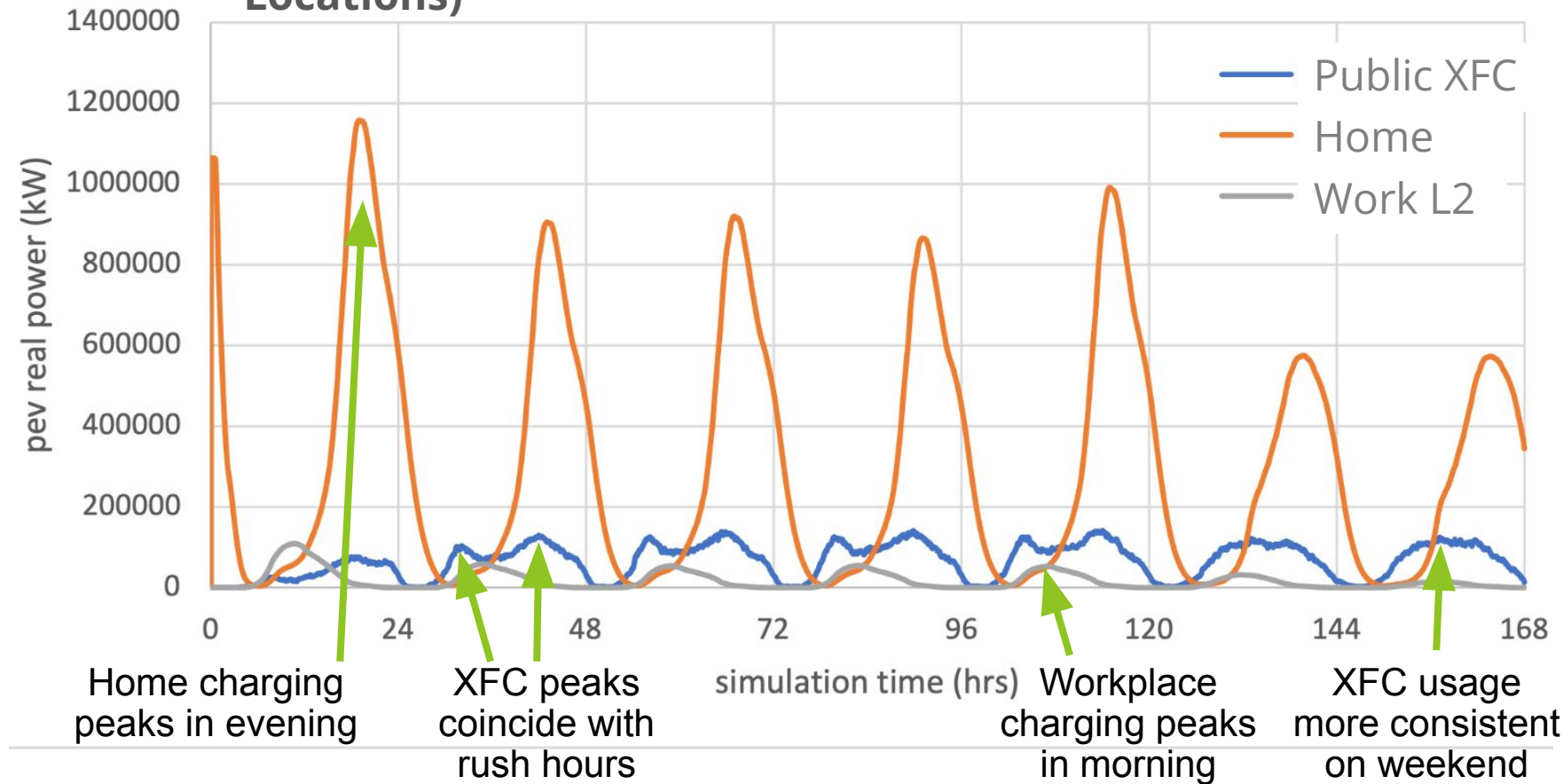


- Demand charge might be >\$25k per month
- While energy charge is <\$2k

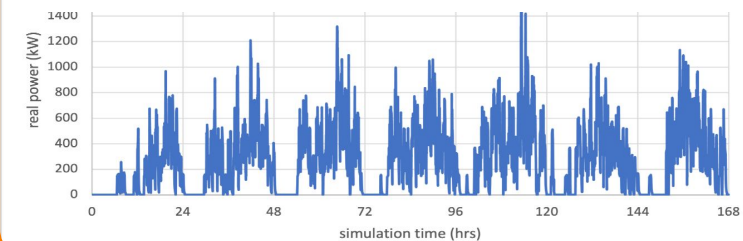


Forecasting Charging Load from 1.1M Personal-Use EVs

Regional Aggregate Load Profile (Power of All Locations)



Power of Single XFC Station

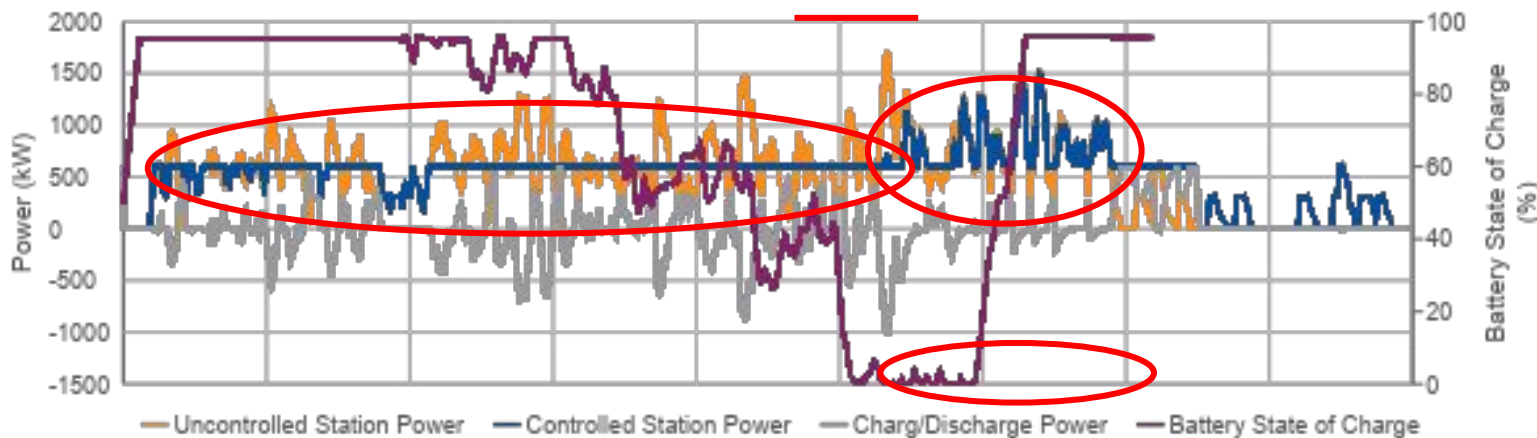


Total Energy Use:

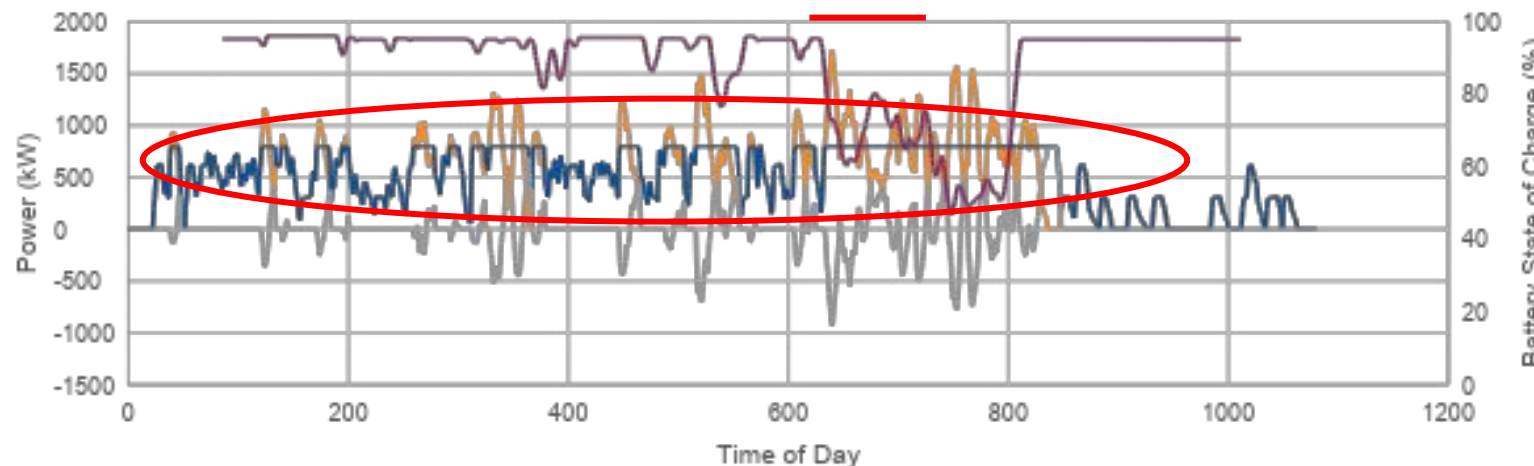
Simulating XFC with Energy Storage and Station Control

XFC Station Power with SES and Station

XFC Station - 500kWh SES - 600kW Control Threshold



XFC Station - 500kWh SES - 800kW Control Threshold



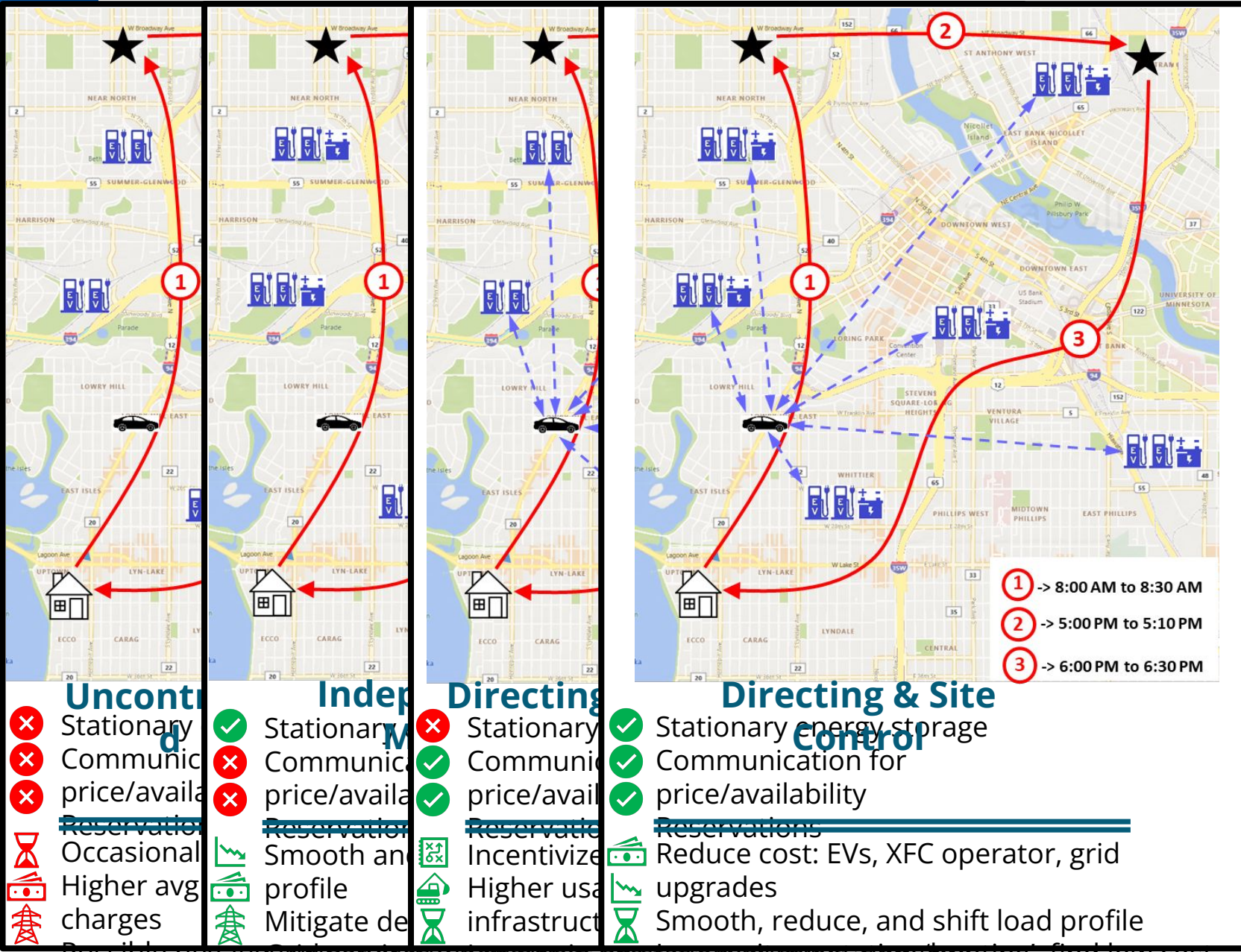
Battery Energy Storage System:

- 500kWh battery costs ~\$500k
- Reduces 1730kW peak to 725kW
- If demand charge were \$15/kW BESS saves \$15,000/month
- BESS payback period = 33months

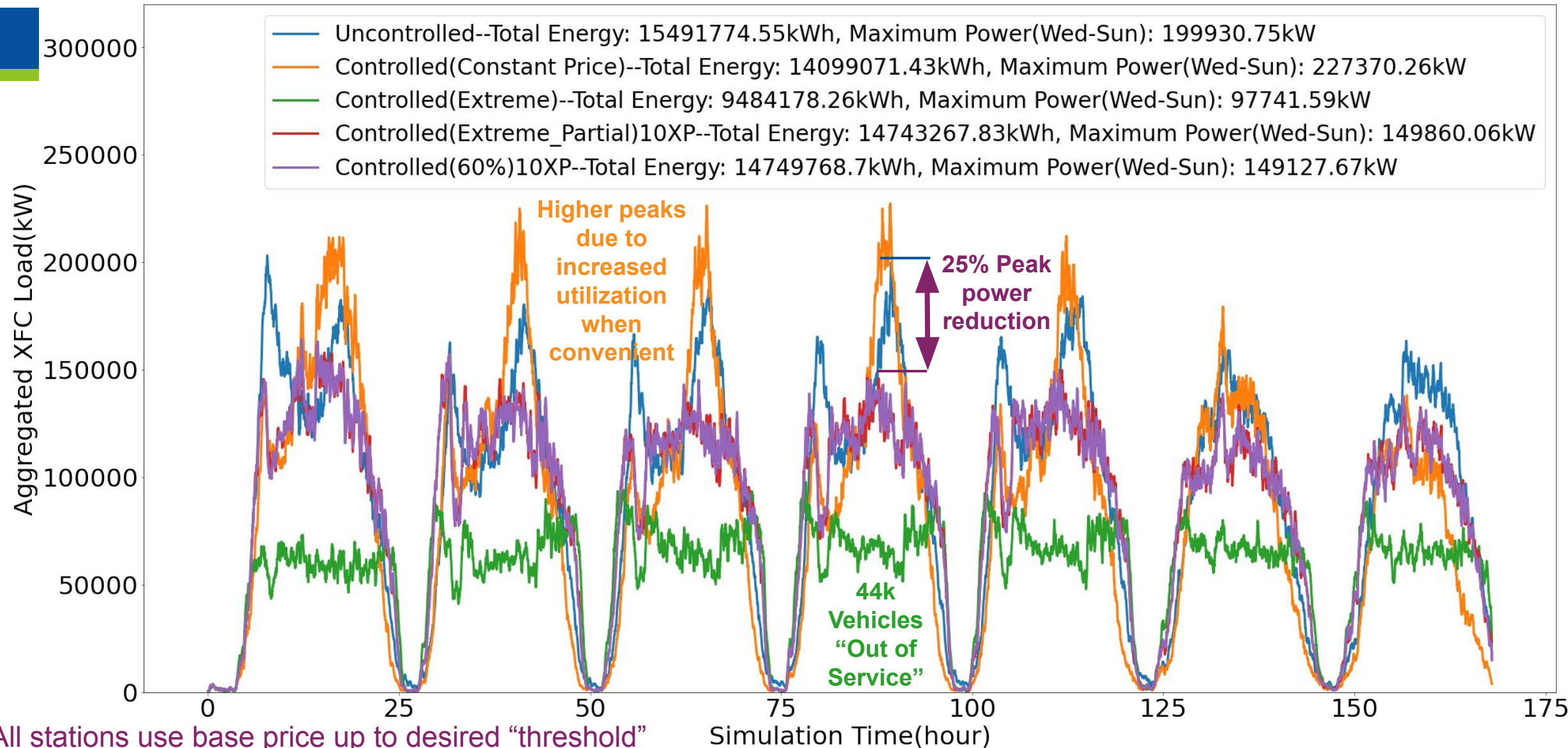
Caldera can help design and simulate other EV charging power controls.

Communications and Reservations as SCM

- What are the Options?
 - Close the station?
 - Charge the last EVs \$1000s?
 - Close some charge points?
 - Limit the charge power?
- Require reservations
- Price disincentives
- Manage the end SOC
- Customer Relations
 - Some charge points or some station operators might be first come first serve
 - Peak capacity reservation only
 - Well integrated communications would only recommend available stations and present variable pricing in logical, consumable fashion



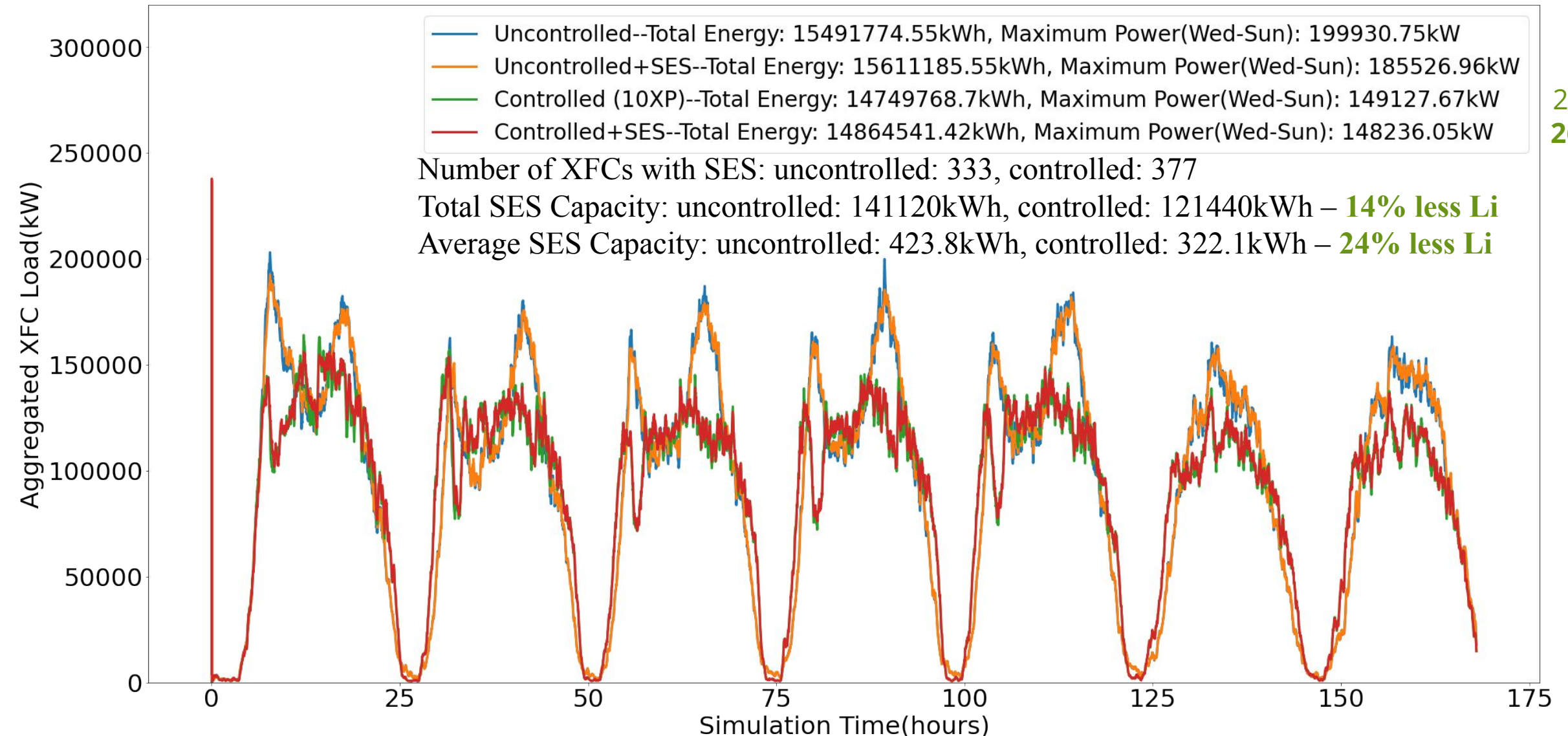
Regional XFC Power Results with Different Price Controls



- All stations use base price up to desired "threshold"
- Additional chargers are offered with price multiplier
- Vehicles chose alternate station or charge time through cost optimization algorithm
- **Peak Reduction 25%** (200MW to 150MW)

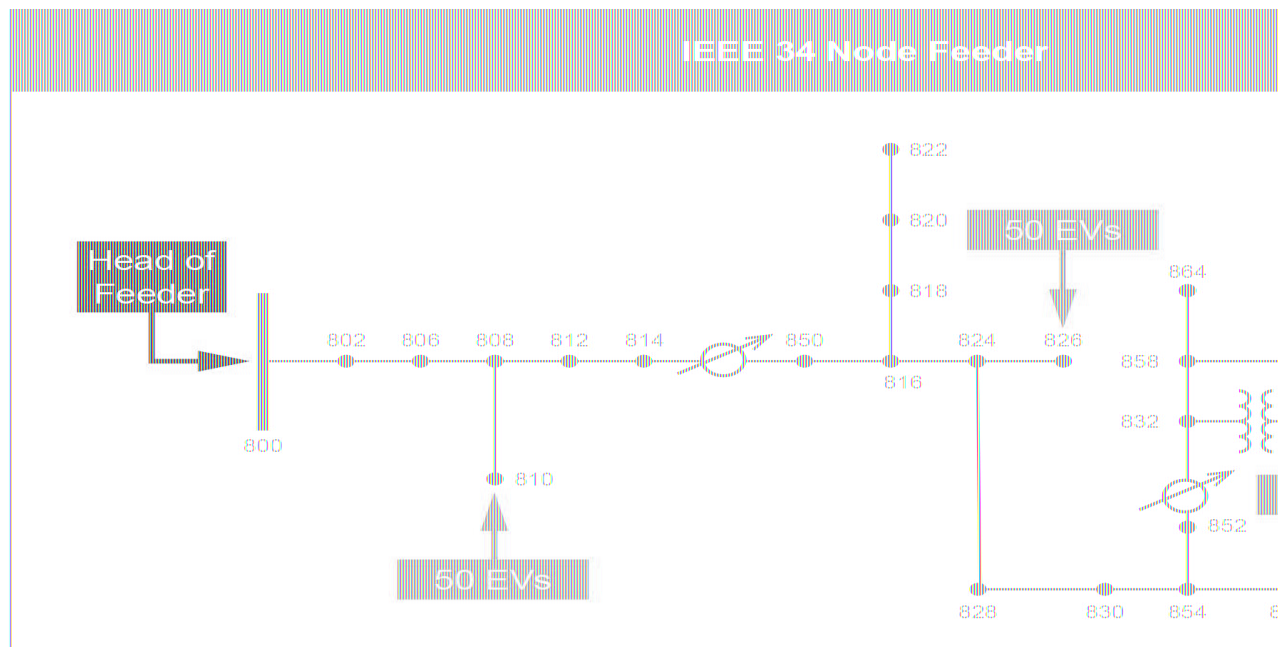
Aggregated XFC Load – 4 Scenarios

Peak Reduction

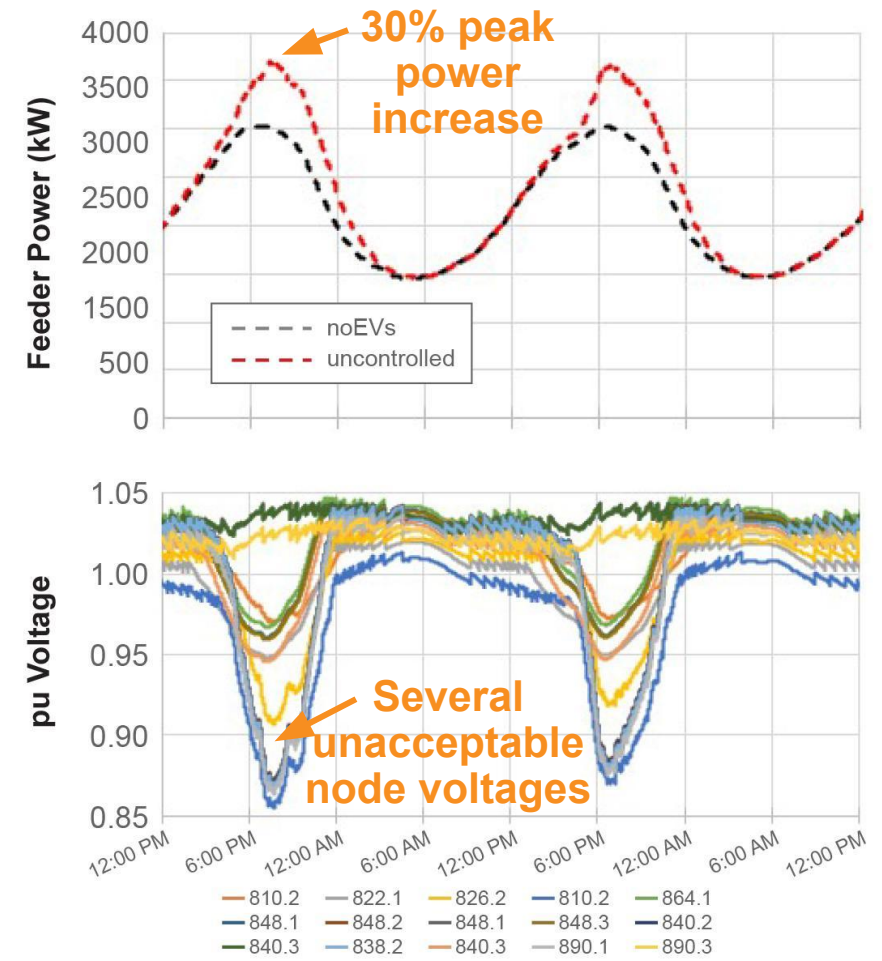


Grid Impact Demonstration Platform – AC L2 Residential

- Transportation simulation determines when and where vehicles are connected to the grid
- Charging model library accurately simulates loads which are applied to the grid model and can be viewed as an aggregate impact
- **Uncontrolled charging** is demonstrated and resulting impacts on the grid such as peak feeder power and node voltage are assessed for improvement

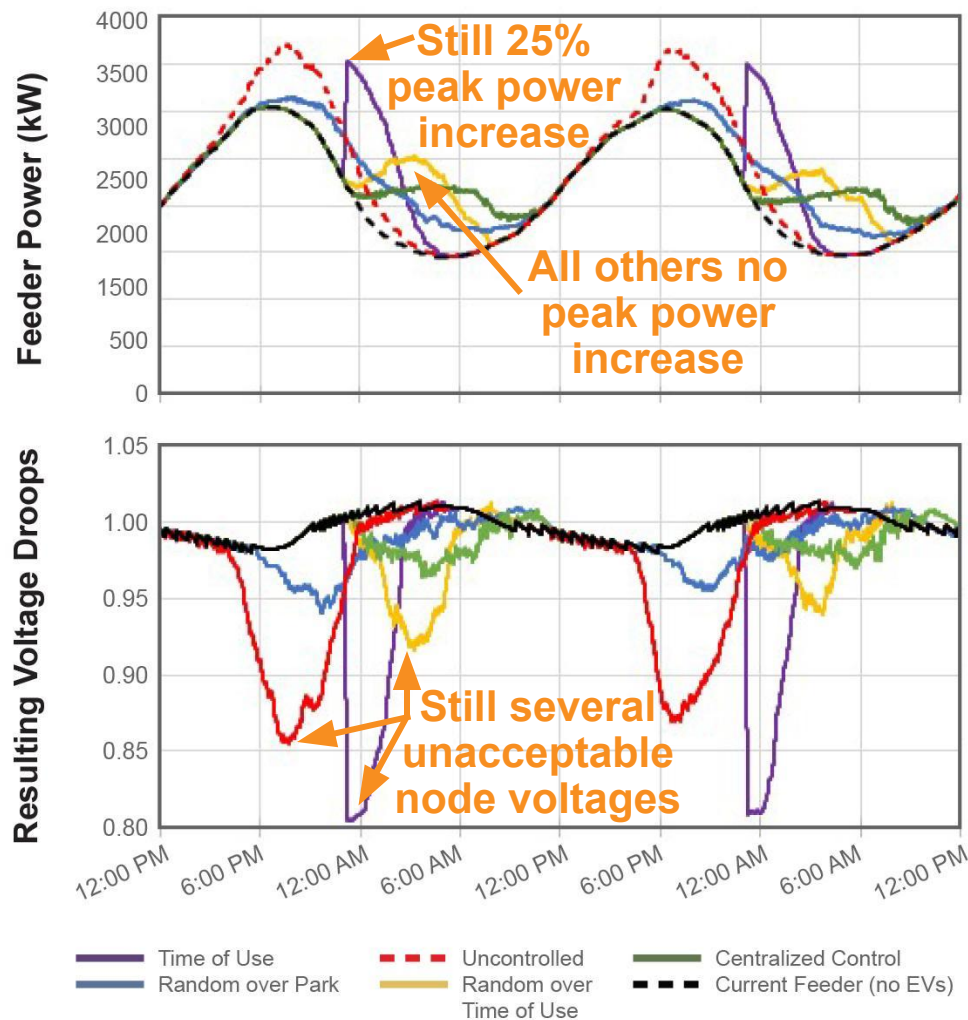


Power and Voltage with Uncontrolled Charging



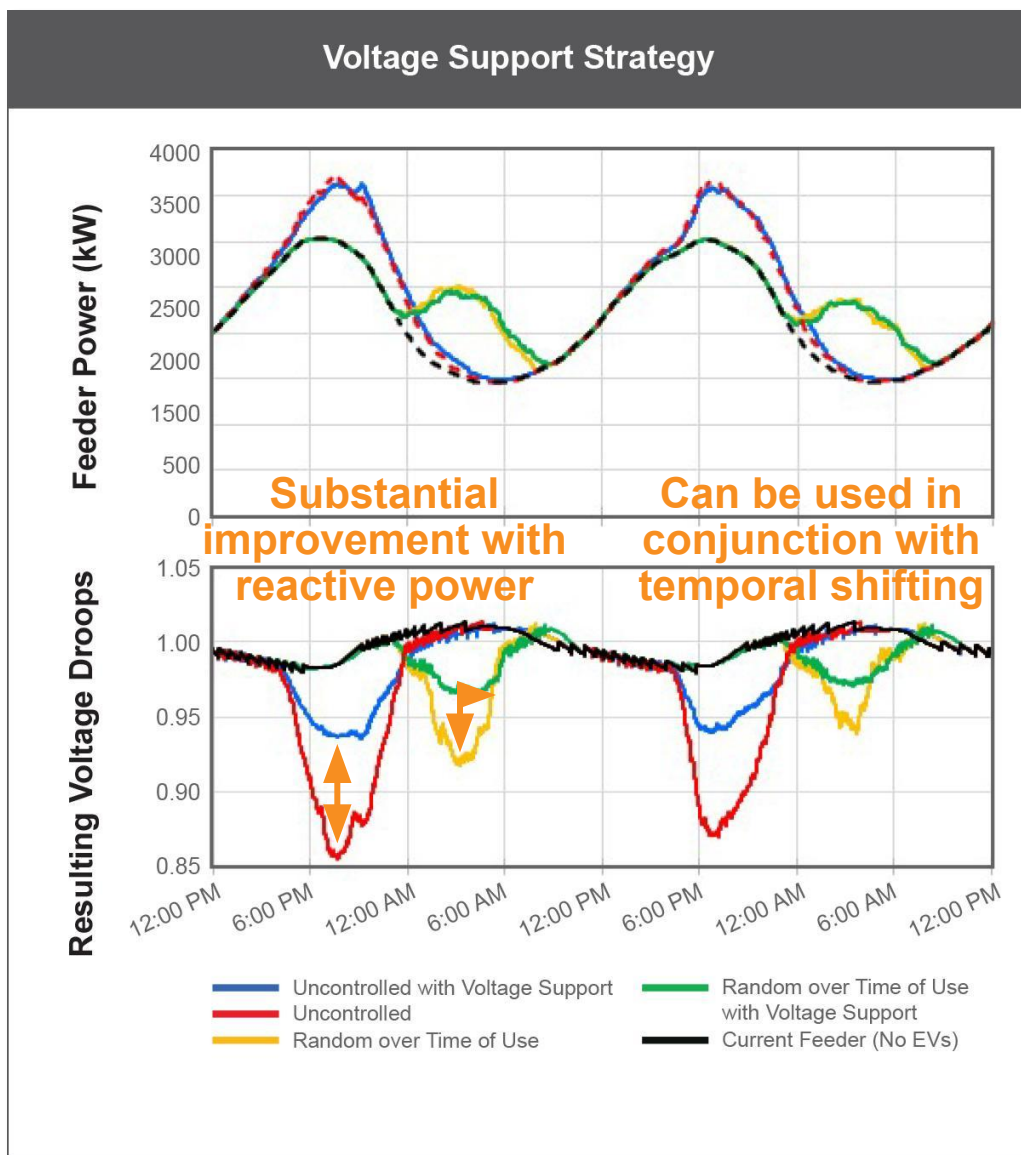
Control Strategy Demonstration Platform

Energy Shifting Strategies

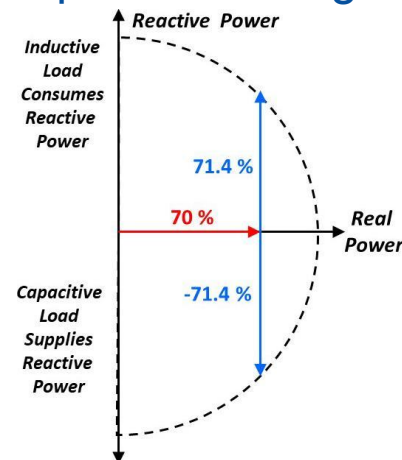


- Control Strategies are developed, tested, and compared in Caldera
- Energy shifting control strategies shown here include:
 - Centralized aggregator
 - Distributed random start
 - Time-of-Use rates (TofU)
 - Random starts during TofU
- Benefits increase with increasing EV Adoption, filling in trough can consume otherwise curtailed renewables
- Voltage may continue to be a problem

Voltage support using Reactive Power



- Just as Smart Inverters are currently proliferating in the solar industry and allow solar generation to provide better support to the grid, we envision improved power electronics in EV battery charging hardware could provide reactive power and substantially lessen EV impacts on the grid; and Caldera can prove that.



- EVs (with smart invertors) charging at less than 100% power, or connected and not charging are able to provide reactive power to the grid.
- The results show that with the energy shifting decentralized strategy of random starts over the Time of Use rate period, the peak power is not increased, but the voltage would fall to unacceptable levels; until the Reactive Power strategy is added and it then stays above 0.95 puVA



Broad Regional Analysis

INL PI: Manoj Kumar Cebol Sundarrajan

Part of the EV@S "FUSE" Project:

*Flexible charging to Unify the grid and
transportation Sectors for EVs at scale*



- **Smart Charge Management strategies are developed to improve the impact of EV charging on the grid.**
- **But they must be based on the conditions of a particular grid at a particular time.**

When is the best time to charge EVs?

It depends.

Depends on what?

Which way the wind blows...

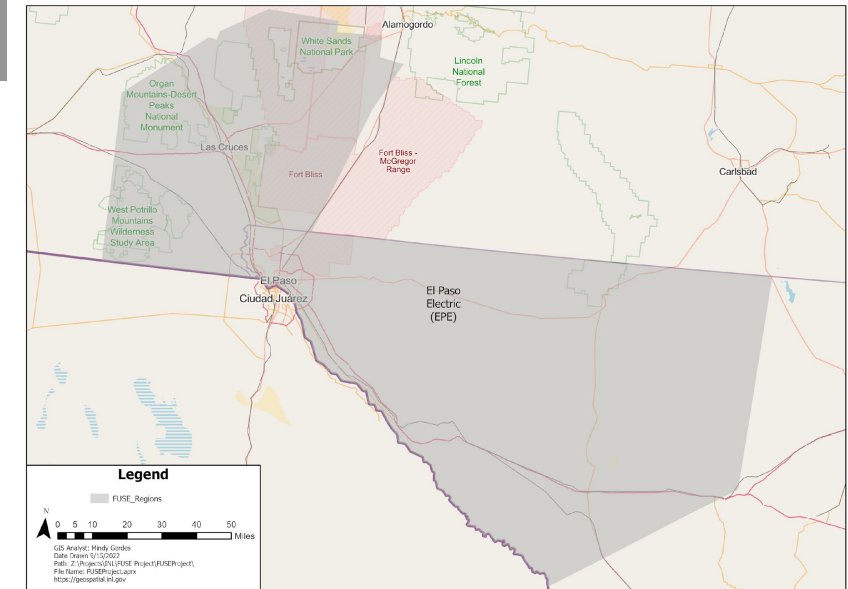
And your regions: Wind deployment, Solar deployment, Air Conditioning load, Electric Heat, Existing load shape (residential, commercial, industrial), the current season, the daily weather, and many other characteristics

Broad Assessment Study Regions

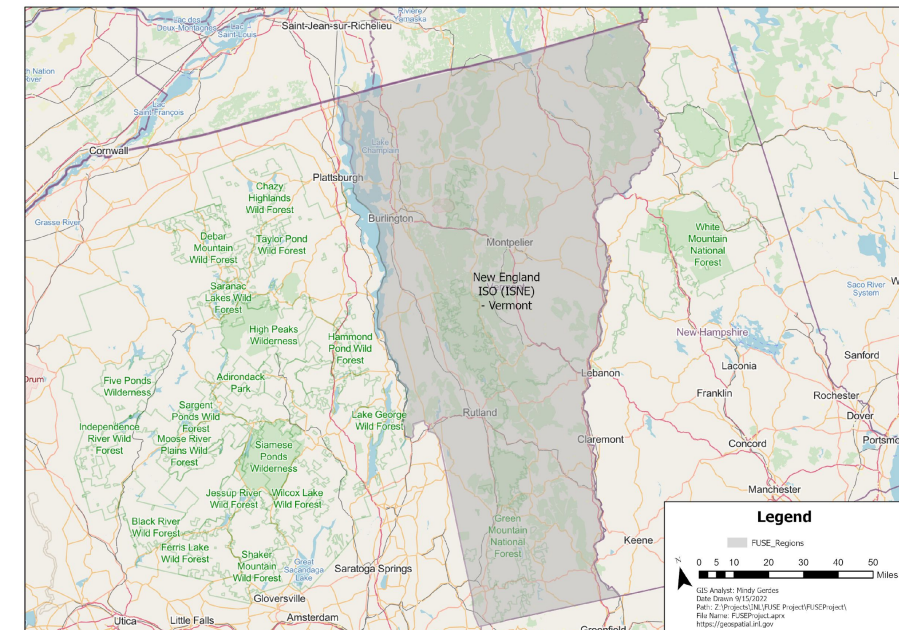
FUSE Regions



El Paso Electric (EPE) Region



New England ISO (ISNE) - Vermont Region



Regional Characteristics Matrix

Characteristics	ERCOT Coast	El Paso Electric (EPE)	Evergy	New England ISO (ISNE) - Vermont	Dominion Energy	Final
High Solar	X	X				X
Inland Wind	X		X			X
Offshore Wind				X	X	X
Extreme Summer Peaking		X				X
Winter Peaking				X		X
Large Metro Area	X	X				X
Rural Region				X		X
Large Seaport	X					X
Large Airport	X					X
Pass-Through Truck Traffic			X			X
International Truck Traffic		X				X

Renewable generation adoption – **Green**

Electrical demand – **Yellow**

Transportation – **Blue**

Computational modelling approach

• Input stage

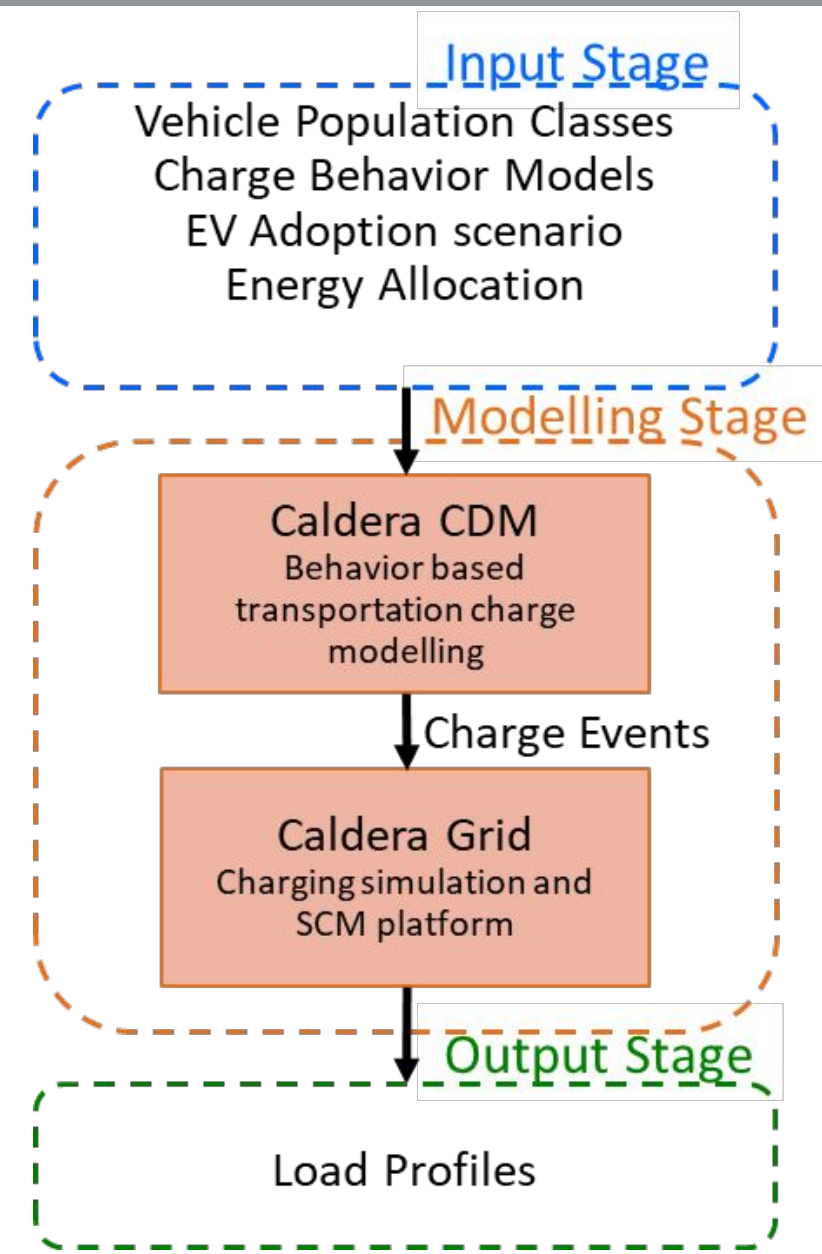
- Eleven Light-Duty vehicle classes were used
- Charging behavior models were derived from purchased WEJO itinerary data for the Virginia region
- LD EV adoption scenario for 2040 was modeled using TEMPO tool with 50% EV adoption rate
- Two energy allocation scenarios were used
 - home dominant (Home : 60%, Work : 10%, Public : 30%)
 - work dominant (Home : 20%, Work : 50%, Public : 30%)

• Modelling stage

- The Caldera Charging Decision Module (CDM) software tool using stochastic modelling generated charge events from the charging behavior models
- The Caldera Grid software tool generated power profiles by applying SCM strategies on the charge events

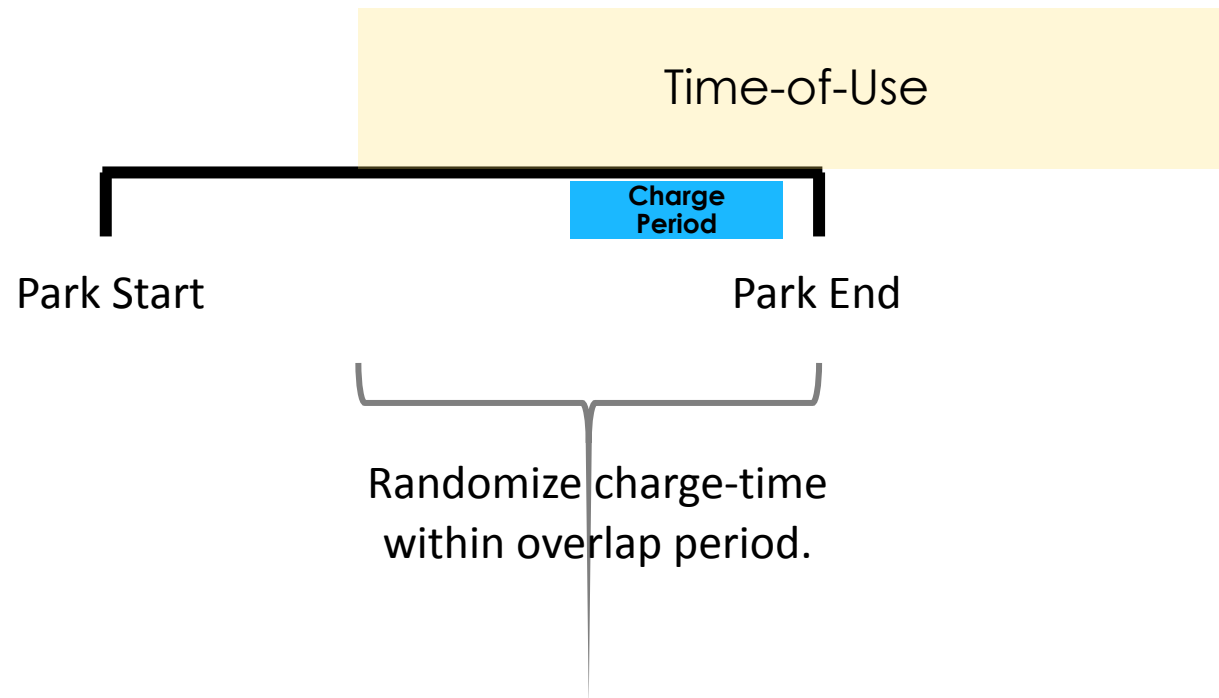
• Output stage

- Time series load profiles were used in post-processing for analysis



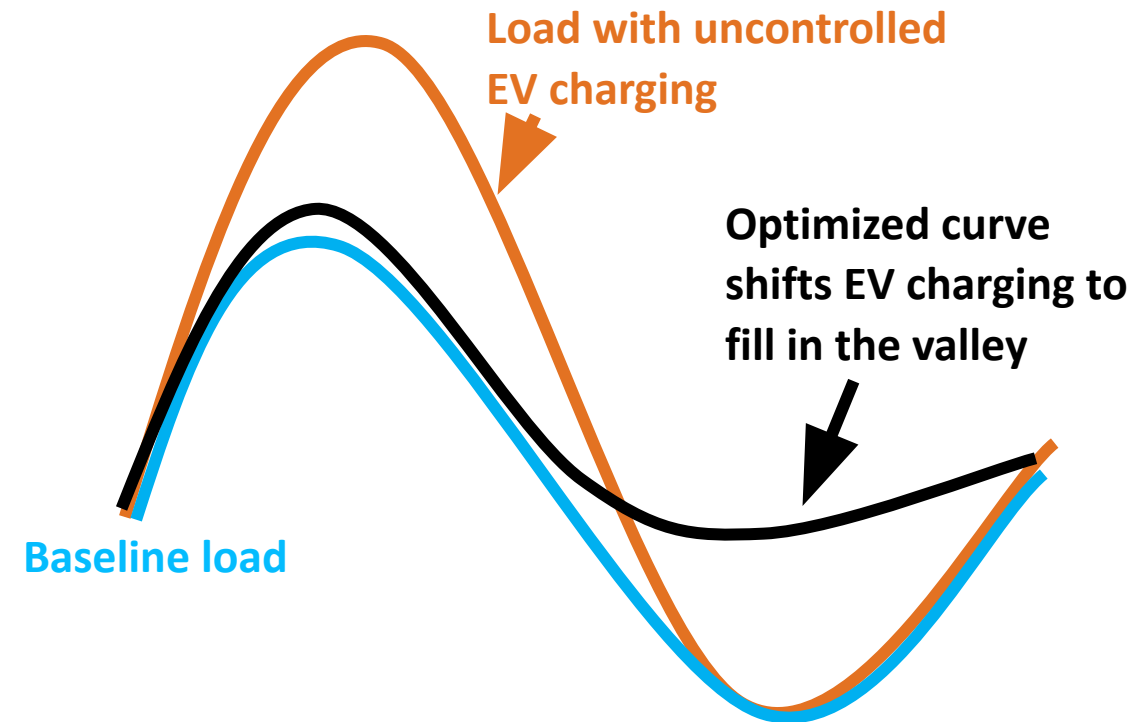
- **Solar TOU-Random**

- EVs prefer to randomly distribute charging in the TOU window
- Updated Time of Use (TOU) period from nighttime to daytime.



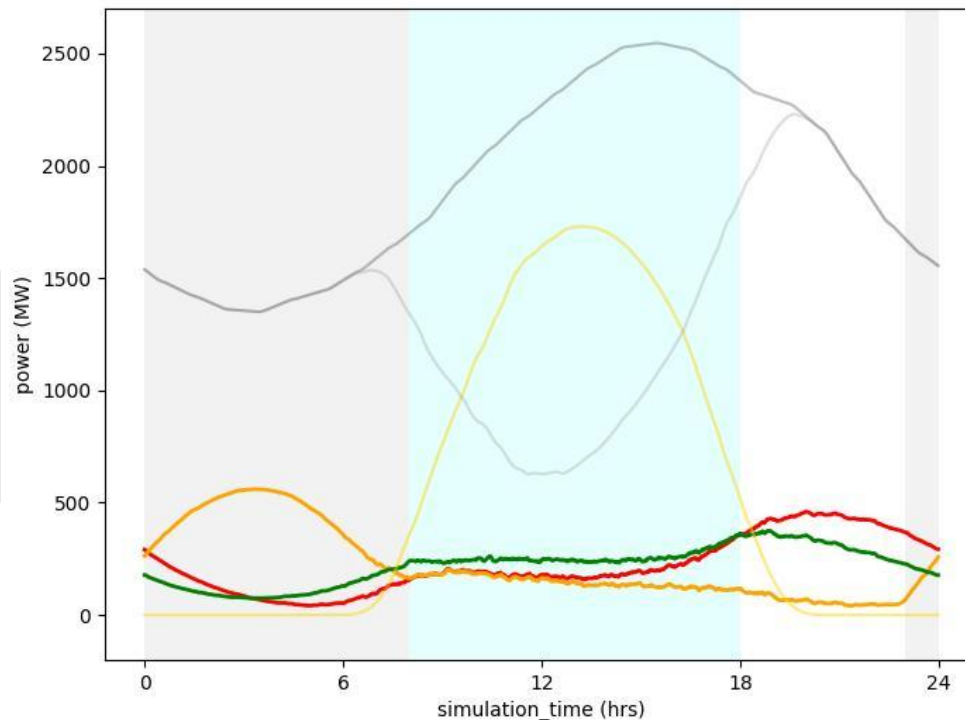
- **Solar Centralized Aggregator**

- Centralized strategy shifts EV charging within vehicle dwell to minimize feeder peak
- New objective function to maximize charging following solar curve.

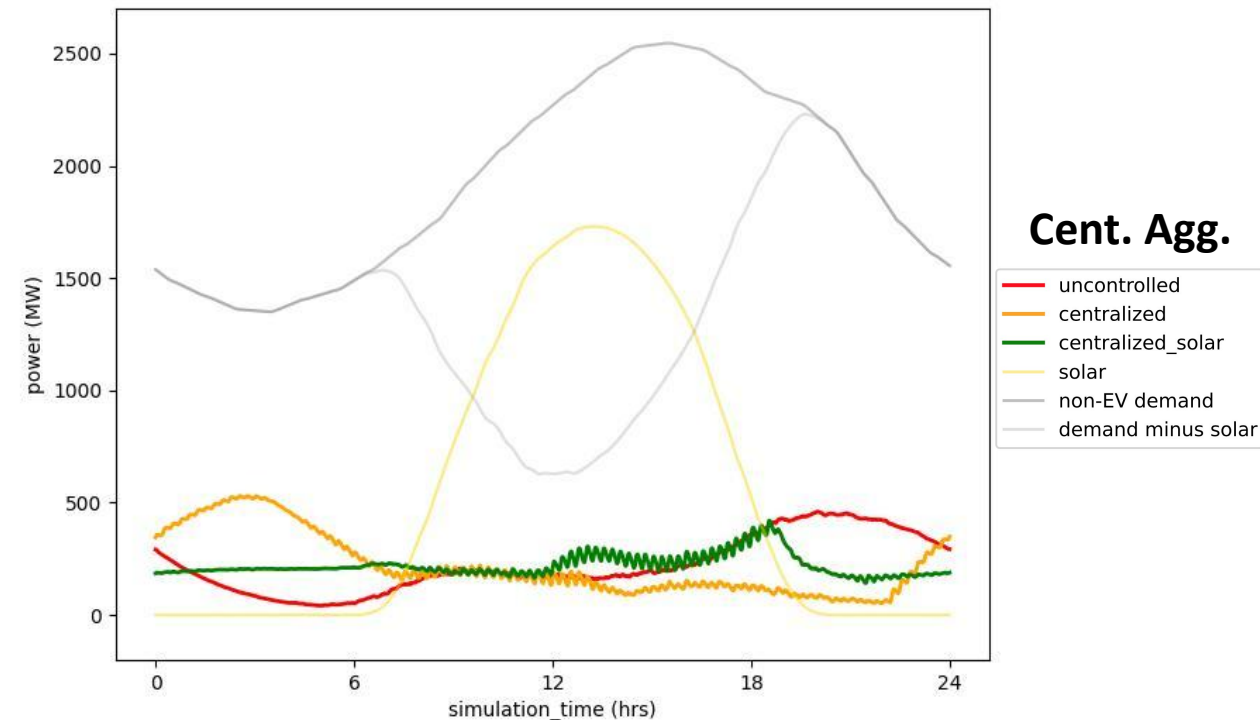


- Both solar TOU random and solar centralized aggregator strategies struggled to shift charging towards the solar period due to most cars only charging at home at night.

EPE, Summer home-dominant TOU random



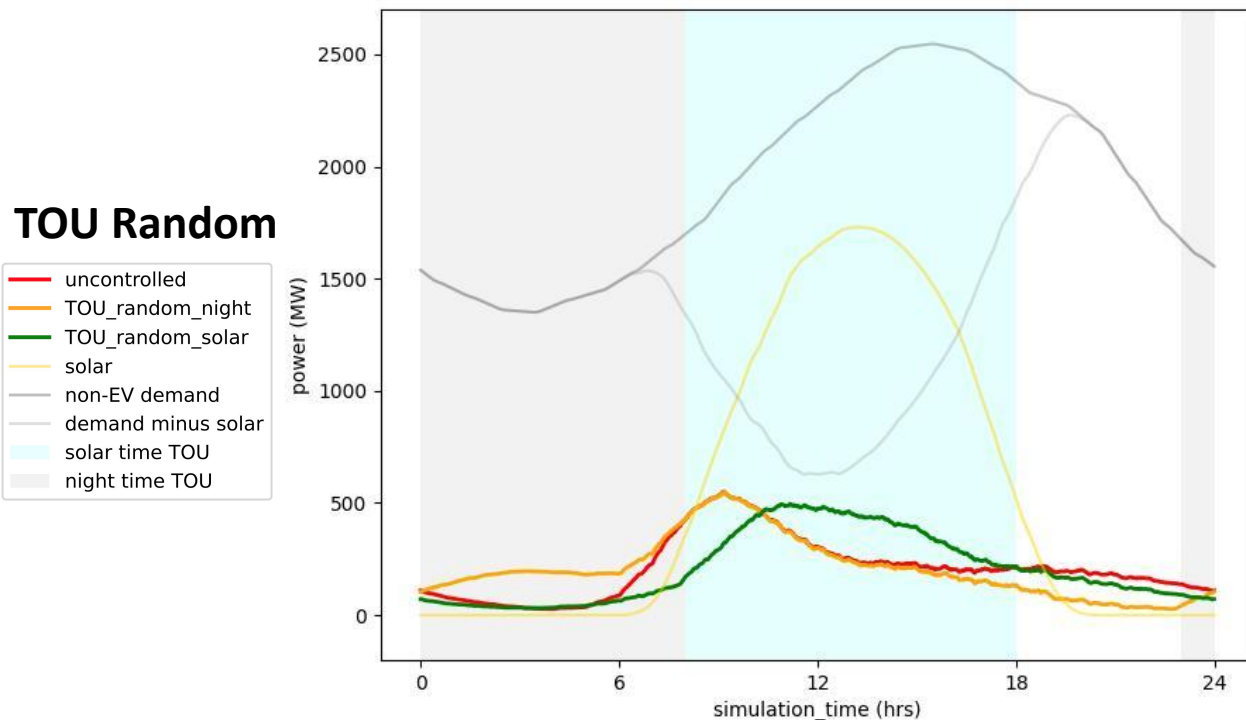
EPE, Summer home-dominant centralized aggregator



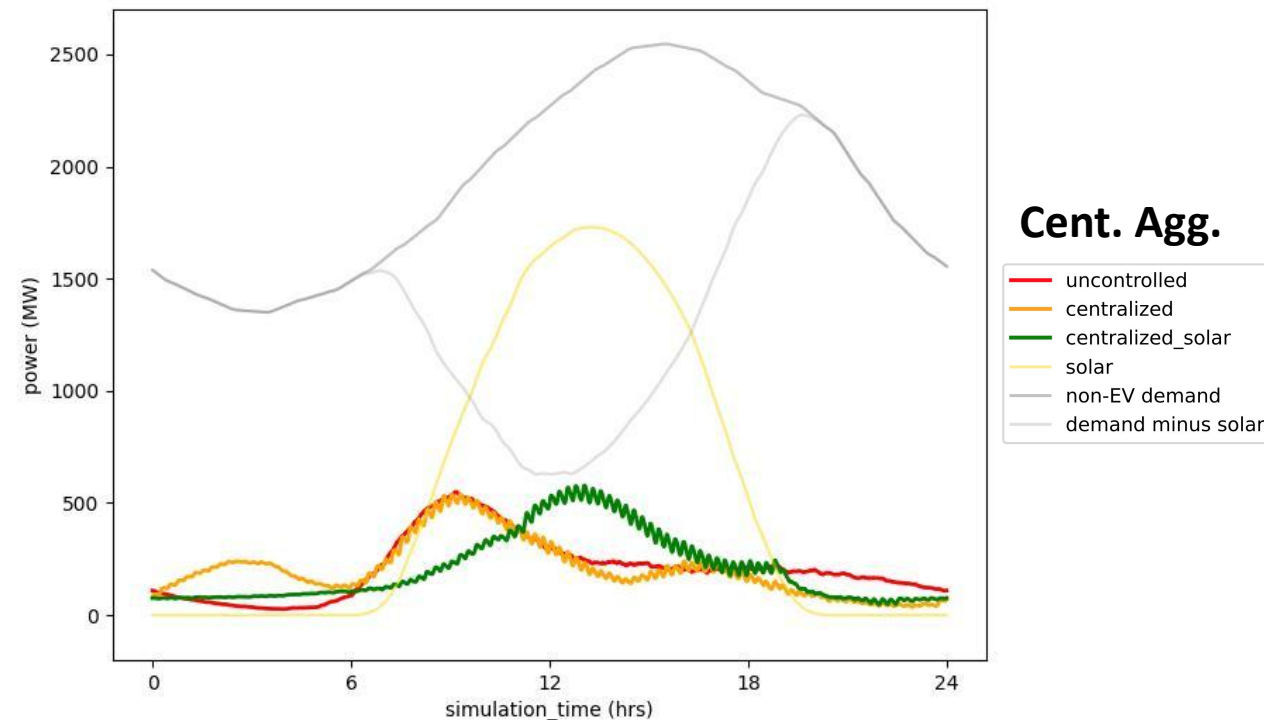
- A significant amount of charging shifted from nighttime to daytime due to EVs charging at work, but the charging peak does not coincide with the solar peak.
- Both solar TOU random and solar centralized aggregator strategies were able to shift charging towards the solar peak.

EPE, Summer work-dominant TOU random

TOU Random



EPE, Summer work-dominant centralized aggregator



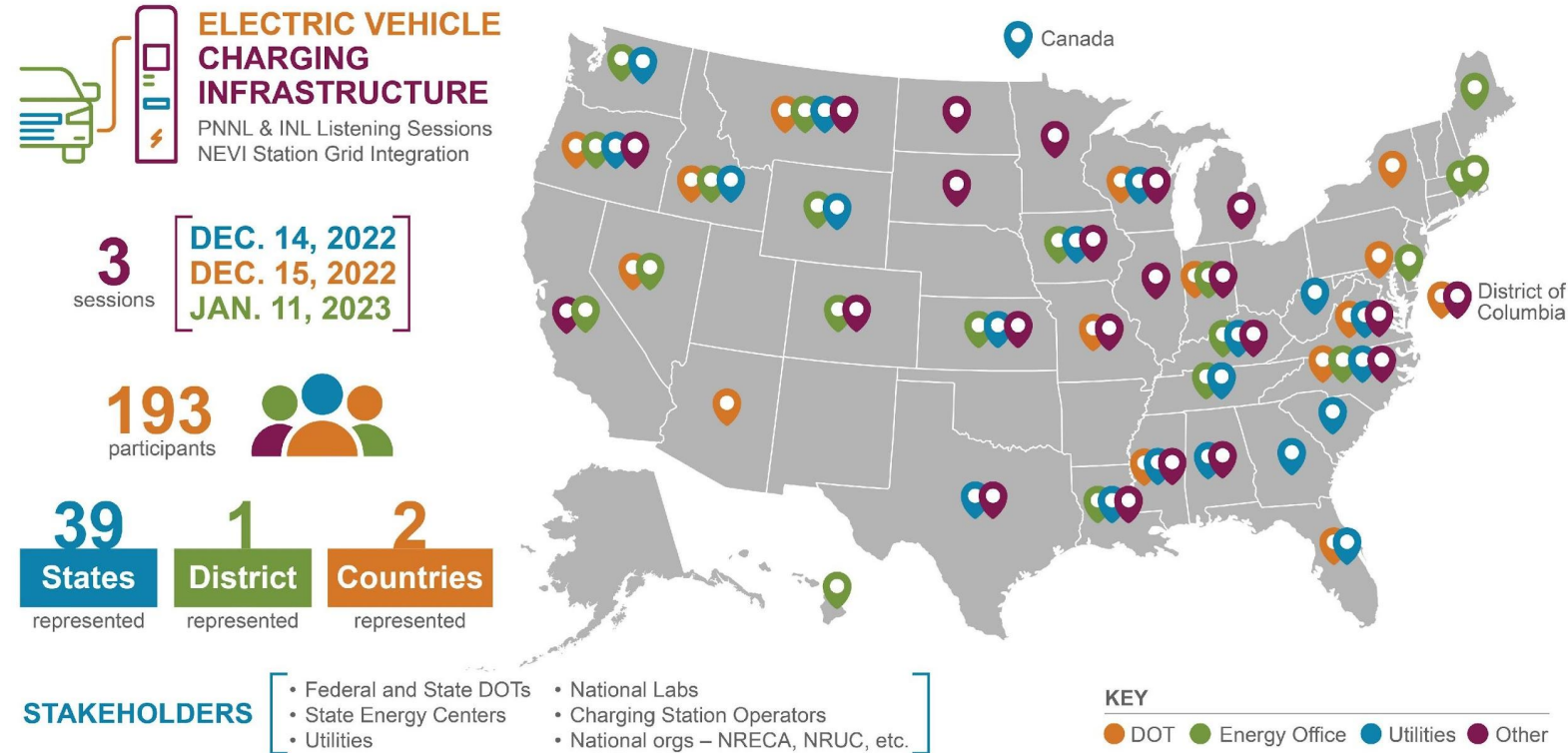
CalderCast:

A Joint Office for Energy and Transportation Tech Assistance tool

*A publicly available web tool to forecast
load at any possible NEVI compliant
station.*

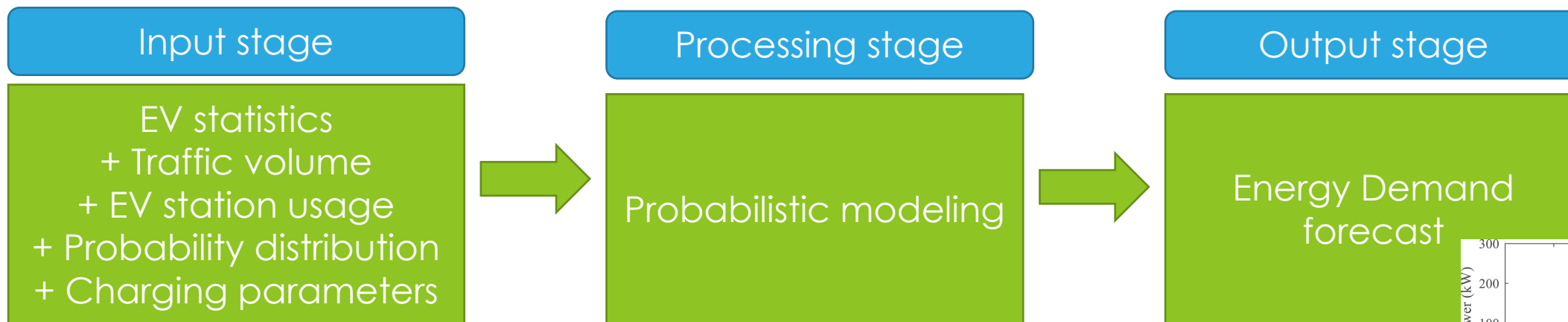
Stakeholder Outreach and Beta-tester Solicitation (Feb. Update)

- Recently held 3 “Listening Sessions” including NEVI stakeholders
- Received very useful feedback:
 - More than half have never done EV infrastructure before
 - Majority use nameplate power rating, some use static derating, some have proprietary method
 - Interested in the “average daily peak power” as well as the range of power profiles
 - **Several individuals reached out for follow-up and offers to Beta-test.**



- Powder River Energy Corp. – Gillette, WY
- Efficiency Maine – Augusta, ME
- Alliant Energy – Madison, WI
- Edison Electric Institute
- Will engage these in discussion and seek out others for diverse users

Modeling approach

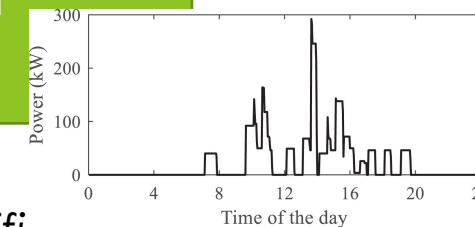


APPROACH

Forecast load modeling using a traffic volume-oriented method based on *EV traffic volume, energy usage distribution and charging station popularity.*

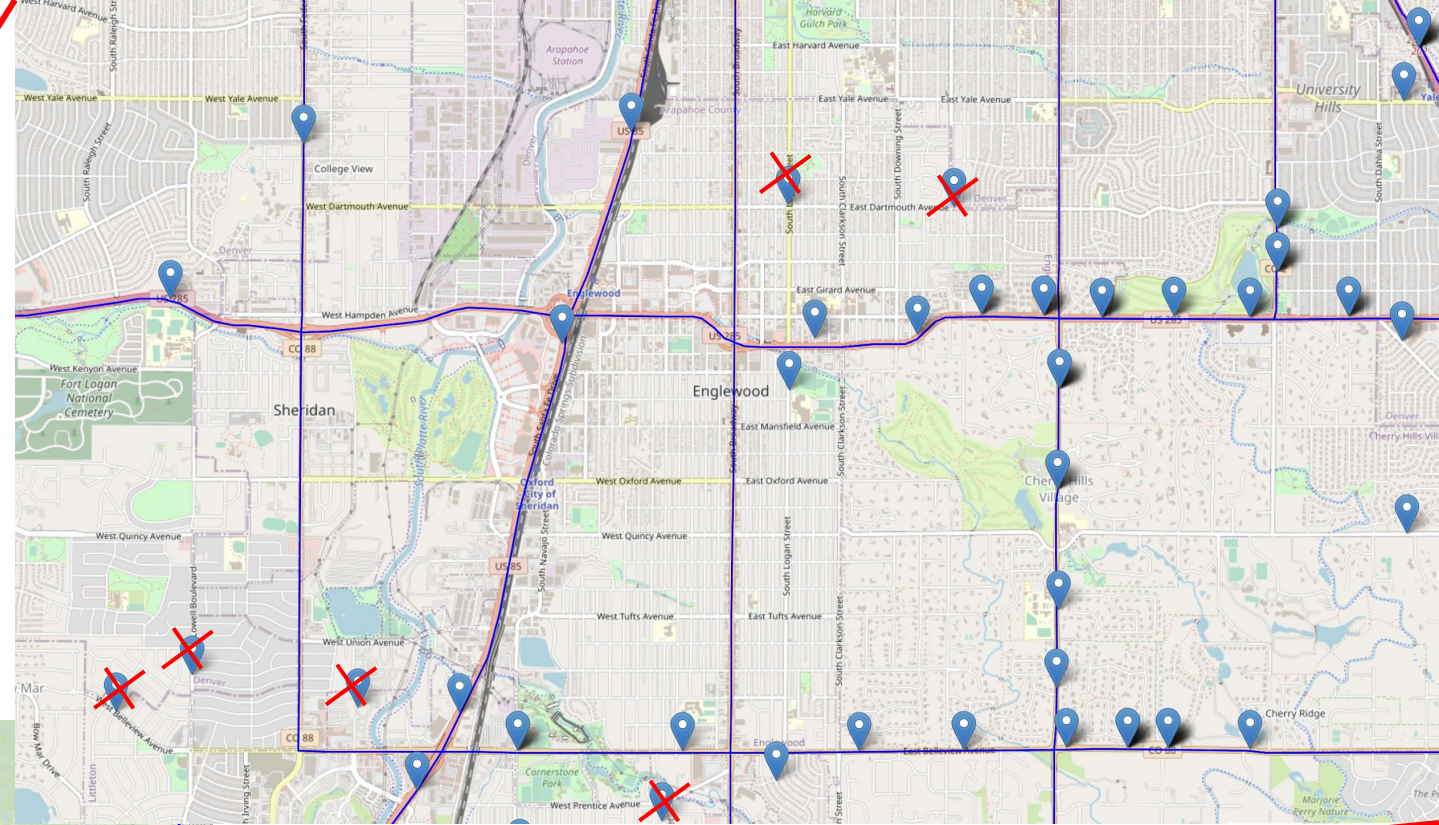
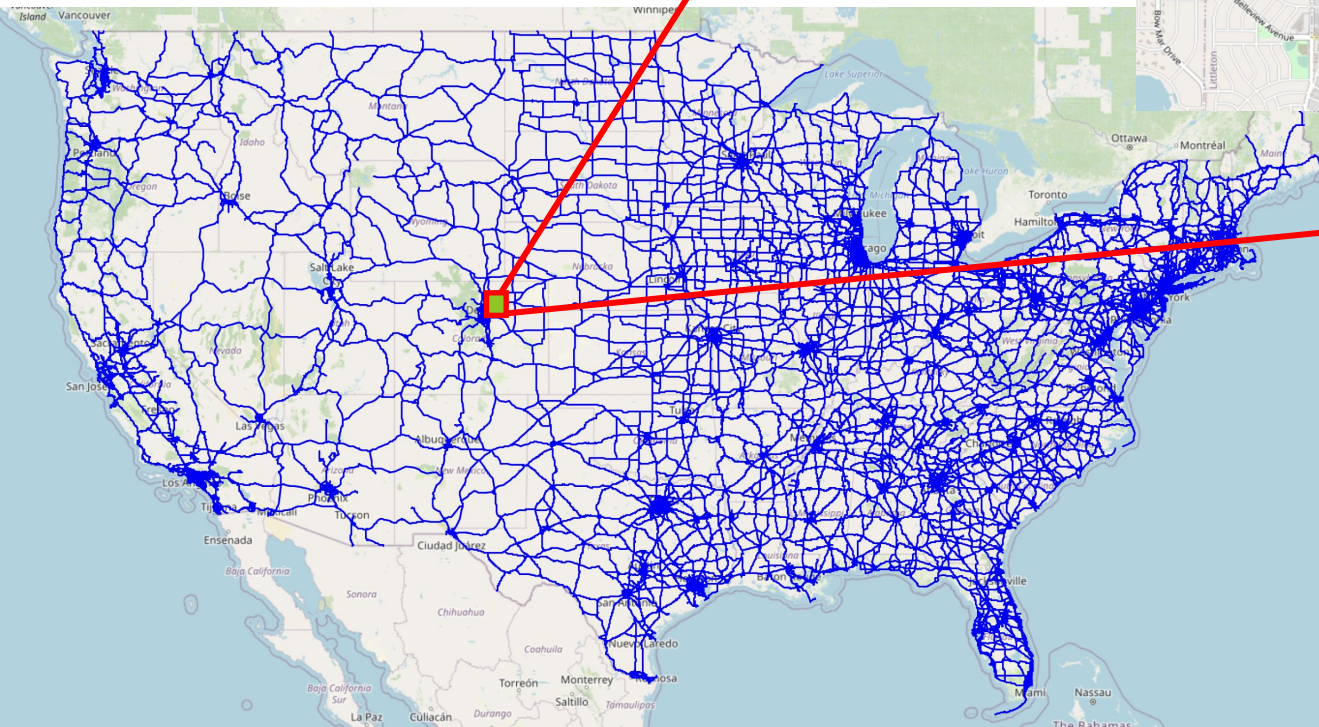
STEPS

- ✓ Identify stations composing the projected National Electric Vehicle Infrastructure
- ✓ Estimate EV traffic volume
- ✓ Model EV arrival distribution and charging power for a typical day
- ✓ Forecast energy demand over time



Data sources

Main data source is EV WATTS from Energetics, National Transportation Atlas Database from BTS and Highway Performance Monitoring System from FHWA and Travel Monitoring Analysis System from USDOT.



STATIONS OF INTEREST

Figure on the left shows the US NHS (National highway system).

Figure on top (blowup of a location in figure on left) shows potential NEVI stations, close to highway. Stations not close to highway (e.g., home-based) are discounted.



Idaho National Laboratory

*Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy.
INL is the nation's center for nuclear energy research and development, and also performs research
in each of DOE's strategic goal areas: energy, national security, science and the environment.*

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<https://cet.inl.gov/caldera>

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