EV Charging Load Forecasting Simulation Platform

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Research Group Lead

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

Idaho National Laboratory

INL/CON-23-73053

Why Caldera?

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

Transportation Models

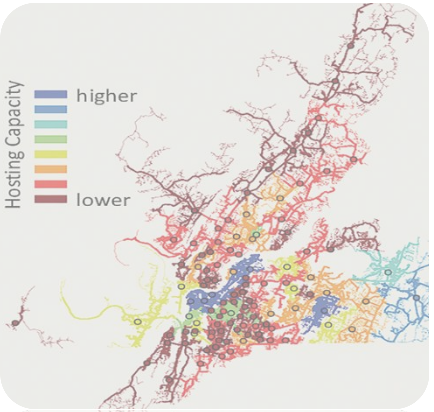
HELICS
Co-simulation

Caldera

EV Modeling Platform

HELICS
Co-simulation

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

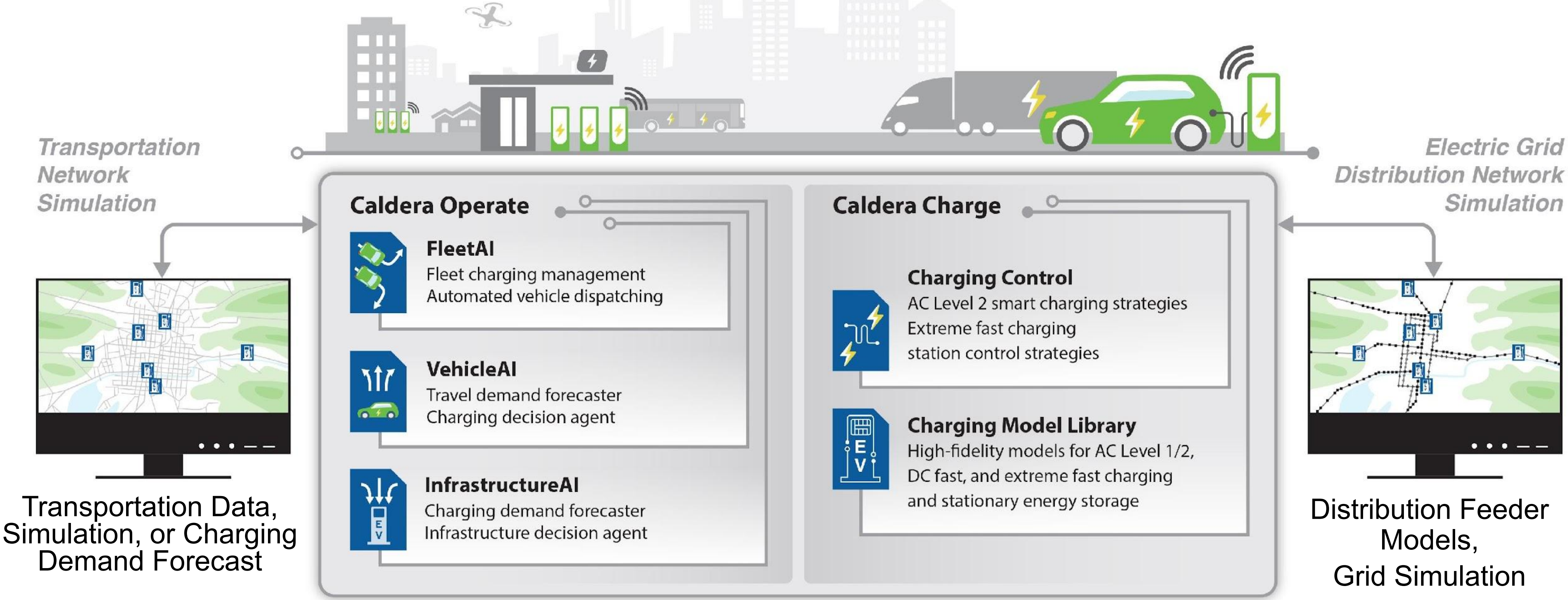
Demonstrates EV charging effects and illustrates system optimization by co-simulating both grid and driving conditions

Simulating distribution and traditional loads

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

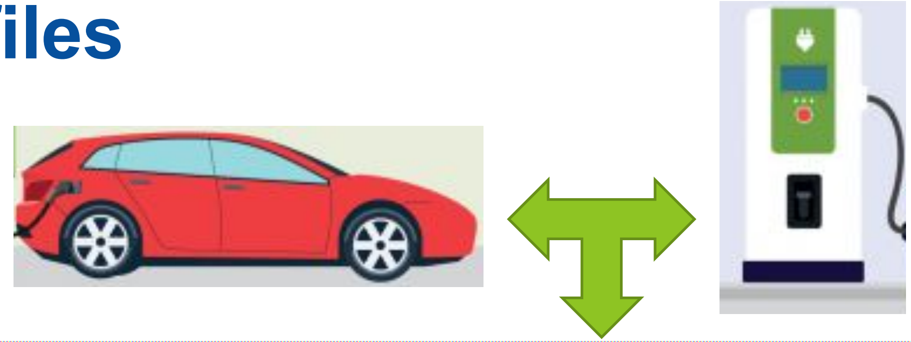
Caldera

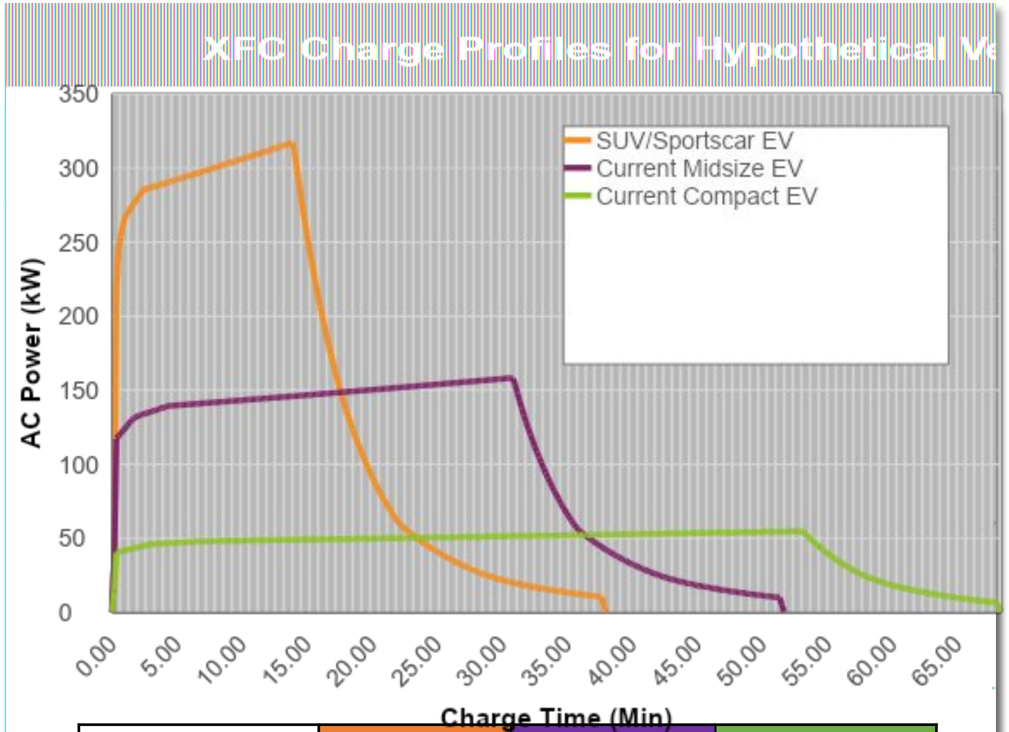
Electric Vehicle & Infrastructure Decision Management Simulation Platform



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

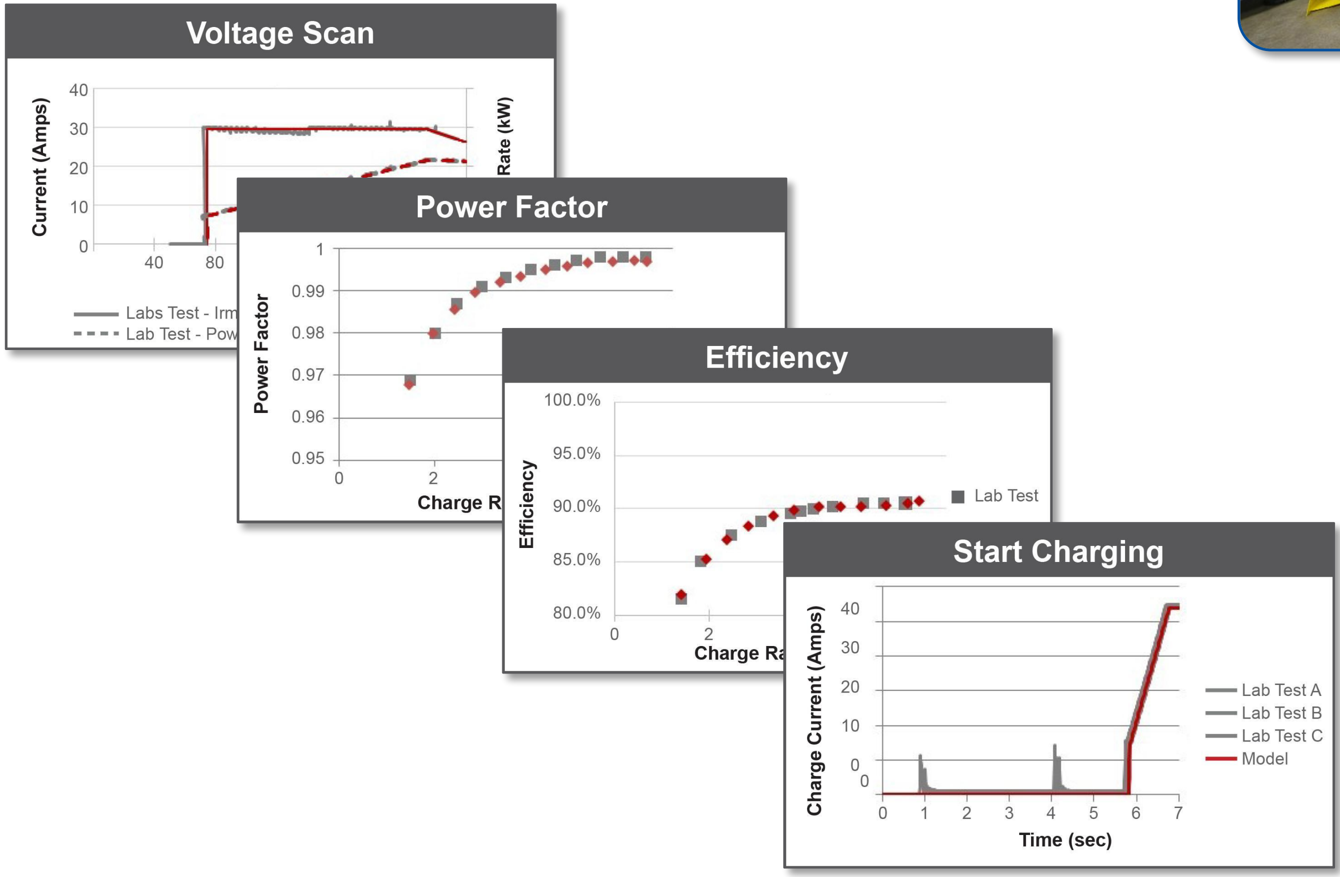




	SUV/ Sportscar EV	Current Midsize EV	Current Compact EV
Max Charge Rate (kW)	300	150	50
Vehicle Range (Miles)	250	275	150
Vehicle Resembles	Porsche Taycan	Tesla Model 3	Nissan Leaf

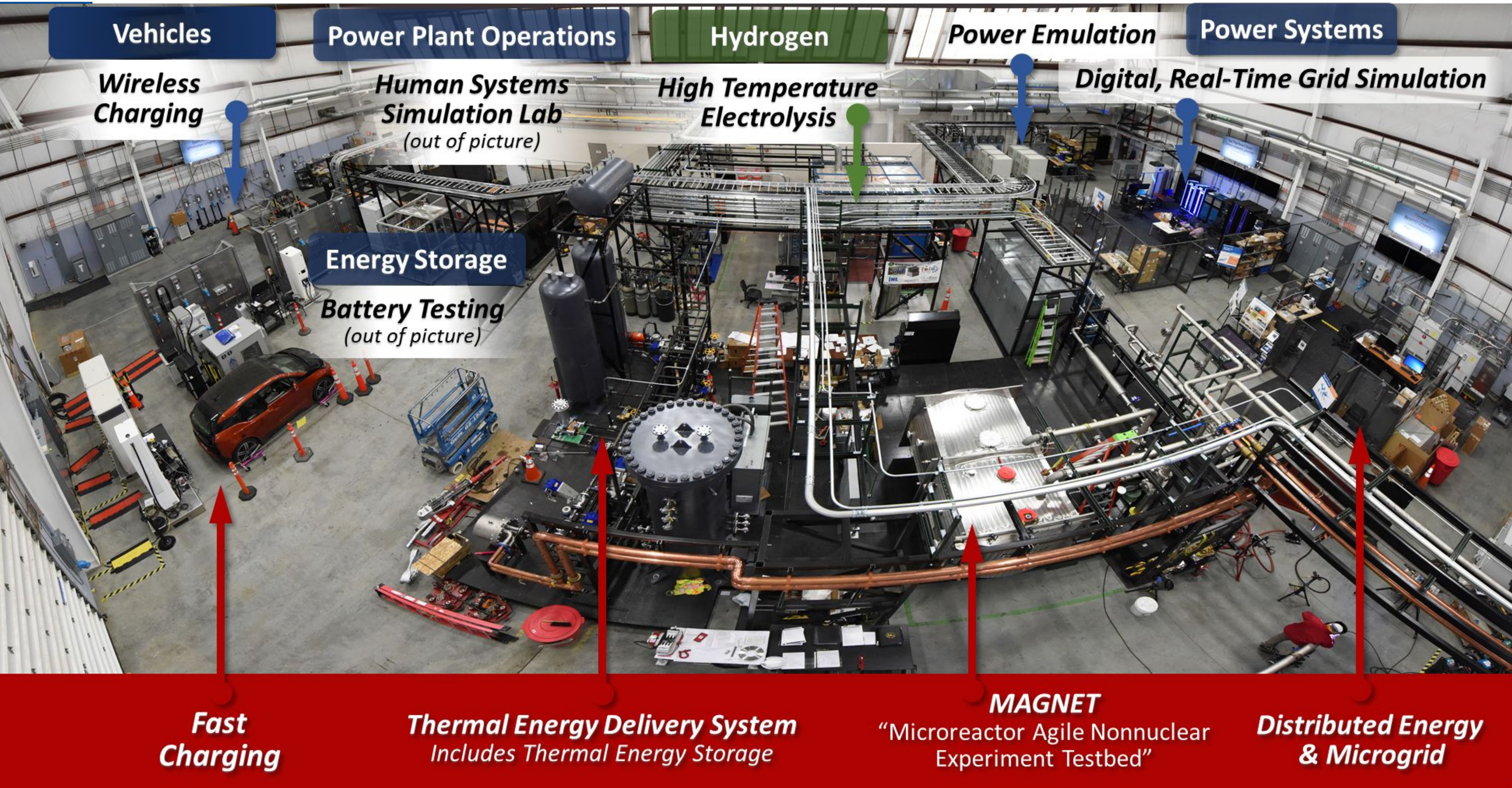
High Fidelity EV / EVSE Charging Model library

- 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.



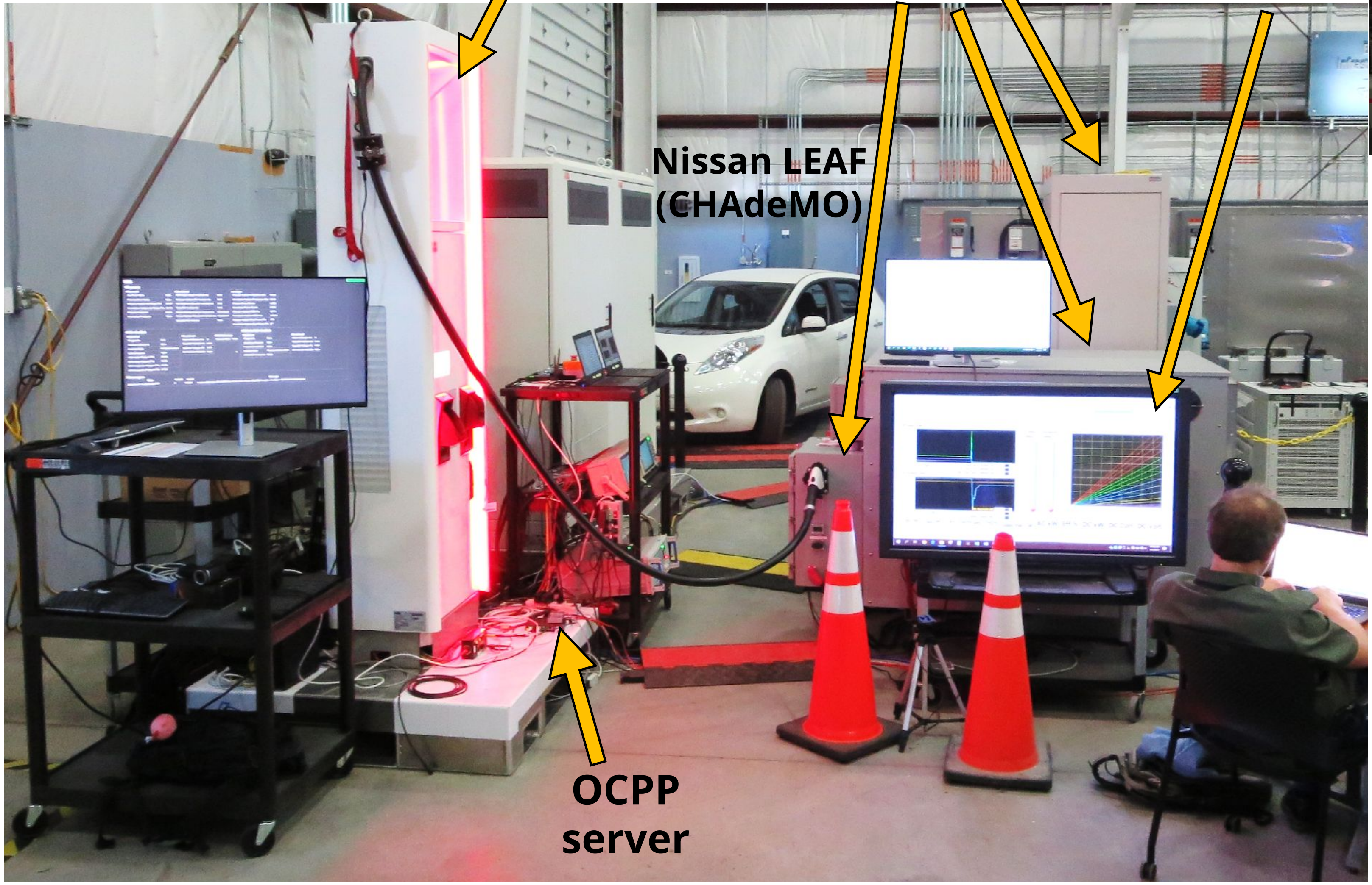
- The testing is done in INL's BTC and EVIL labs.
- Each of these graphs compares lab test results to outputs from one of INL's high fidelity EV charging models.

INL's Integrated Energy Systems Laboratory



EVIL: XFC Test and Demonstrations

Emulated EV Charging >350kW



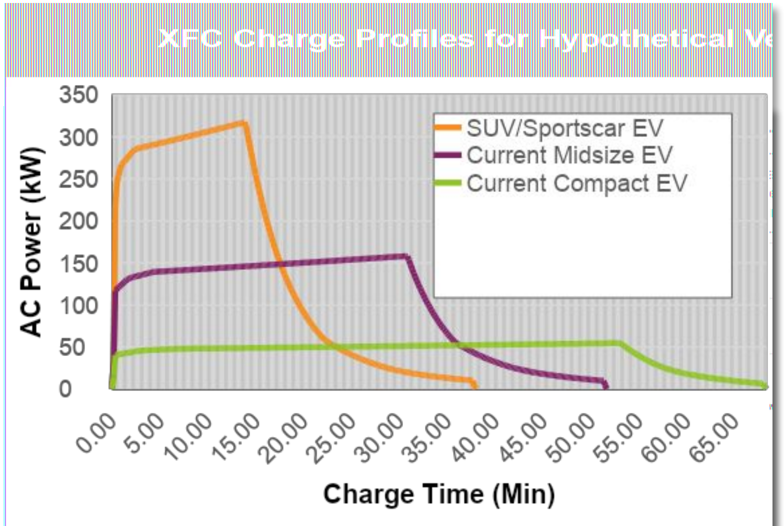
Heavy Duty EV Charging

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



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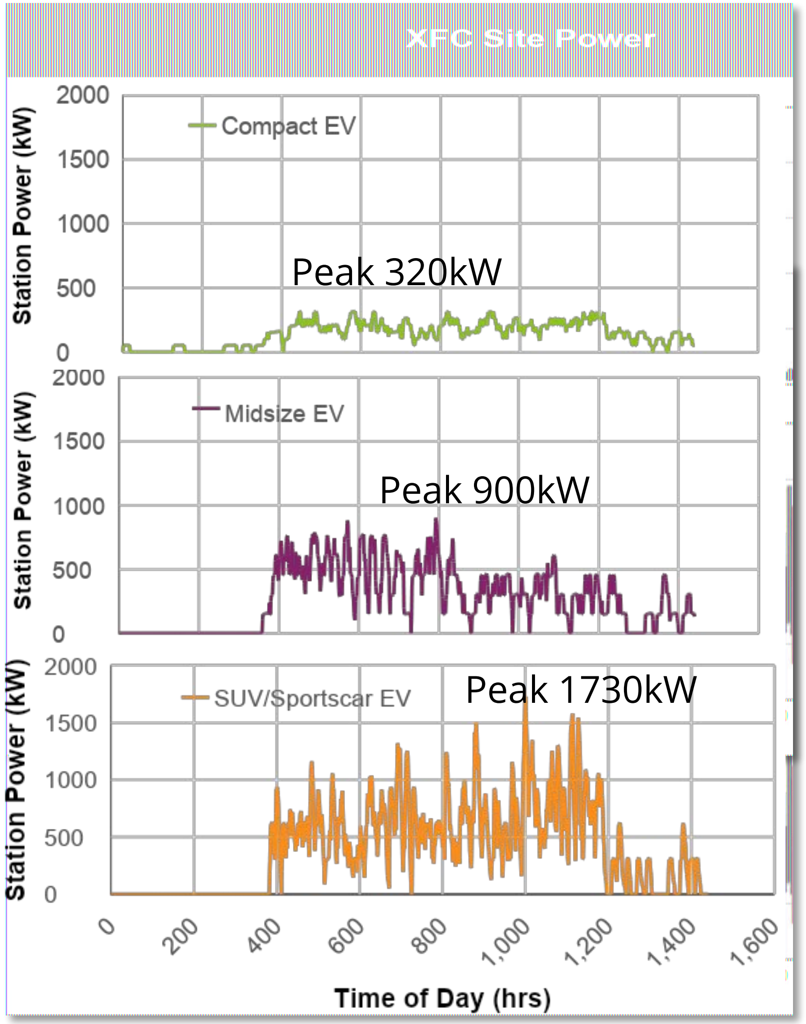
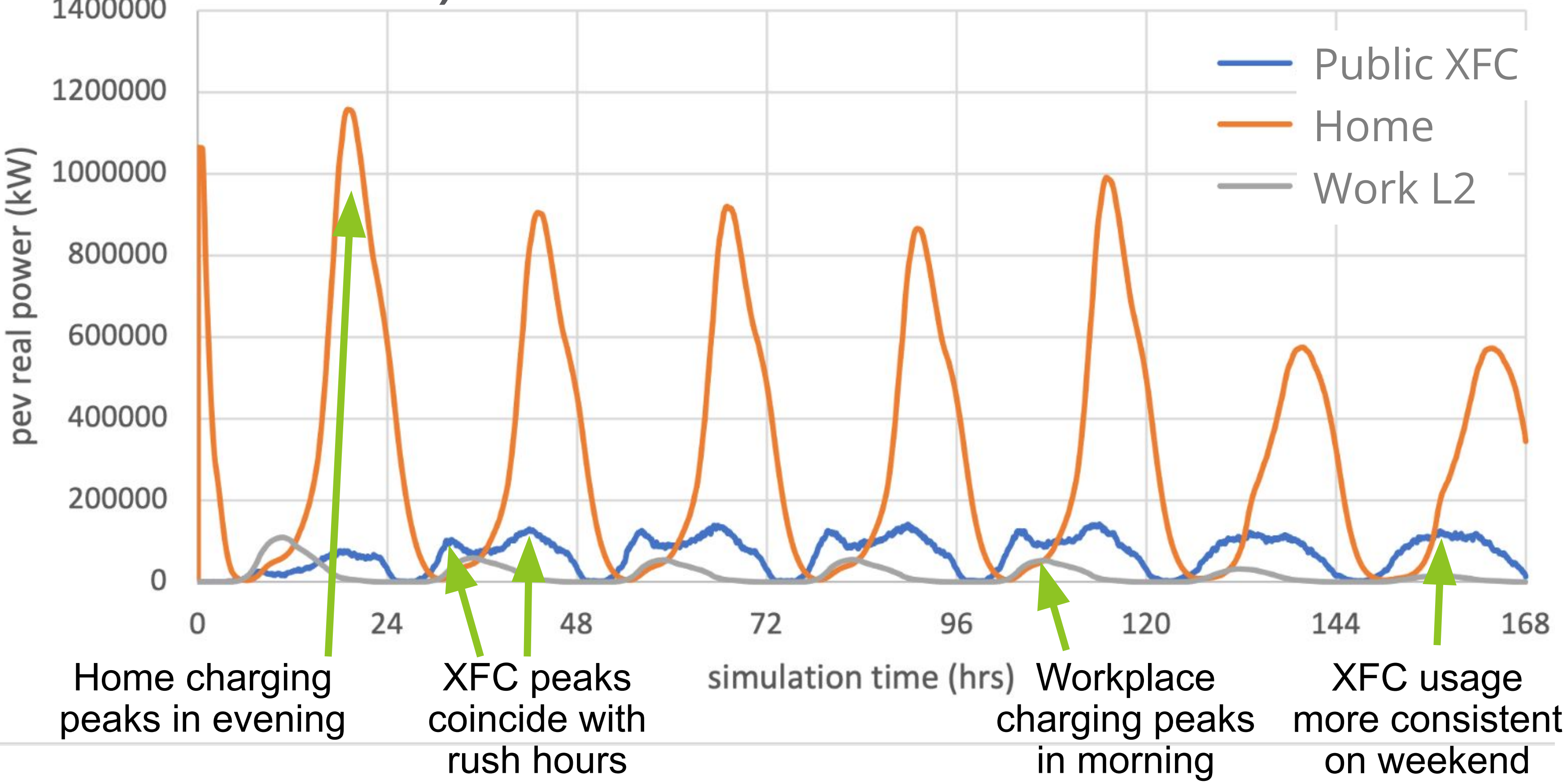
Max Charge Rate (kW)	300	150	50
Vehicle Range (Miles)	250	275	150
Vehicle Resembles	Porsche Taycan	Tesla Model 3	Nissan Leaf

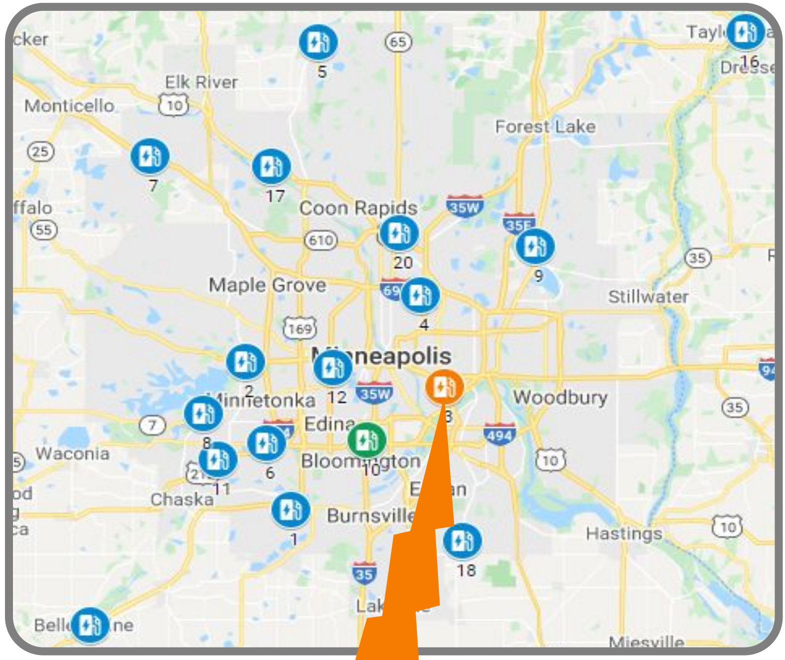
- **Demand charge might be >$25k per month**
- **While energy charge is <$2k**



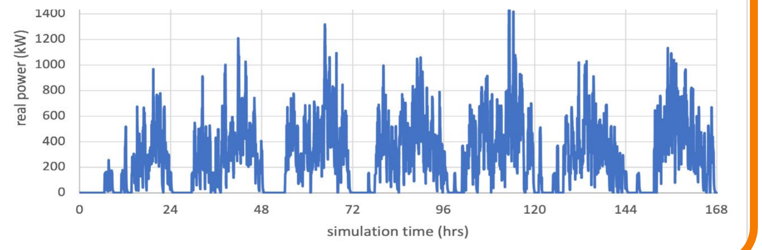
Forecasting Charging Load from 1.1M Personal-Use EVs

Regional Aggregate Load Profile (Power of All Locations)





Power of Single XFC Station

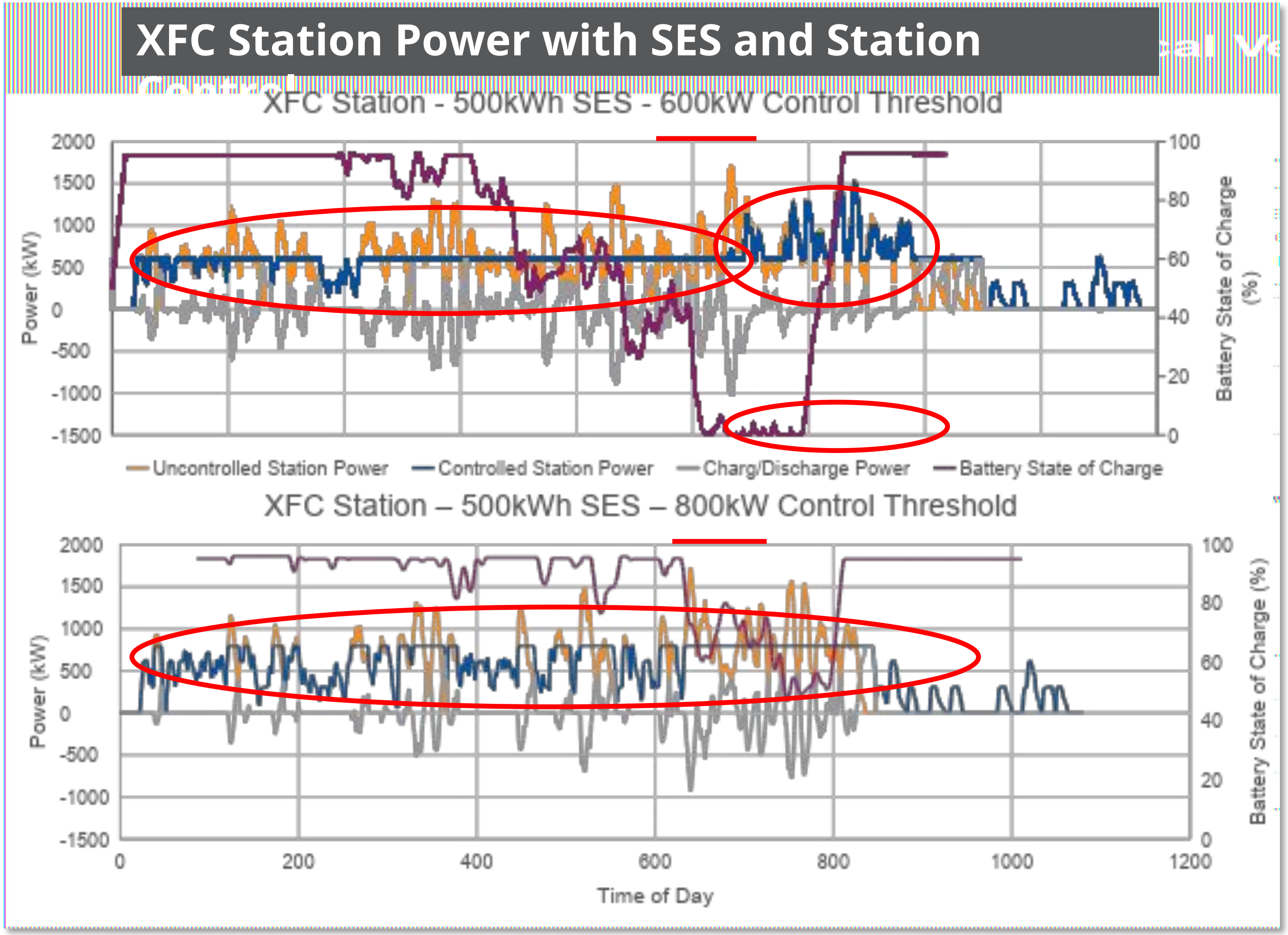


Total Energy Use:

•78% L2 Home

Results from Caldera in DirectXFC DOE Project

Simulating XFC with Energy Storage and Station Control



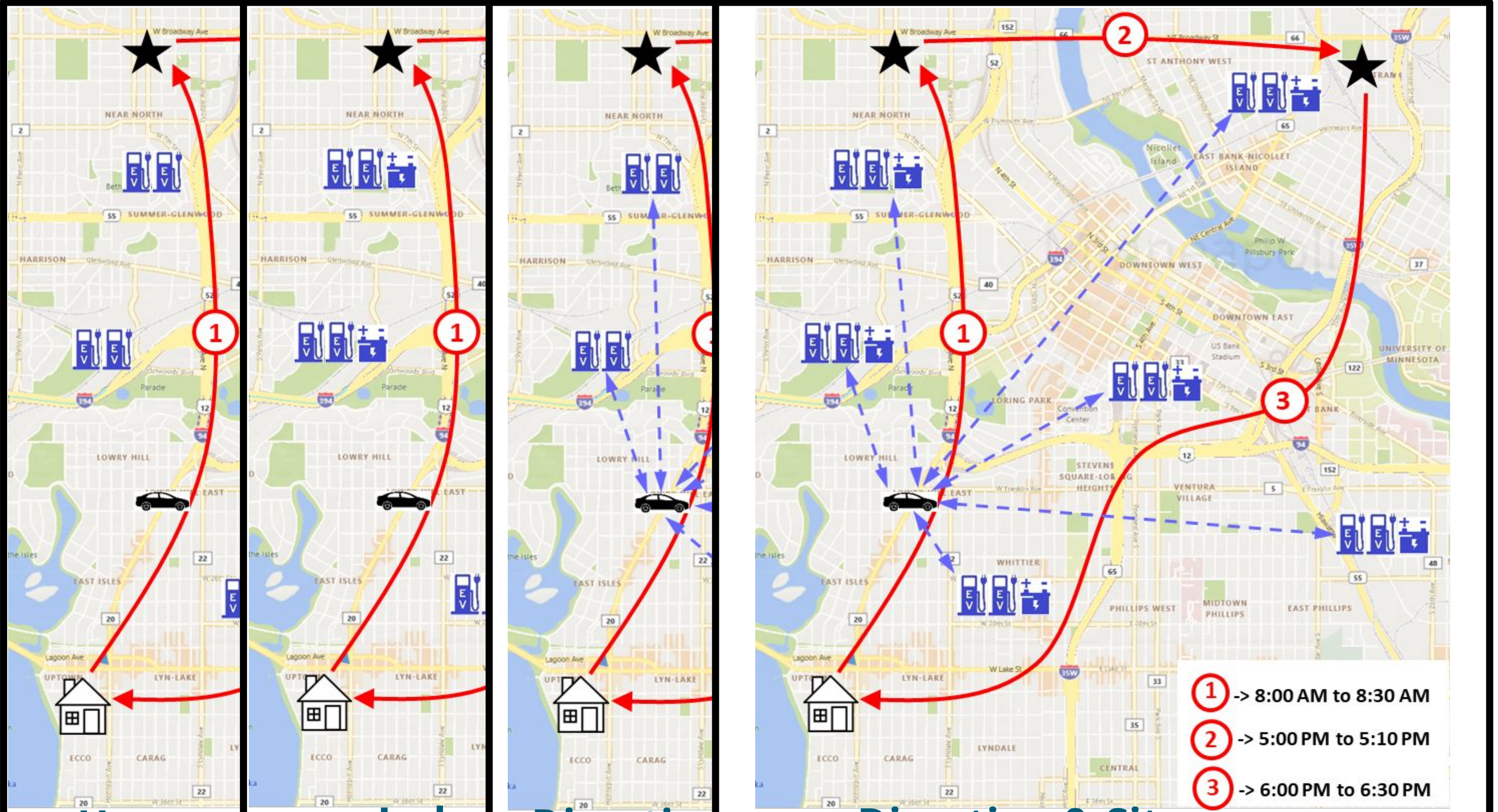
Results from Caldera in DirectXFC DOE Project

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



Uncontrolled

- Stationary
- Communic
- price/availa
- ~~Reservatio~~
- Occasional
- Higher avg
- charges

Independent M

- Stationary
- Communica
- price/availa
- ~~Reservation~~
- Smooth and
- profile
- Mitigate de

Directing

- Stationary
- Communic
- price/avail
- ~~Reservatio~~
- Incentivize
- Higher usa
- infrastruct

Directing & Site Control

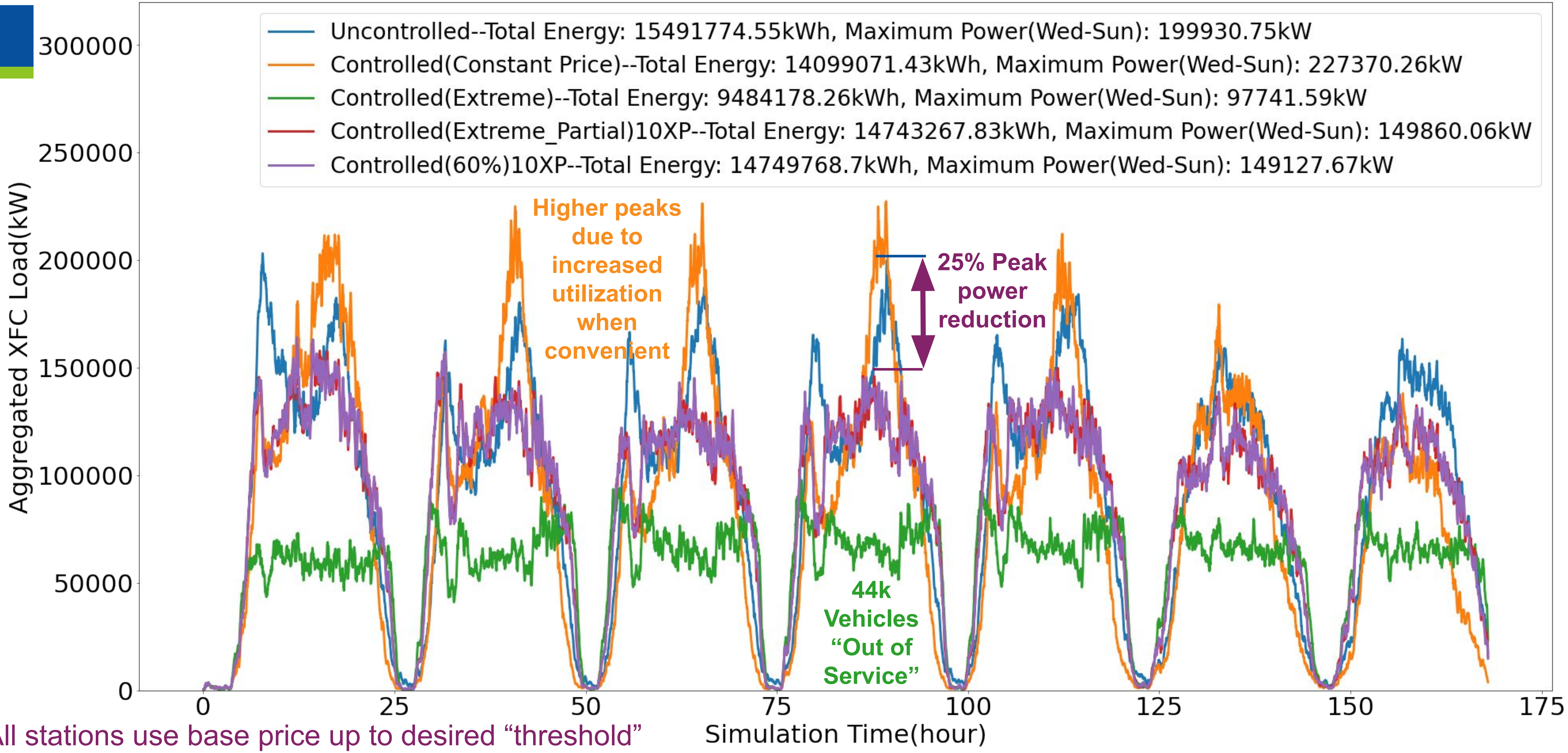
- Stationary energy storage
- Communication for price/availability
- ~~Reservations~~
- Reduce cost: EVs, XFC operator, grid upgrades
- Smooth, reduce, and shift load profile

- 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)

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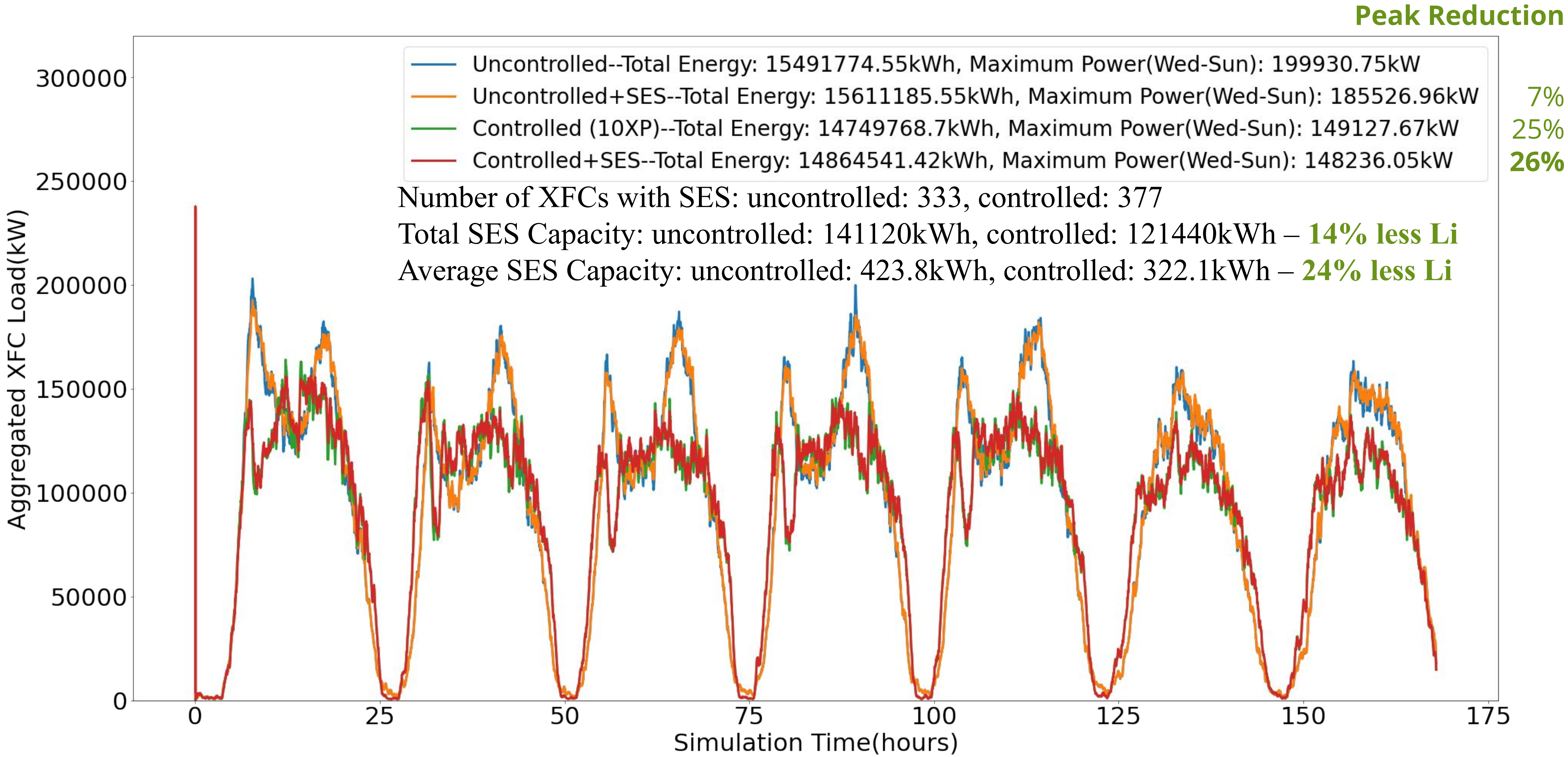
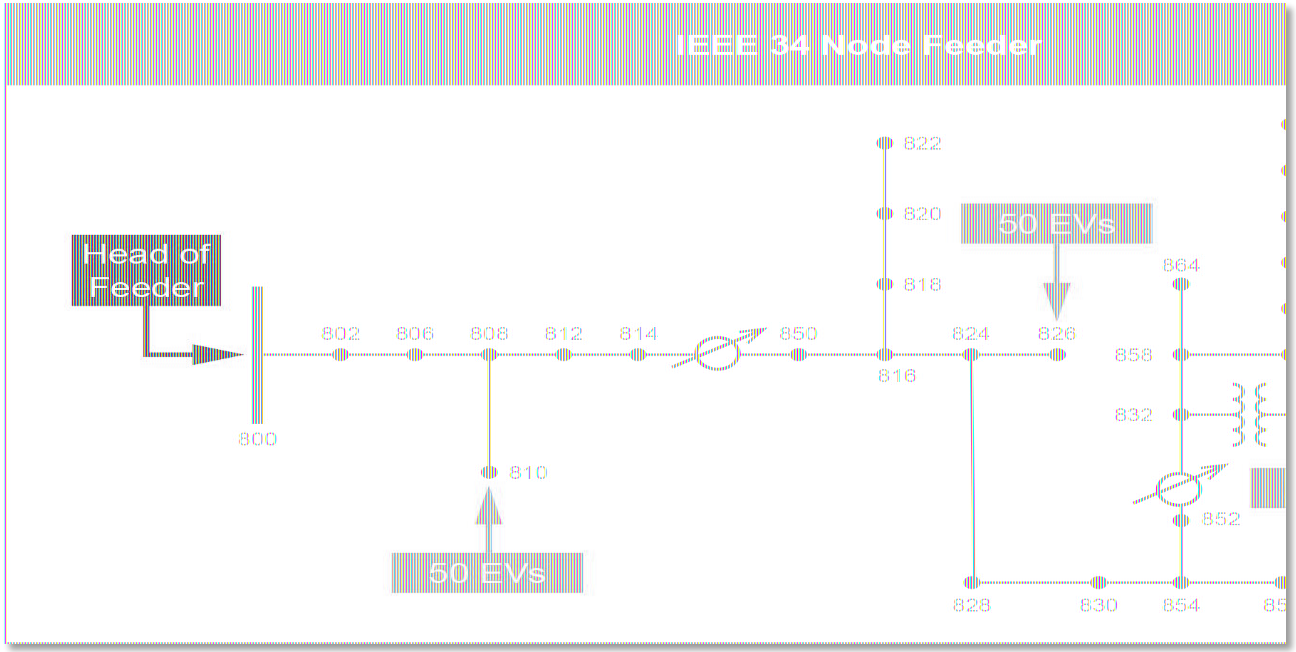
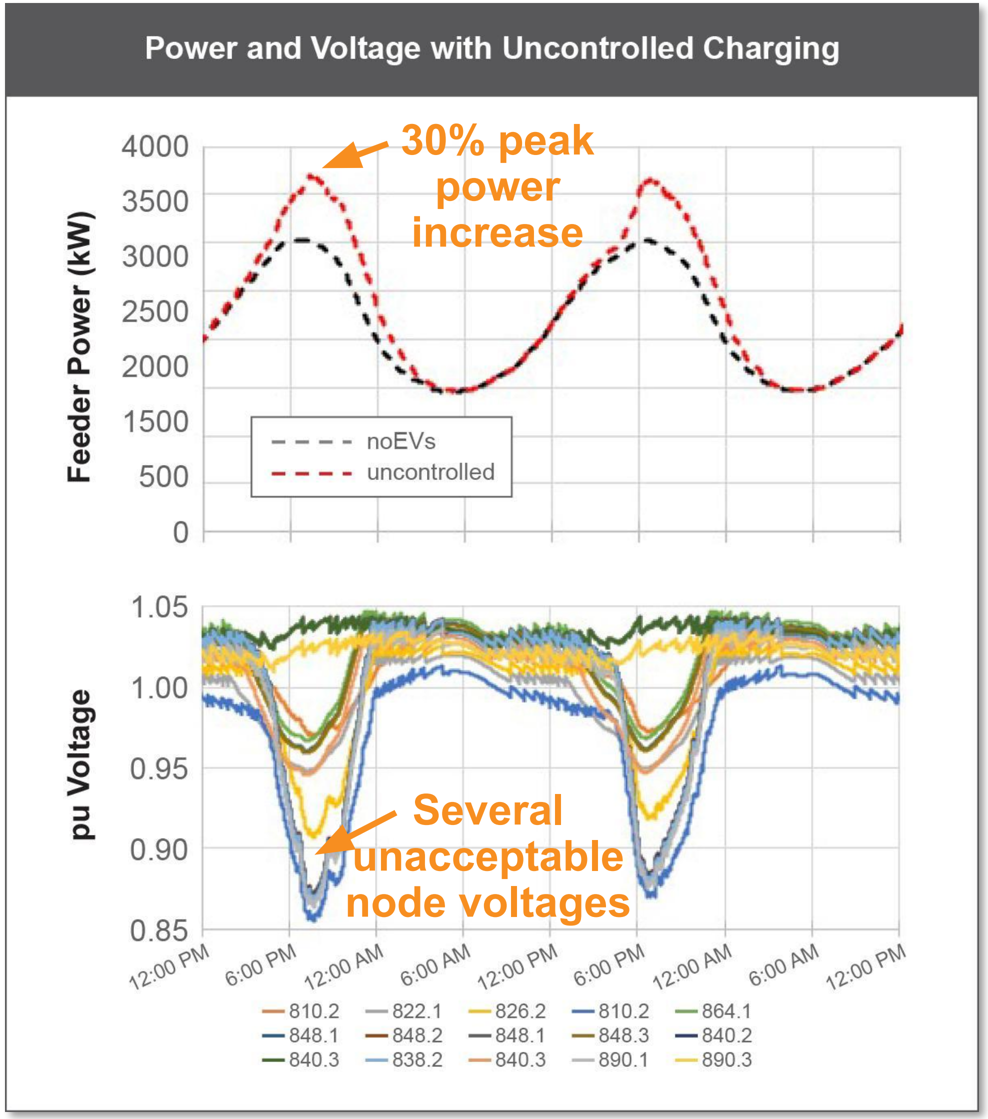
Aggregated XFC Load – 4 Scenarios



Grid Impact Demonstration Platform – AC L2 Residential

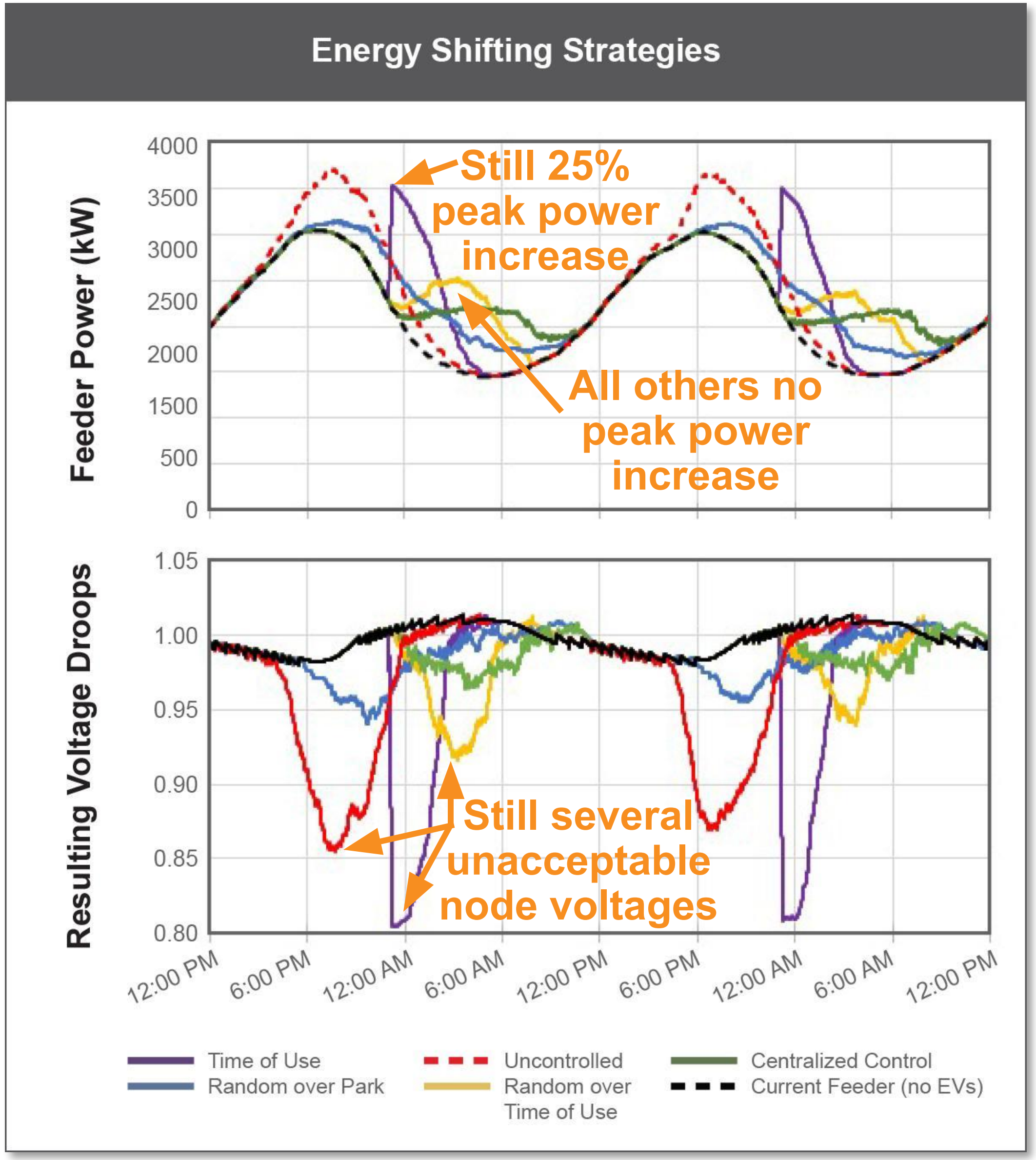
- Transportation simulation determines when and where vehicles are connected to the grid
- Charging model library accurately simulates loads which are applied to the grid model and can be viewed as an aggregate impact
- **Uncontrolled charging** is demonstrated and resulting impacts on the grid such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





Results from Caldera in RECHARGE DOE Project

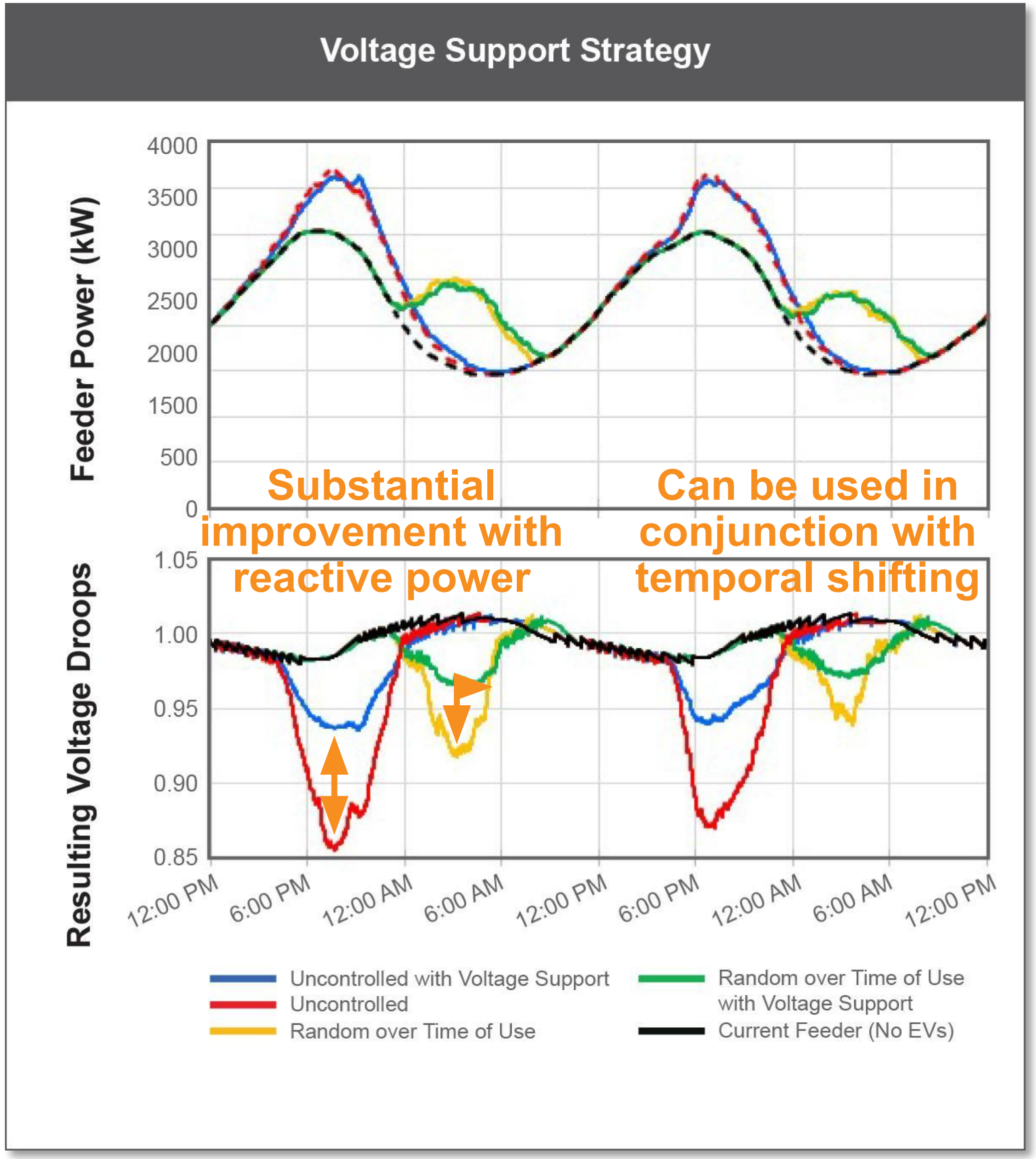
Control Strategy Demonstration Platform



Results from Caldera in RECHARGE DOE Project

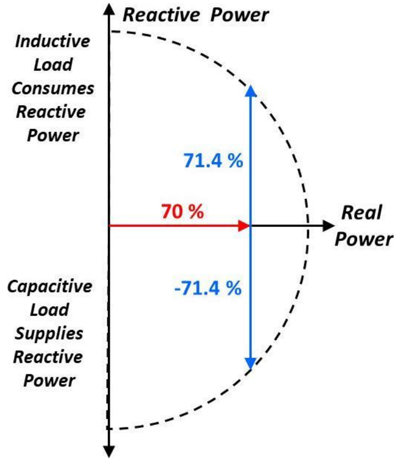
- Control Strategies are developed, tested, and compared in Caldera
- Energy shifting control strategies shown here include:
  - Centralized aggregator
  - Distributed random start
  - Time-of-Use rates (TofU)
  - Random starts during TofU
- Benefits increase with increasing EV Adoption, filling in trough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

Voltage support using Reactive Power



Results from Caldera in RECHARGE DOE Project

- 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

EVs @ Scale

U.S. Department of Energy

Broad Regional Analysis

INL PI: Manoj Kumar Cebol Sundarrajan

Part of the EV@S "FUSE" Project:

__F__lexible charging to __U__nify the grid and transportation __S__ectors for __E__Vs at scale

Smart charge management limitations

- **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?

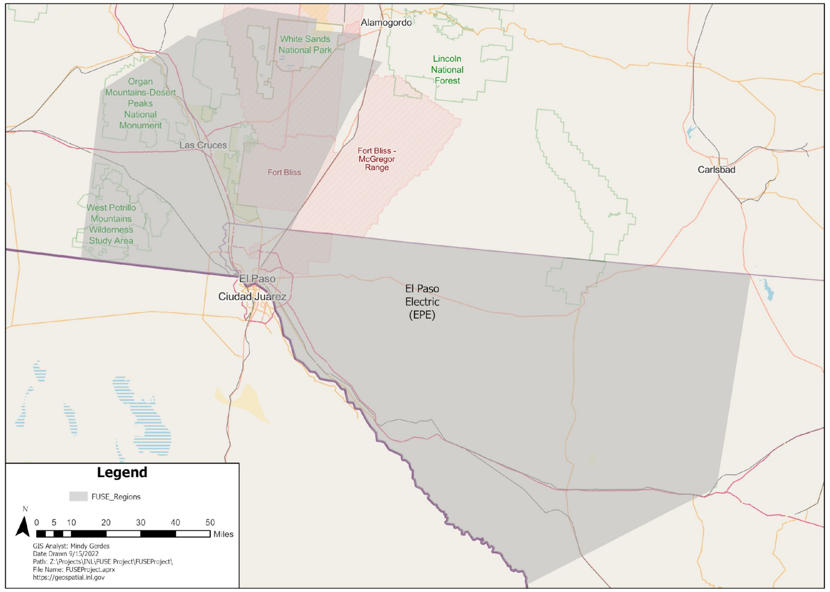
Which way the wind blows…

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

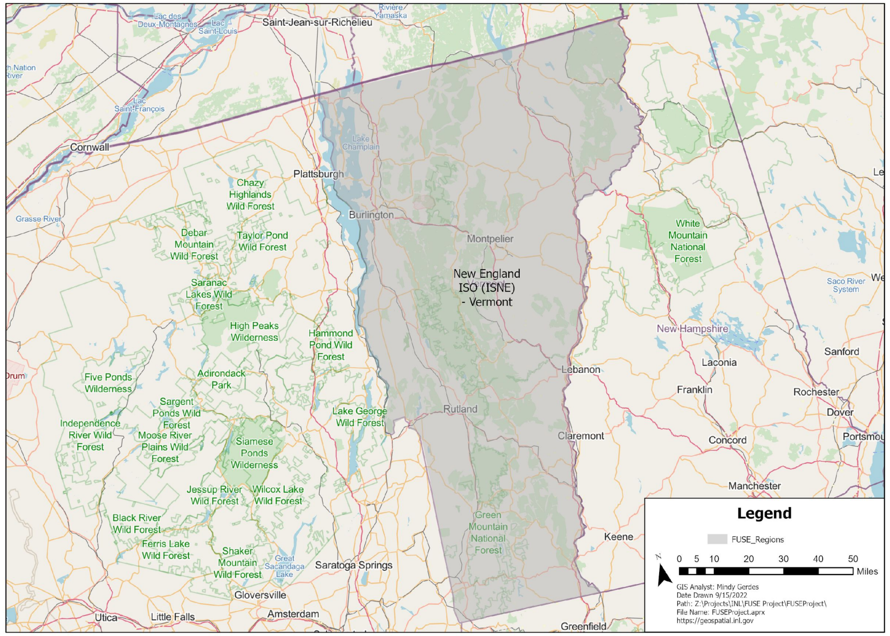
Broad Assessment Study Regions

FUSE Regions

El Paso Electric (EPE) Region



New England ISO (ISNE) - Vermont Region



Regional Characteristics Matrix

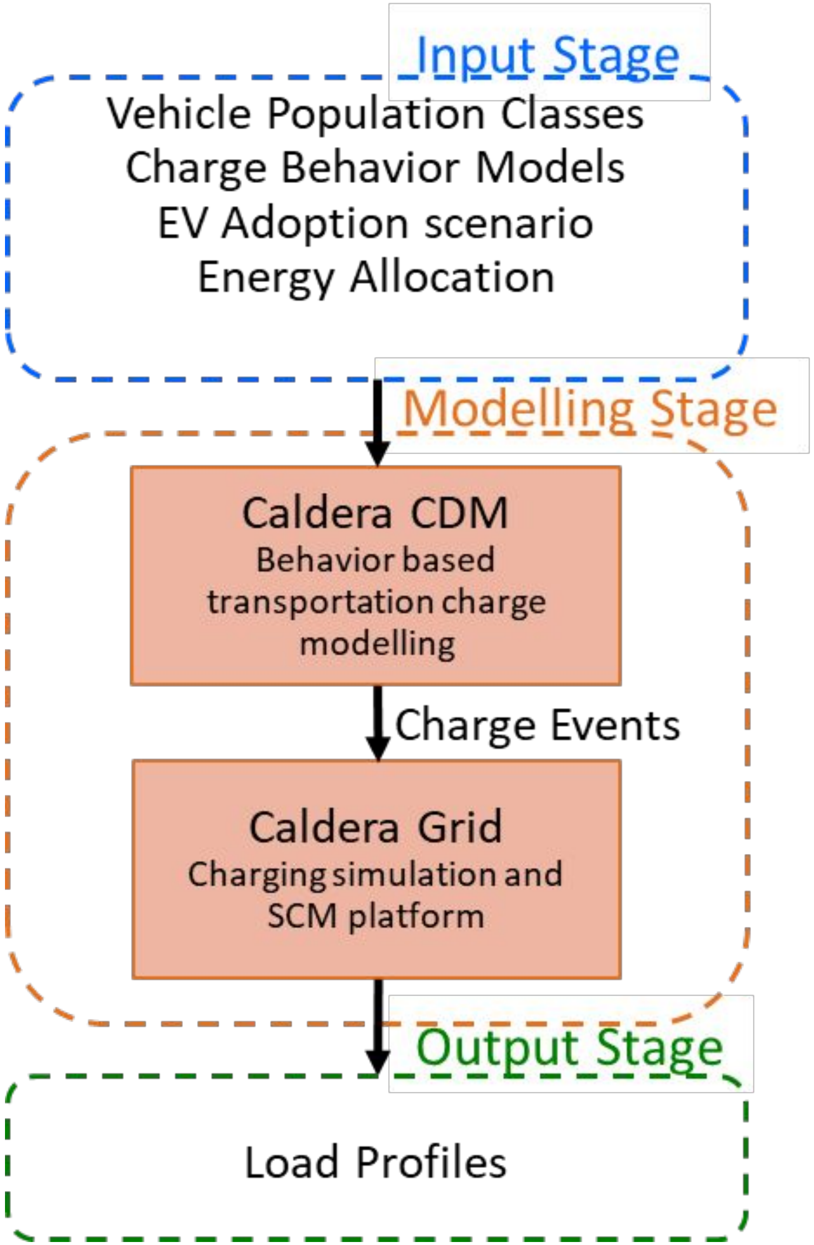
EVs@Scale U.S. Department of Energy

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**

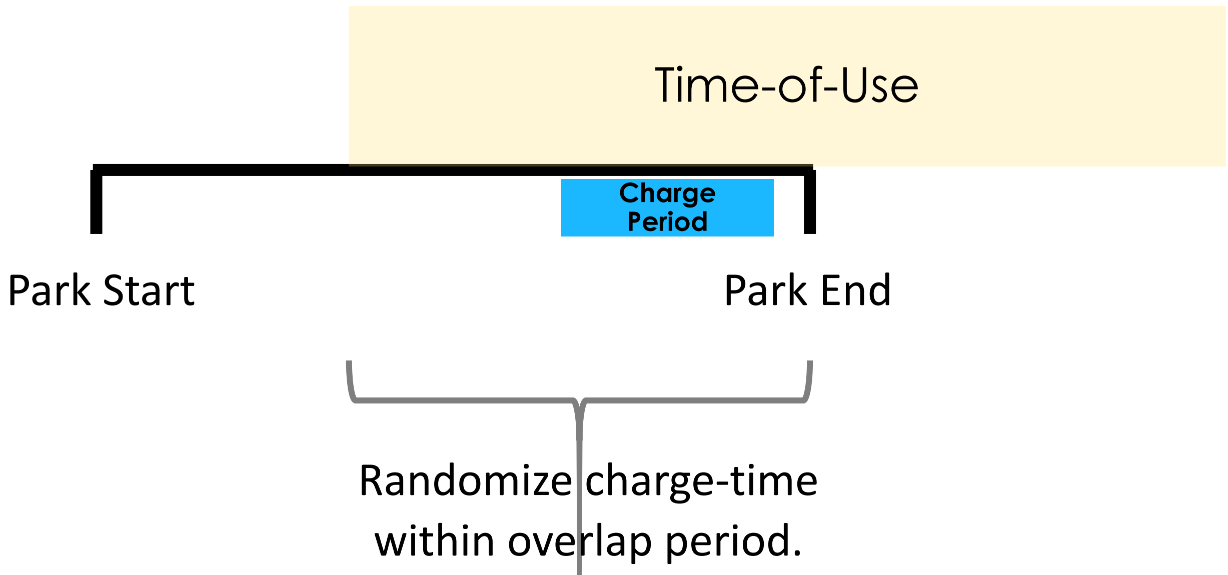
Computational modelling approach

- **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

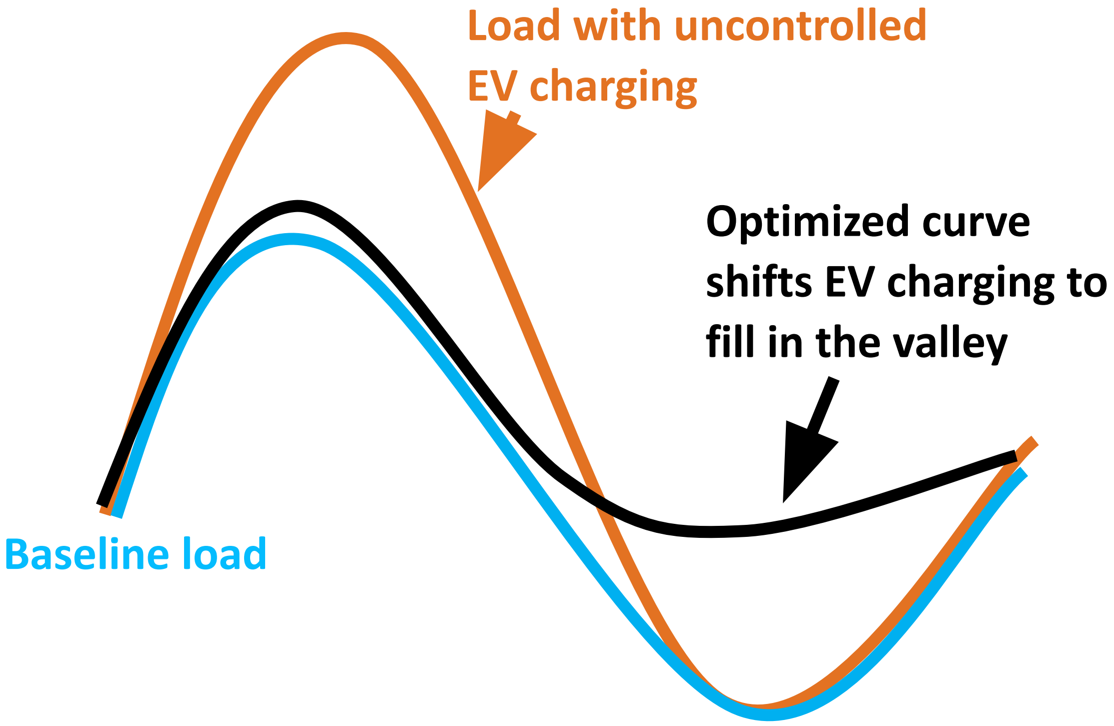


SCM strategies

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

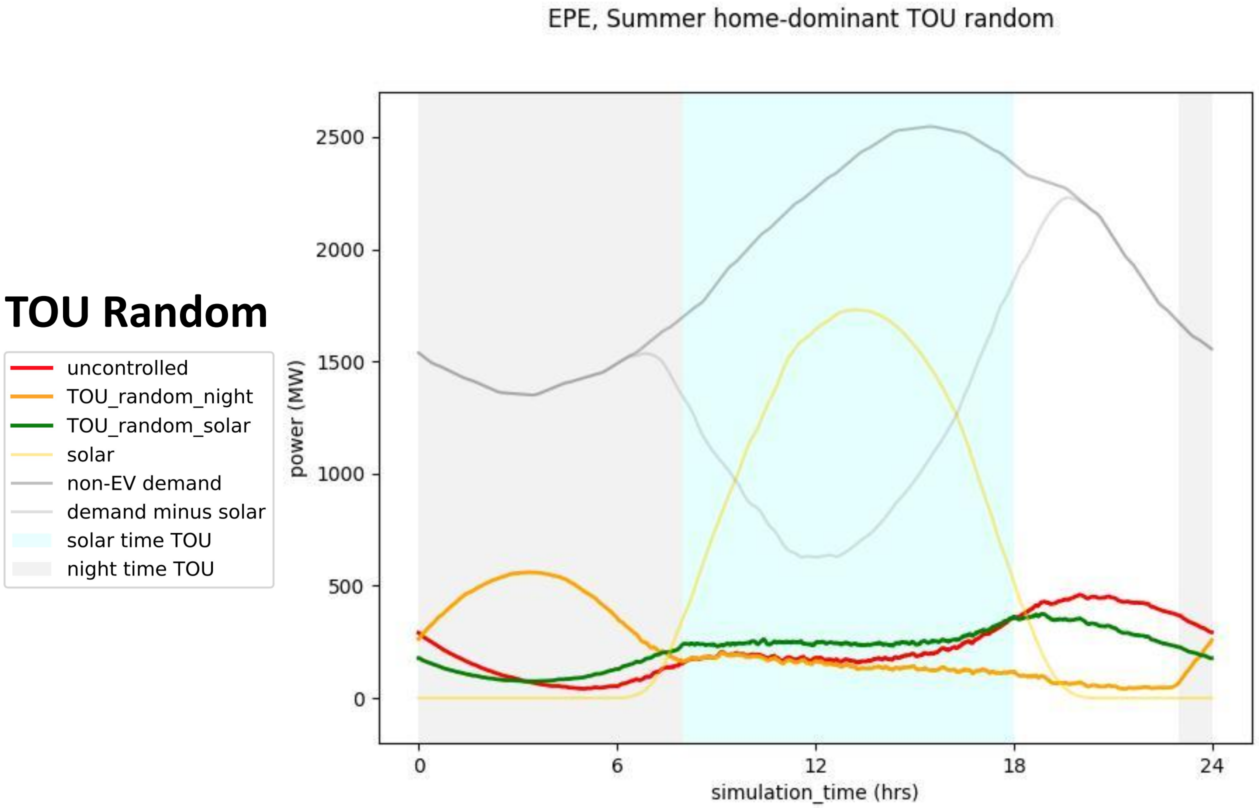


- **Solar Centralized Aggregator**
  - Centralized strategy shifts EV charging within vehicle dwell to minimize feeder peak
  - New objective function to maximize charging following solar curve.



- **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.**

TOU Random



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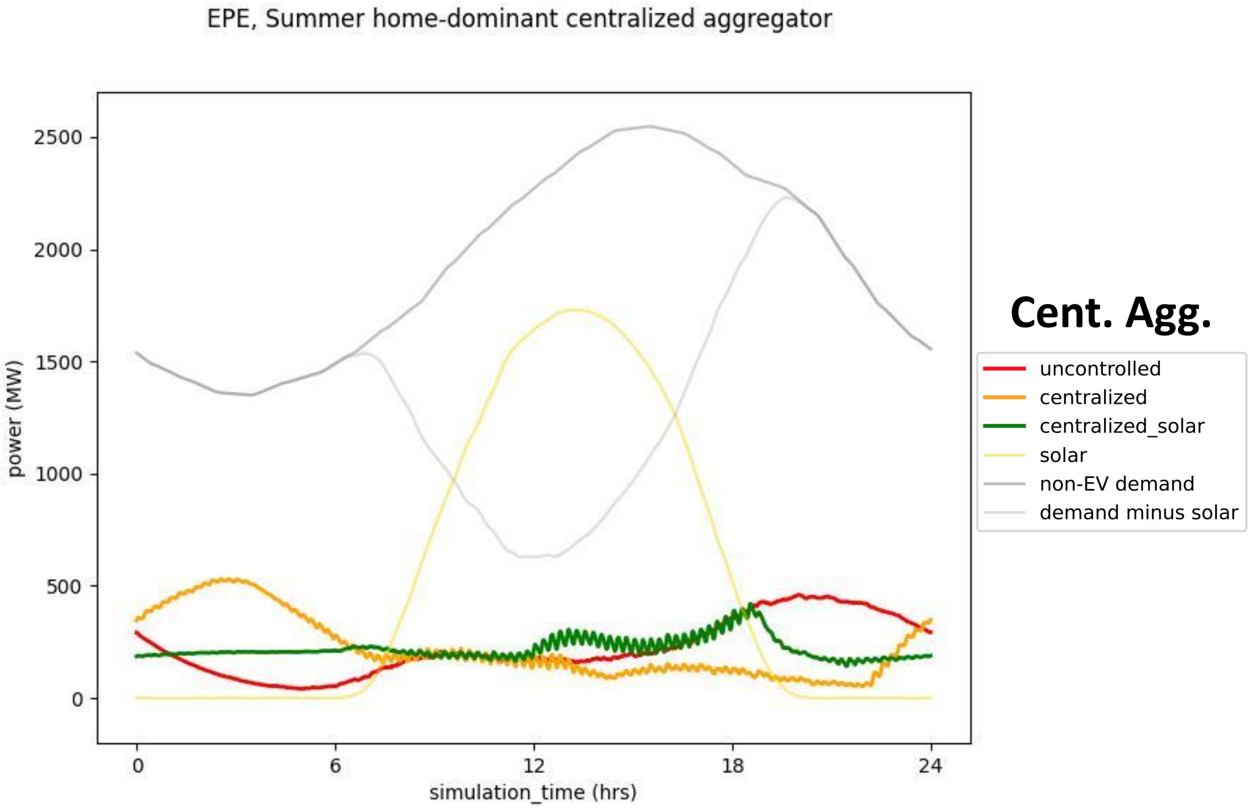
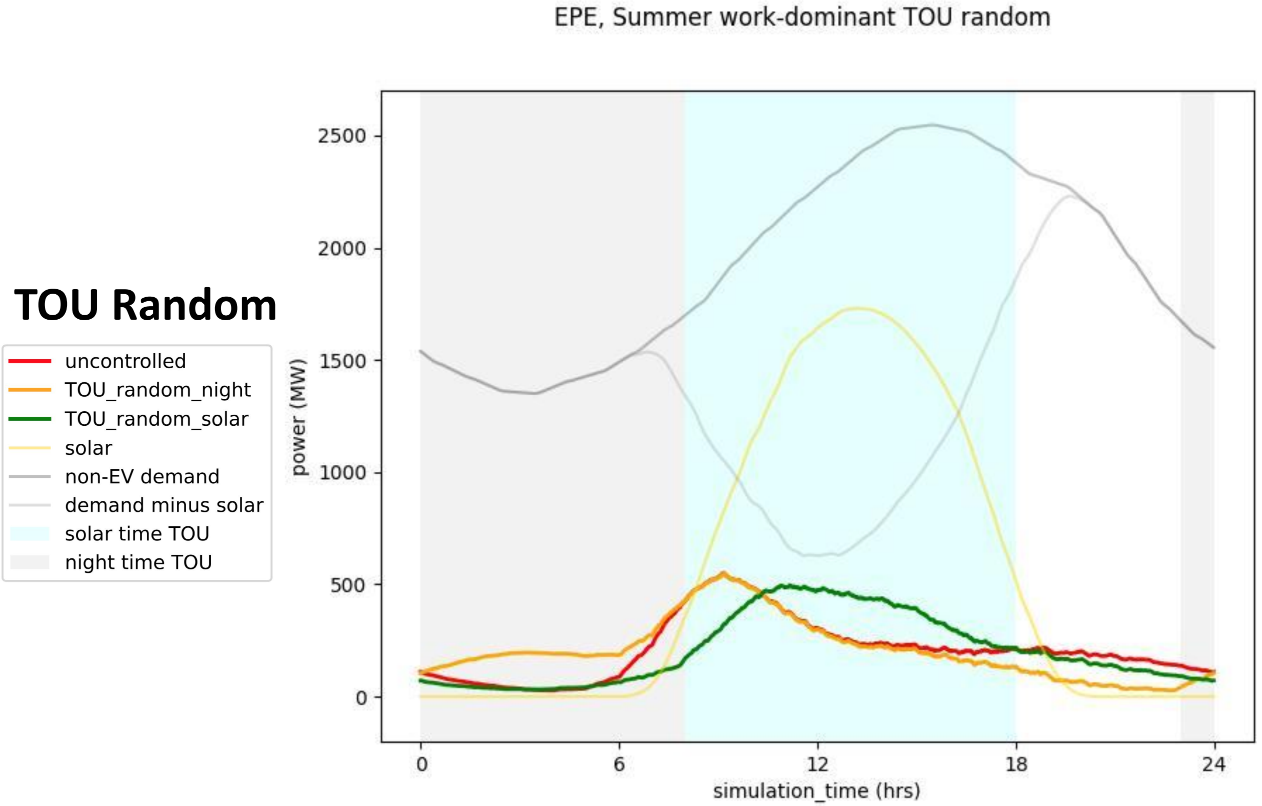


Work Dominant – El Paso summer

- **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.**

TOU Random



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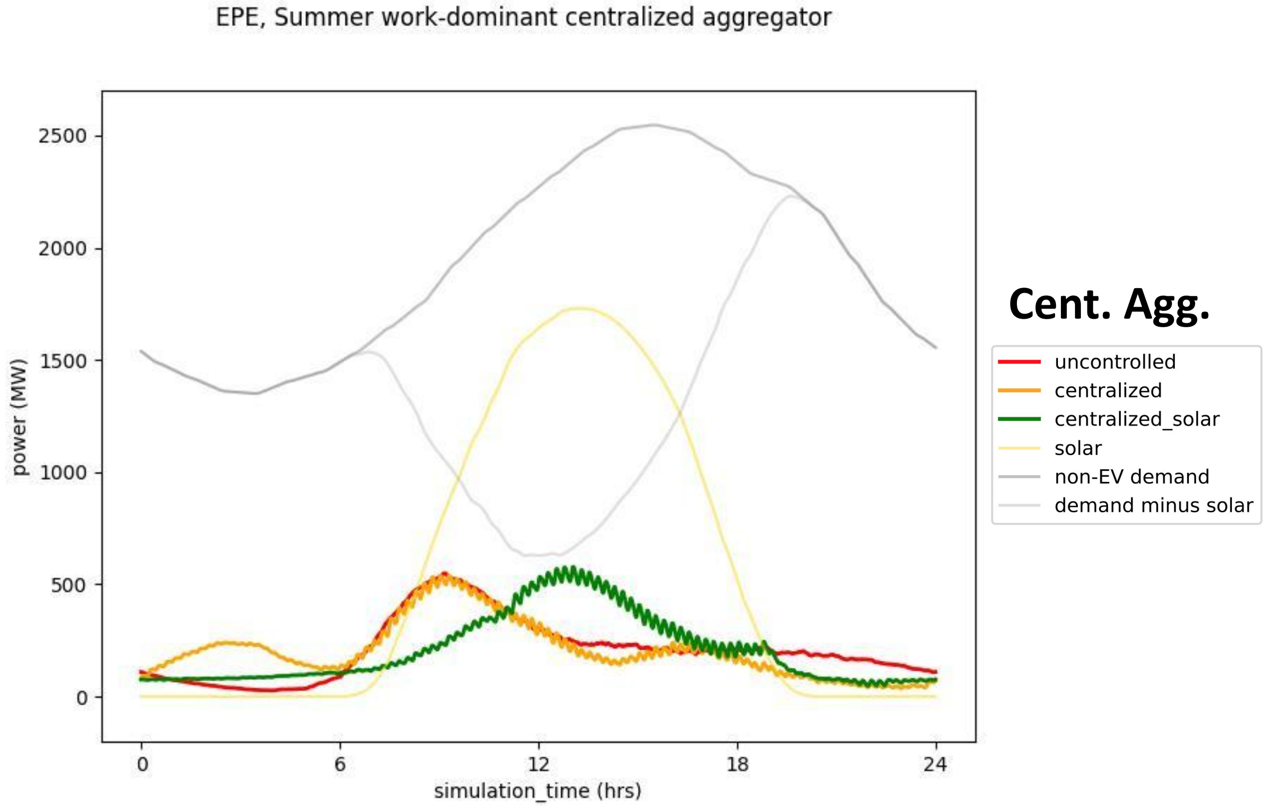


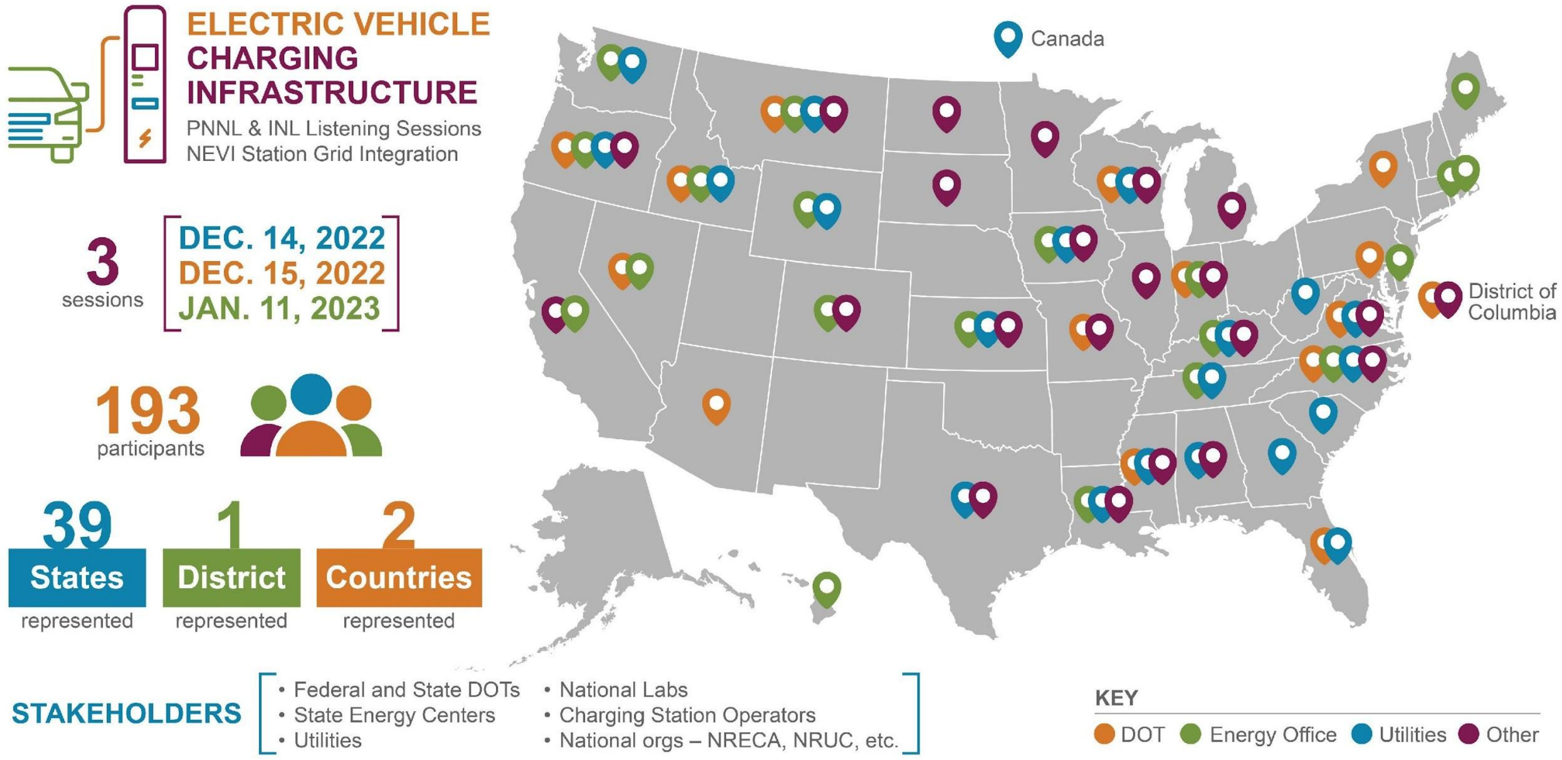
CalderCast:

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

Input stage

EV statistics
+ Traffic volume
+ EV station usage
+ Probability distribution
+ Charging parameters

→

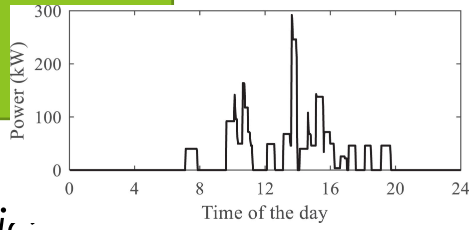
Processing stage

Probabilistic modeling

→

Output stage

Energy Demand forecast



APPROACH

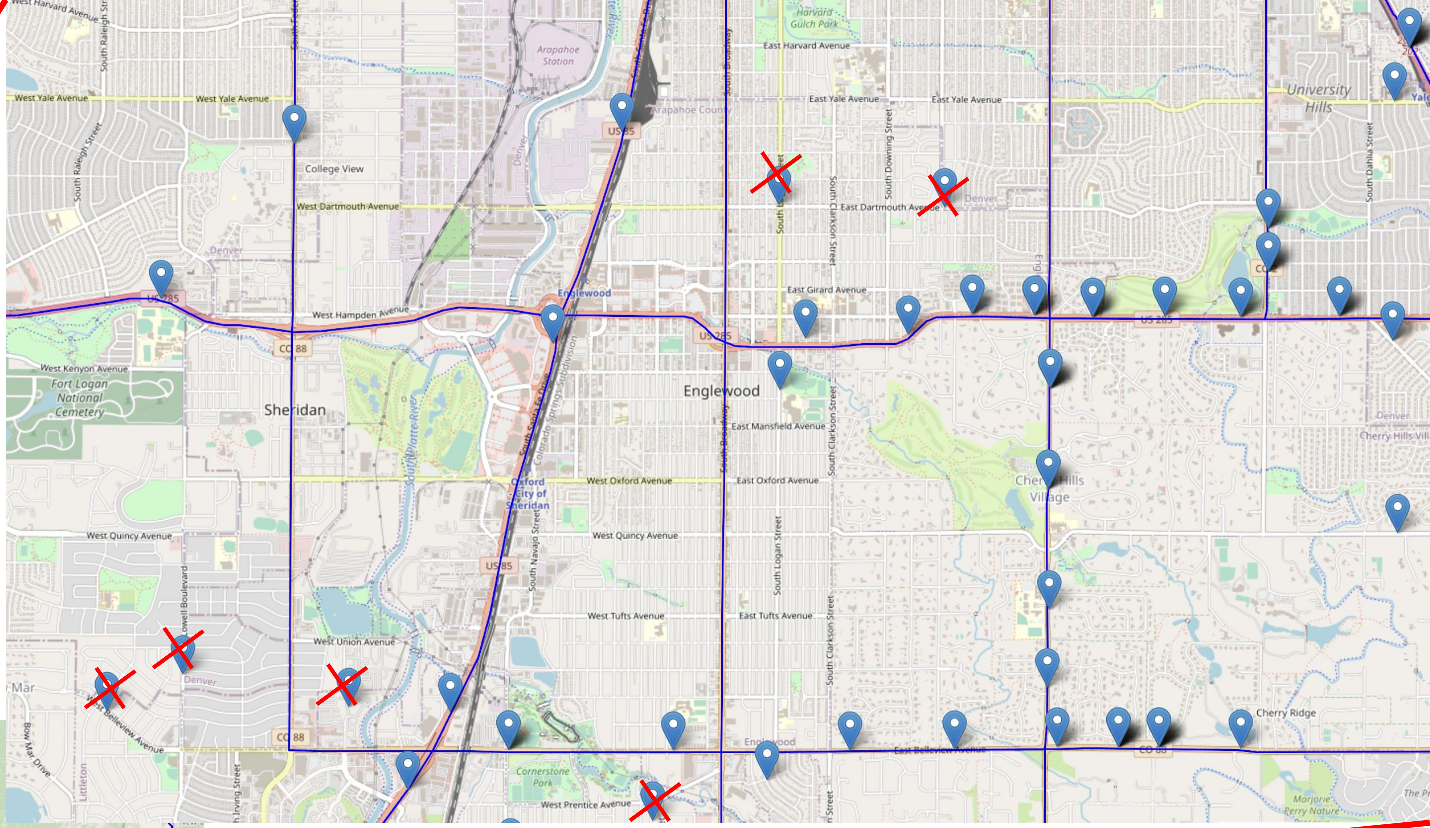
Forecast load modeling using a traffic volume-oriented method based on *EV traffic volume*, *energy usage distribution* and *charging station popularity*.

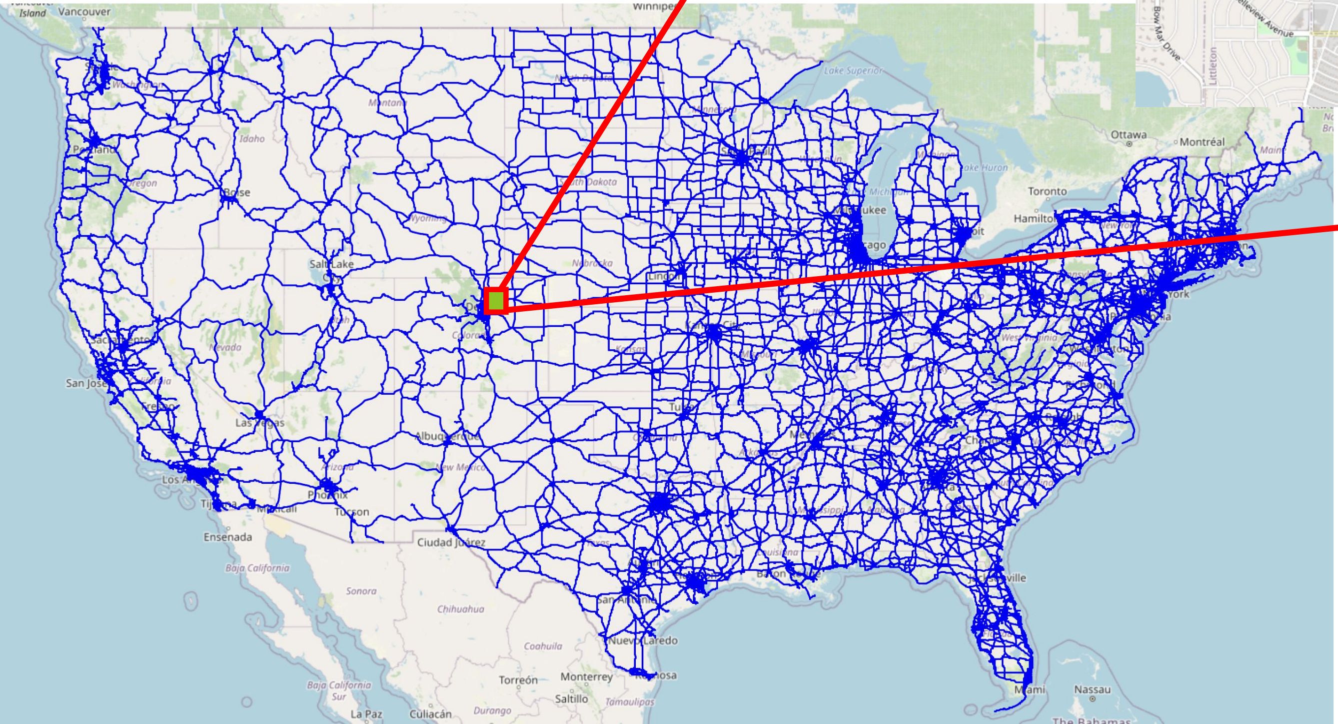
STEPS

- ✔ 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

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