Vehicle Technologies Office

Annual Merit Review 2021

23 June 2021

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DirectXFC

Directed Electric Charging of Transportation using eXtreme Fast Charging (DirectXFC)

Idaho National Laboratory

INL Lab Review System
STI#: INL/CON-20-58162

Project ID# ELT257

Overview

Timeline

- **Project start date: December 2019**
- Project end date: March 2022
- Percent complete: 60%

Barriers and Technical Targets

- eXtreme Fast Charging (XFC) is a desirable capability for PEV owners. If it is implemented without management it may have a negative impact on the grid, exasperated by variable generation
- Determine controlled and directed XFC strategies with most value to owners and grid
- Demonstrate local XFC station operation strategies for optimal energy management

Budget

- Total project funding: $ 3,000k
- DOE Share: $ 3,000k
- Contractor Share: $ 0
- Fiscal Year 2019 Funding: $ 0
- Fiscal Year 2021 Funding: $ 1,500k

Partners

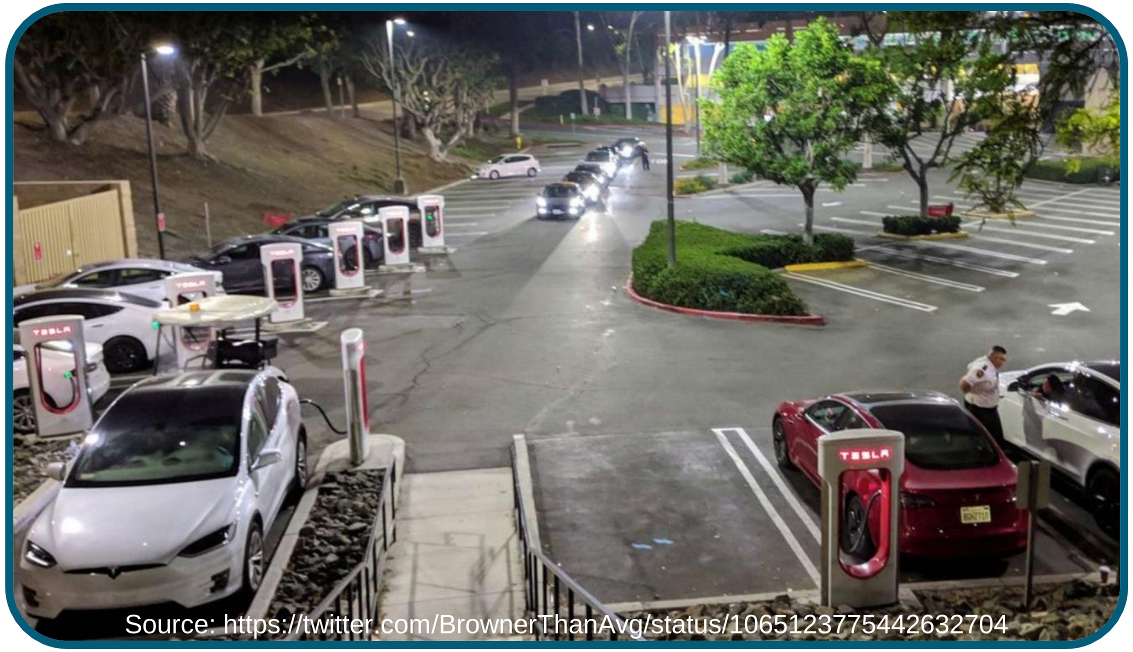
- Idaho National Laboratory (INL)
- National Renewable Energy Laboratory (NREL)
- Argonne National Laboratory (ANL)

Relevance

- More vehicles are offering XFC charging (>150kW) and more XFC stations are being installed
- As EV adoption grows and XFC usage increases, it could have a larger impact on the grid, higher charging costs for EV owners, and challenges for charge network operators

DirectXFC Objectives

1. Determine the value of directing when and where drivers charge to minimize cost and grid impact
2. Demonstrate XFC station operation for optimal energy management
3. Determine requirements for network-level implementation and demonstrate in simulation and hardware-in-the-loop testing



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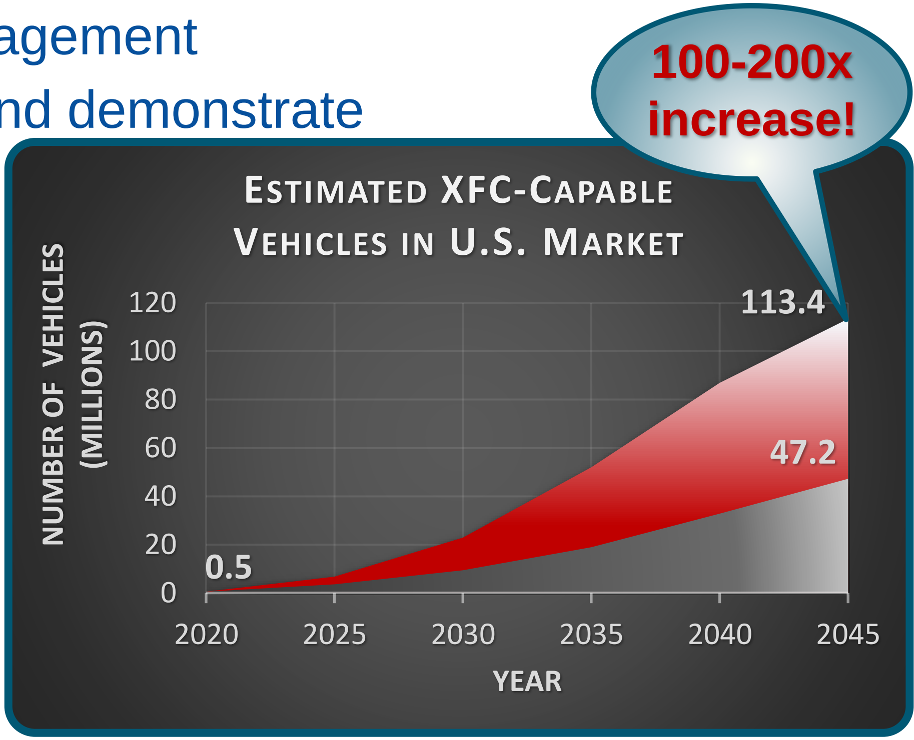
Introducing Caldera™, a research tool for developing and simulating XFC management strategies



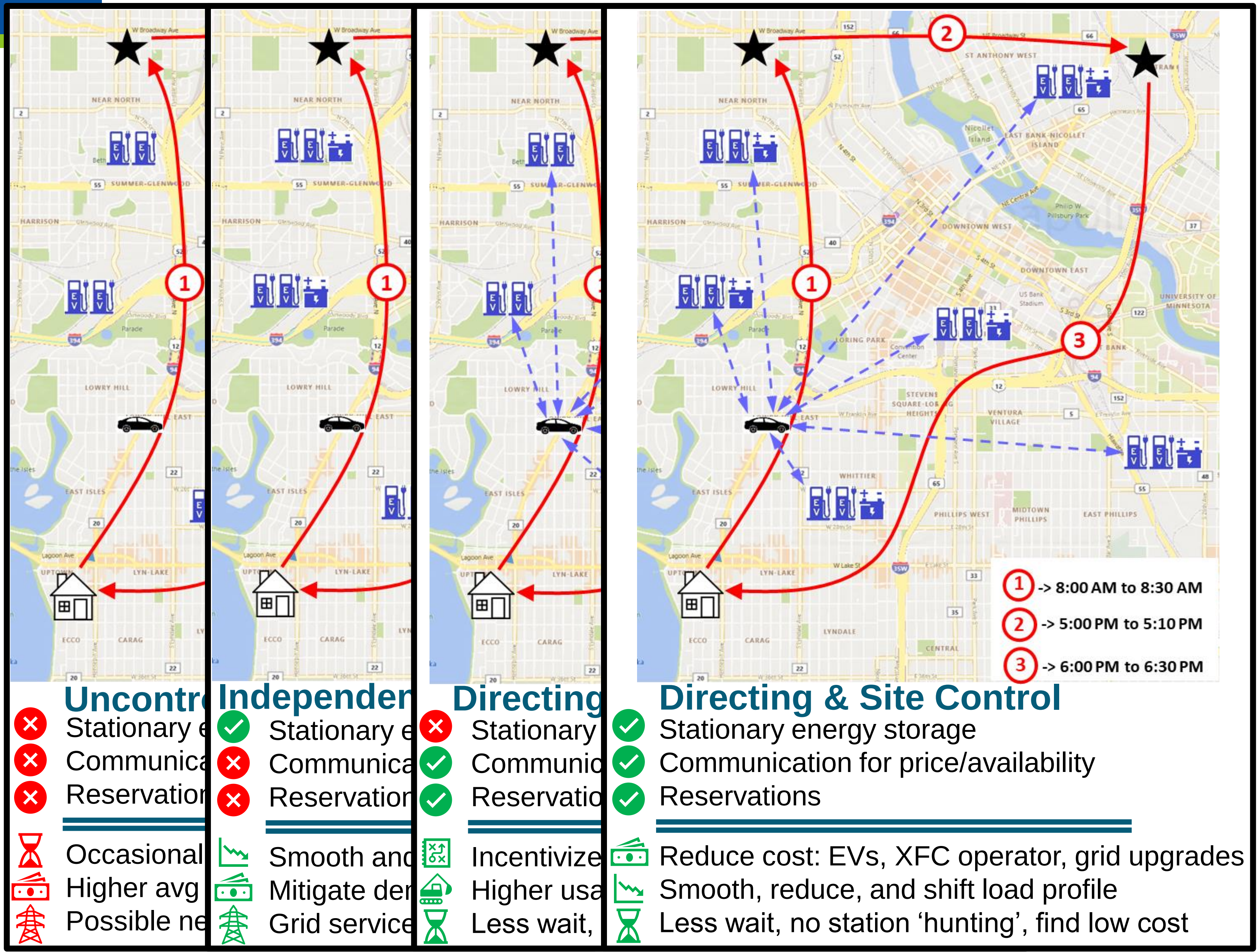
Estimates based on EPRI High/Med and DirectXFC vehicle forecasts

Milestones

Milestone	Task	Deadline	Type	Status
Define simulation scenarios for uncontrolled XFC charging at scale	1.1	3/31/2019	Quarterly	Complete
Complete creation of weekly travel itineraries, and charging station locations	1.1	6/30/2020	Quarterly	Complete
Achieve initial operational capability of XFC hardware with communication, and define ESI with utility	2.1, 2.2	9/30/2020	Annual	In Process
Demonstrate initial operational capability of directed and controlled XFC at scale in Caldera™	1.2	9/30/2020	Go/No-Go	Complete
Demonstrate co-simulation capability of controlled and uncontrolled XFC charging between Caldera™ and OpenDSS, and demonstrate XFC independent site-level integration and control	1.3, 2.3	12/31/2020	Quarterly	In Process
Complete assessment of grid impact of scenarios in Tasks 1.1 and 1.2	1.3	3/31/2021	Quarterly	In Process
Complete process for transferring Caldera™ network/regional-level simulation results to HIL platforms	3.1	6/30/2021	Quarterly	In Process
Demonstrate XFC site management with distributed network and regional input (from Caldera™); develop plan for disseminating site- and network-level control strategies validated in HIL demonstrations	3.2	9/30/2021	Annual	Upcoming
Publish a report quantifying the value of controlled and directed XFC charging, the extent to which XFC stations can provide grid services while still meeting charging needs; complete dissemination of validated control strategies	1.4, All	12/31/2021	Final Report	End of Project

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

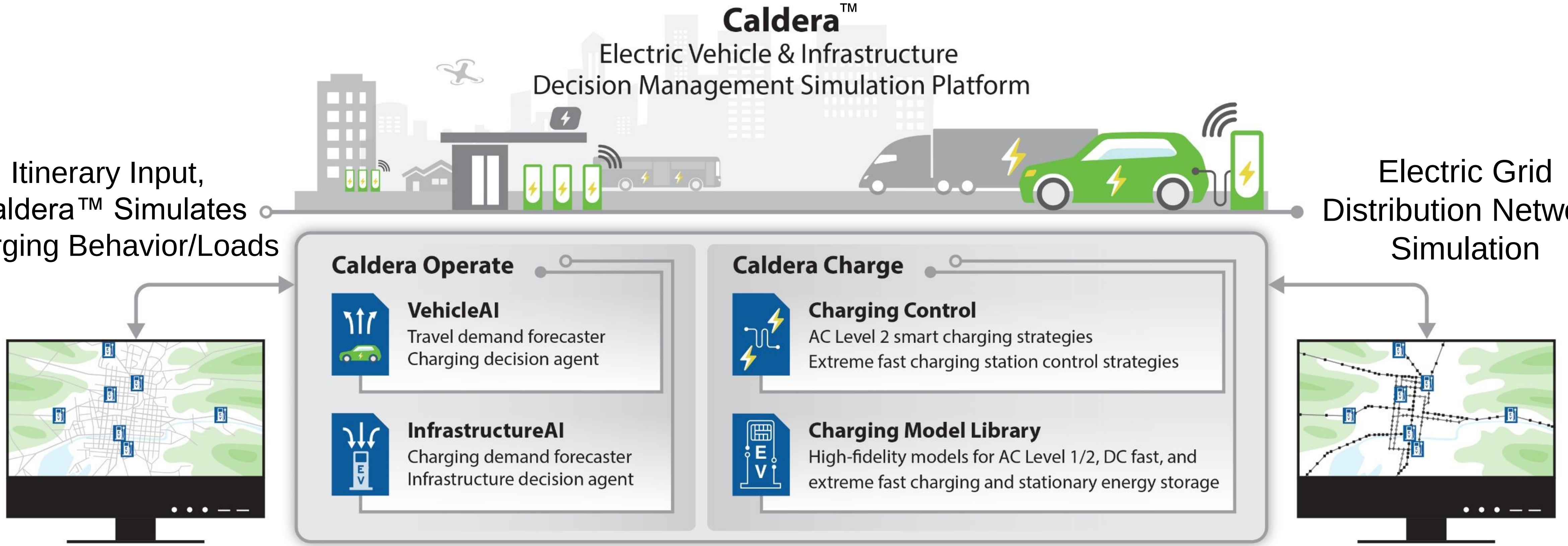
Approach to Directing and Managing XFC



- Simulations conducted in Minneapolis, MN with feeder information provided by Xcel Energy
- INL's Caldera™ tool simulates vehicles selecting chargers as needed during 1-week itinerary
  - EV will communicate with EVSE networks and recommend best charging options based on market conditions
  - Caldera™ simulates owner selections to understand system impacts
- NREL's OpenDSS model co-simulates effects on the distribution network
- NREL and ANL will conduct Hardware-in-the-Loop demonstrations of station control with the Caldera™ simulation

Approach:
Modeling and Simulation including XFC Management Strategies

Itinerary Input,
Caldera™ Simulates
Charging Behavior/Loads



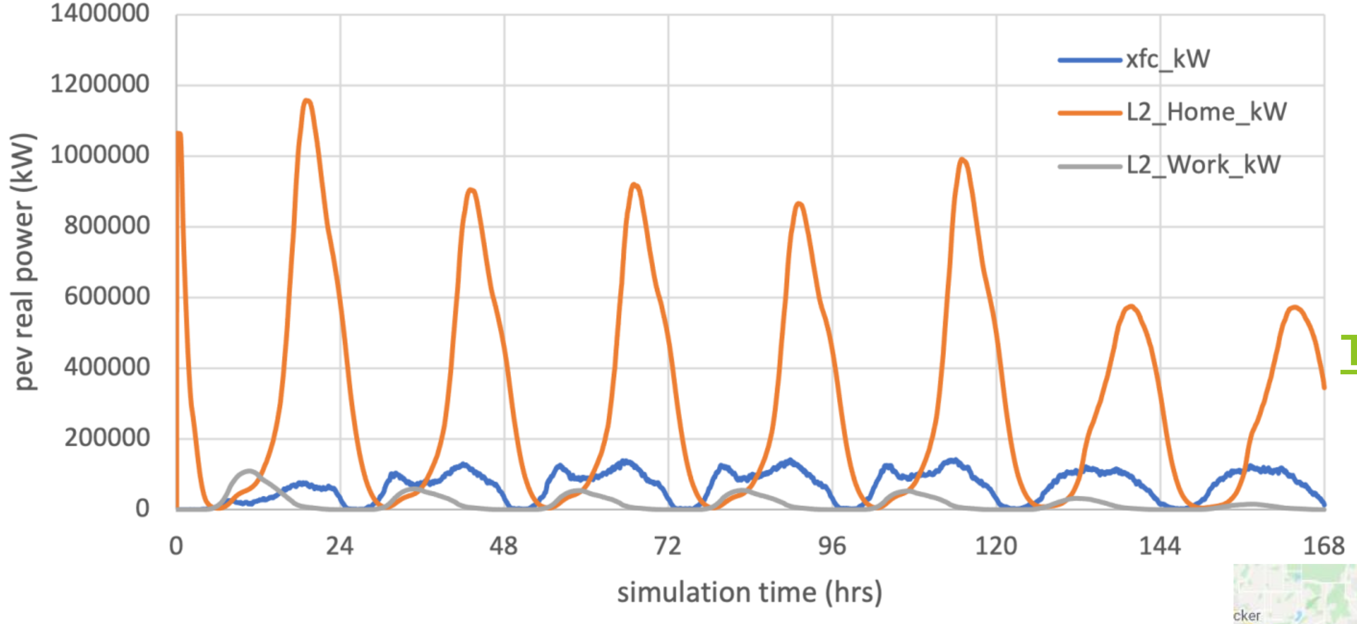
Electric Grid
Distribution Network
Simulation

Real-World Travel Data,
Realistic XFC Stations

OpenDSS Model of Xcel Energy
Minneapolis Feeders

Technical Accomplishments and Progress: Uncontrolled Simulation 2040 High (1.1M PEVs)

Aggregate Power Load Profile (All Charging)



On Tues – Fri can identify

- Morning rush hour XFC peak
- Early day L2 Work peak
- Afternoon rush hour XFC peak
- Evening L2 Home peak
- Weekend Behavior

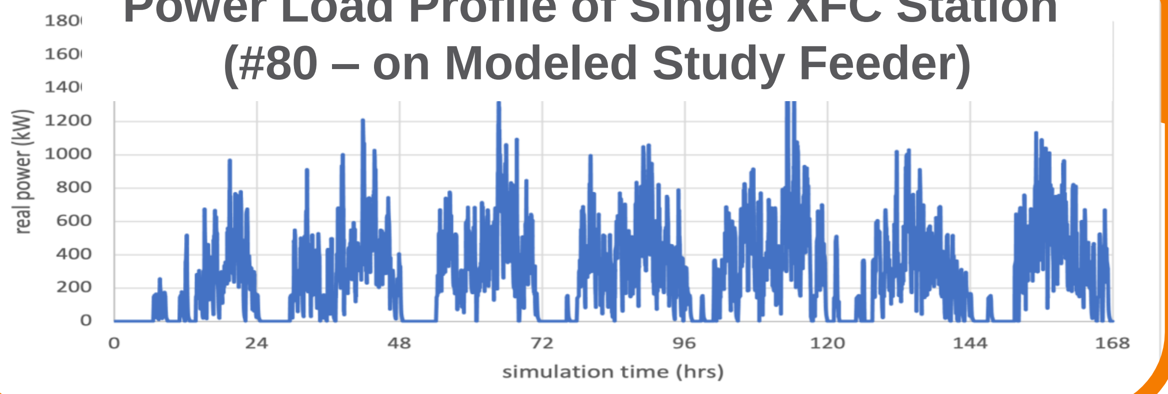
Total Power breakdown:

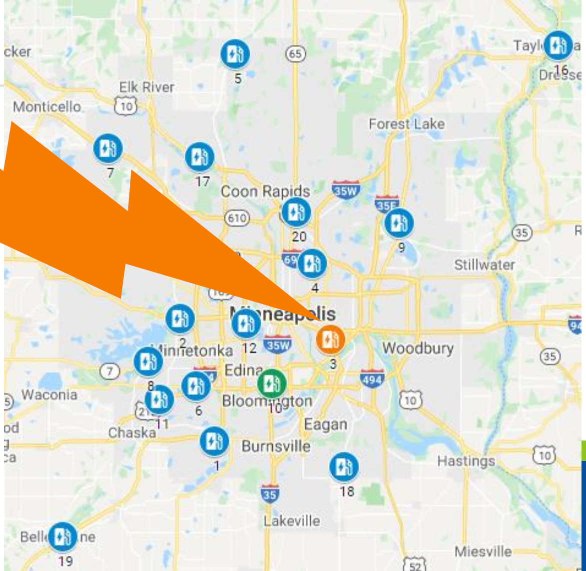
- 78% L2 Home
- 17% XFC Public
- 5% L2 Work

Charging Access

- 70% have Home Charging
- 25% have Work Charging
- 22% have only XFC Public

Power Load Profile of Single XFC Station (#80 – on Modeled Study Feeder)



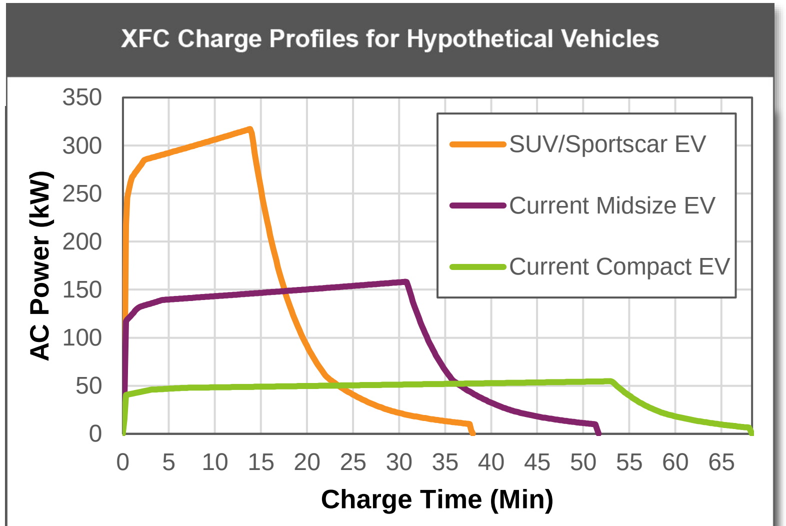


- **Caldera Agent Based Modeling**
  - Allows for individual station and even individual EVSE studies
- **Simulation Efficiency**
  - Reduced supercomputer runtime from 45hrs to >3hrs through code parallelization

Technical Accomplishments and Progress: Load Shapes of XFC Site (Task 2.3)

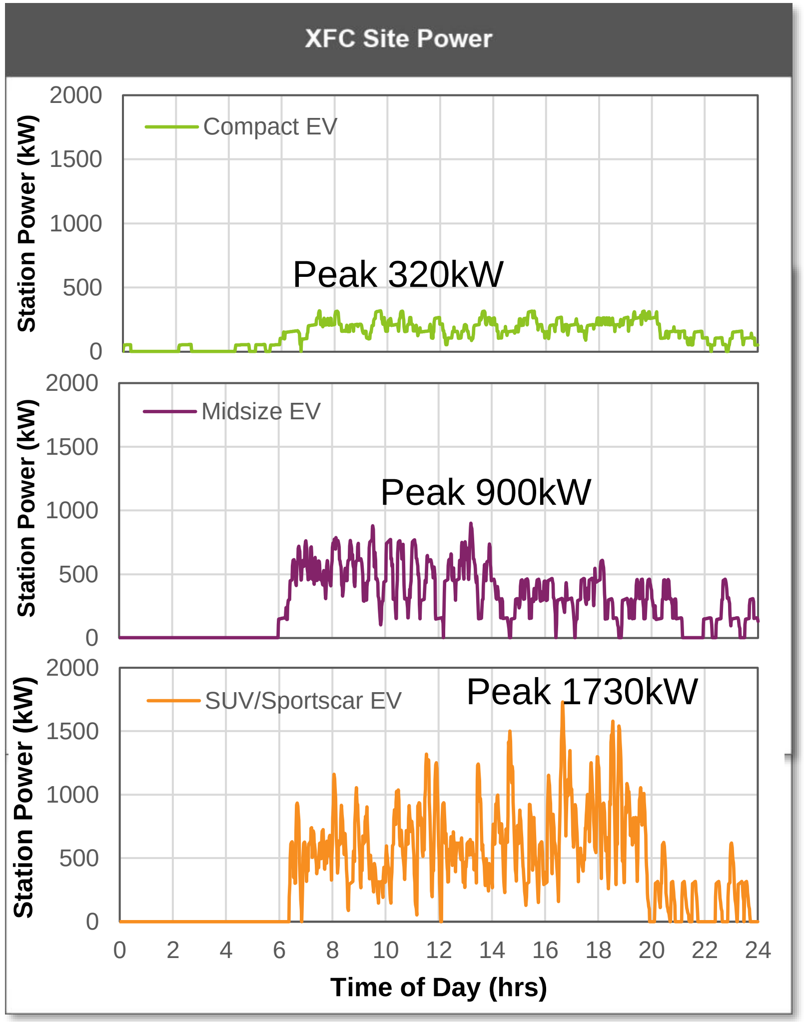
Caldera Simulation of XFC Station:

- 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 electricity bill can be demand charges.”



	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

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



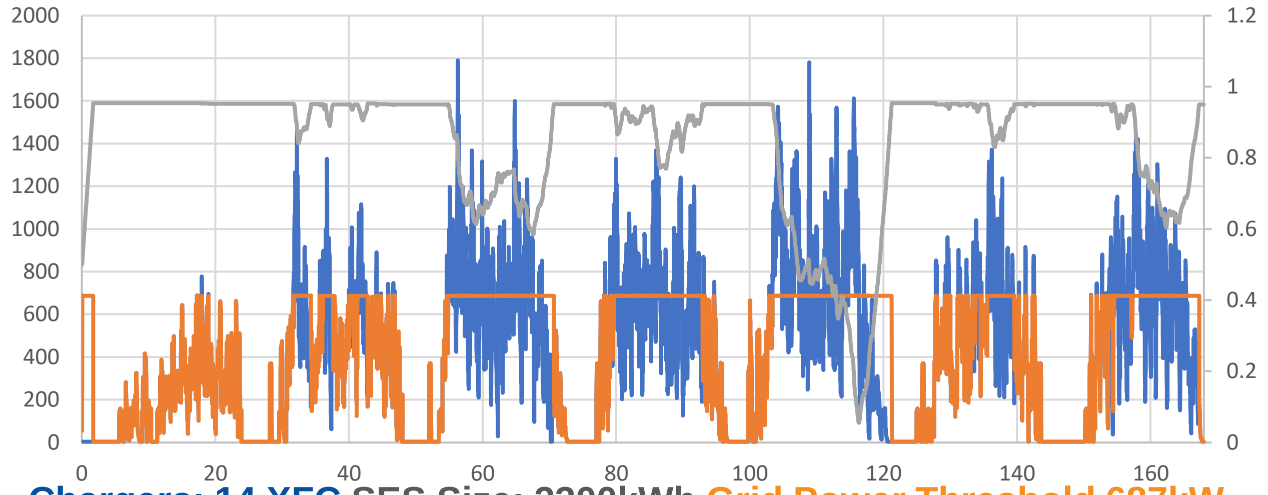
Stationary Energy Storage – Charging Station Site Management

- Local station controls and the presence of stationary energy storage (SES) can smooth and reduce peaks
- With lower peak loads more XFC stations can be placed on weak grid, increasing convenience for EV owners
- Stationary energy storage can mitigate demand charges, increase profits for charge station operators
- Caldera incorporates an accurate Stationary Energy Storage Electro-Chemical Model and site management system in the Infrastructure AI
- This is a tool for utilities and CNPs to study the benefits and aging effects of specific battery energy storage systems on their network

Technical Accomplishments and Progress: Simulated Station Management with SES

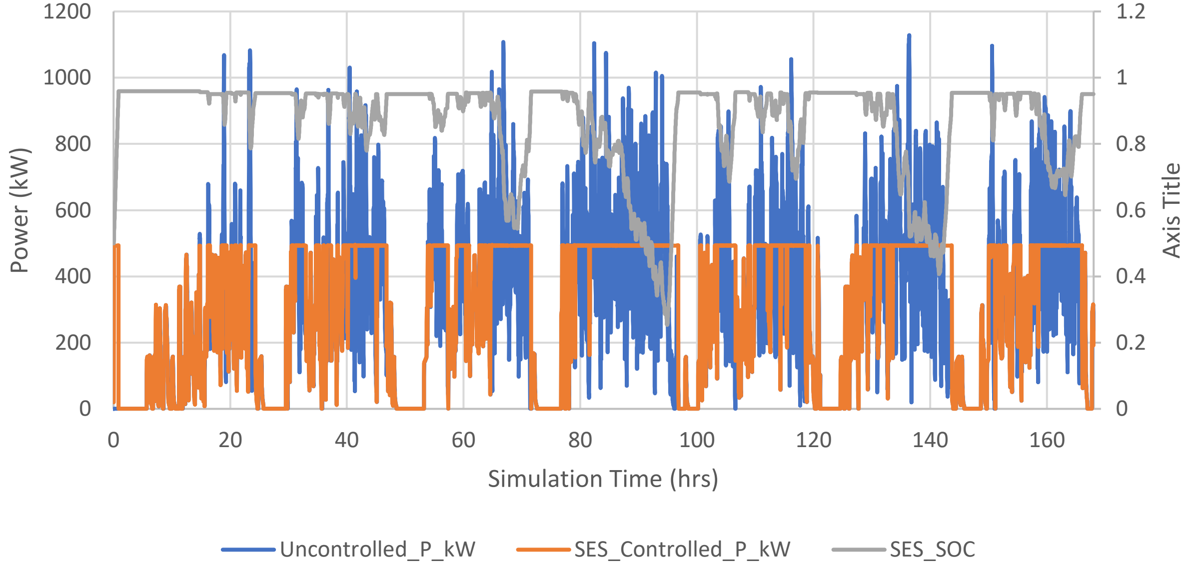
- System wide impacts of Station Management with SES
  - Evaluated each station’s mean power and 15min peak power (demand charge)
  - Targeted a 75% reduction of the peak above mean to identify Grid Power Threshold (kW) and then found minimum SES size (kWH) capable of that.
  - Applied to all 350 XFC stations across the 2040 Simulation

Large XFC Station with High Usage



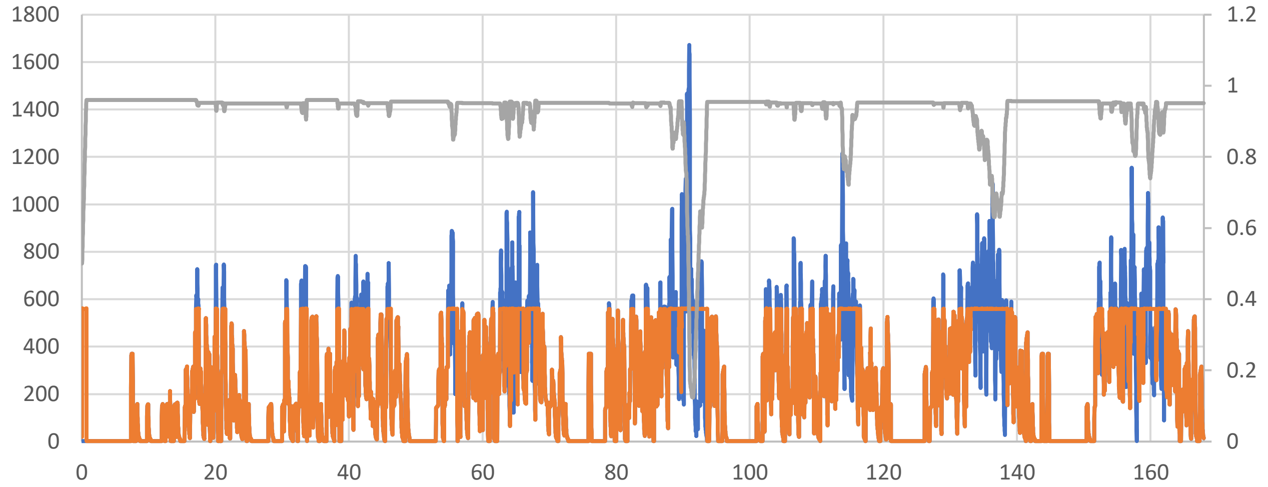
Chargers: 14 XFC SES Size: 2300kWh Grid Power Threshold 687kW

Small XFC Station with High Usage – Consistent Peaks



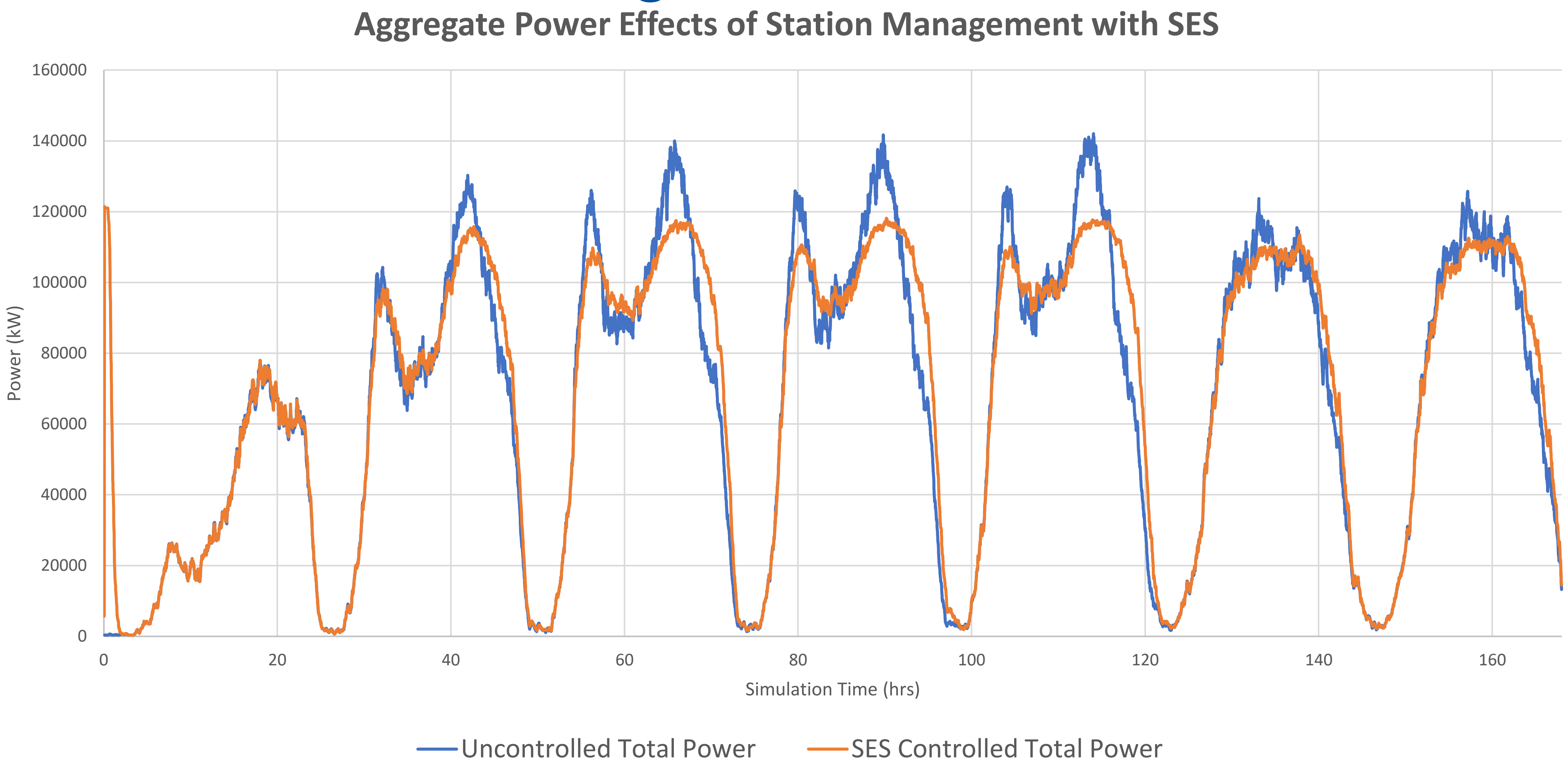
Chargers: 4 XFC SES Size: 800kWh Grid Power Threshold 493kW

Large XFC Station with Lower Usage Inconsistent Peaks



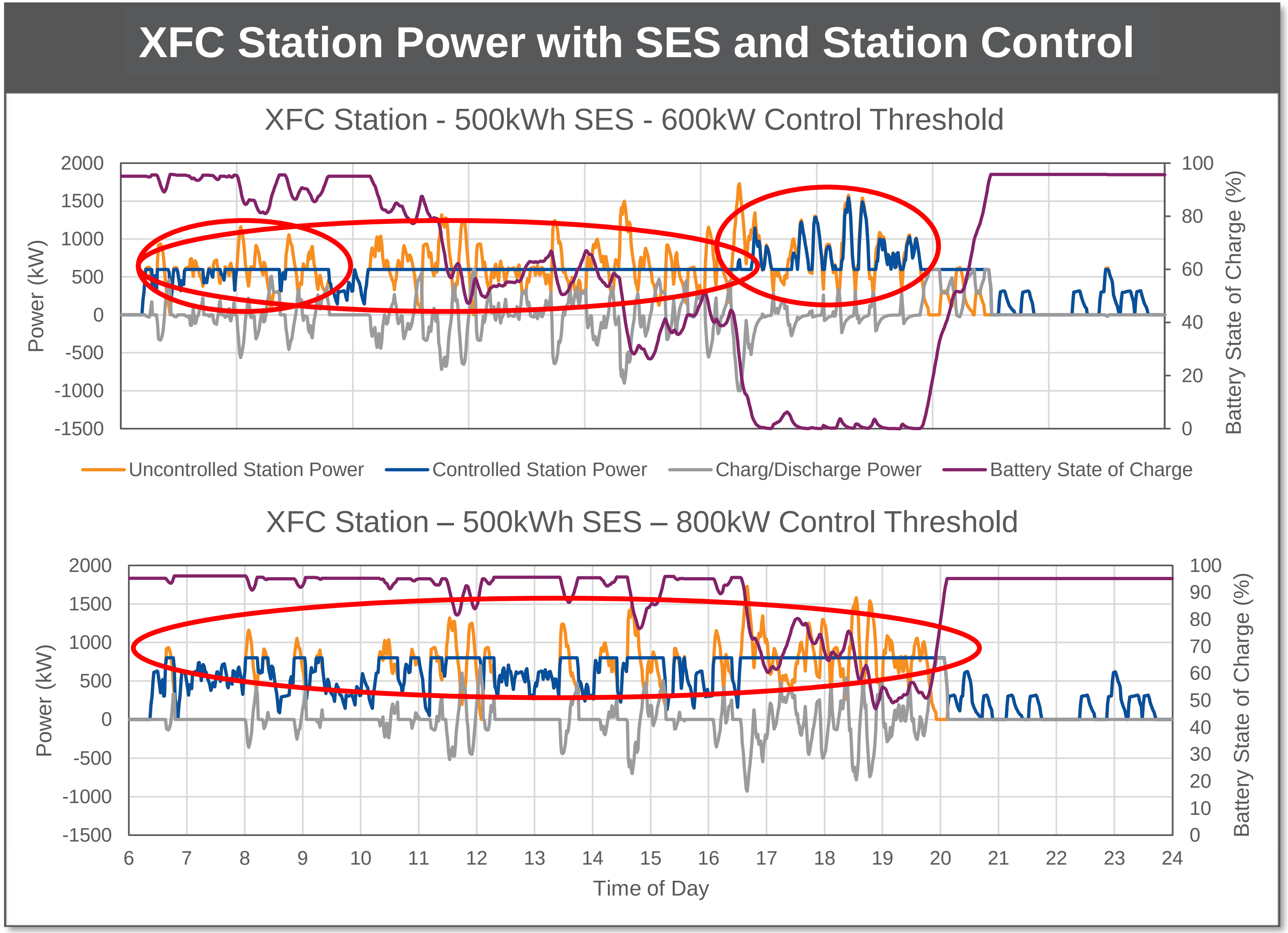
Chargers: 8 XFC SES Size: 700kWh Grid Power Threshold 559kW

Technical Accomplishments and Progress: Simulated Station Management with SES



- Total Energy in each case: Uncontrolled 676,292 MWh Controlled 693,560 MWh
  - 2% difference related to Energy used to charge SES given initial SOS
- Peak Reduction 18% (142MW to 117MW) during Friday afternoon rush hour

Simulating XFC with SES and station control



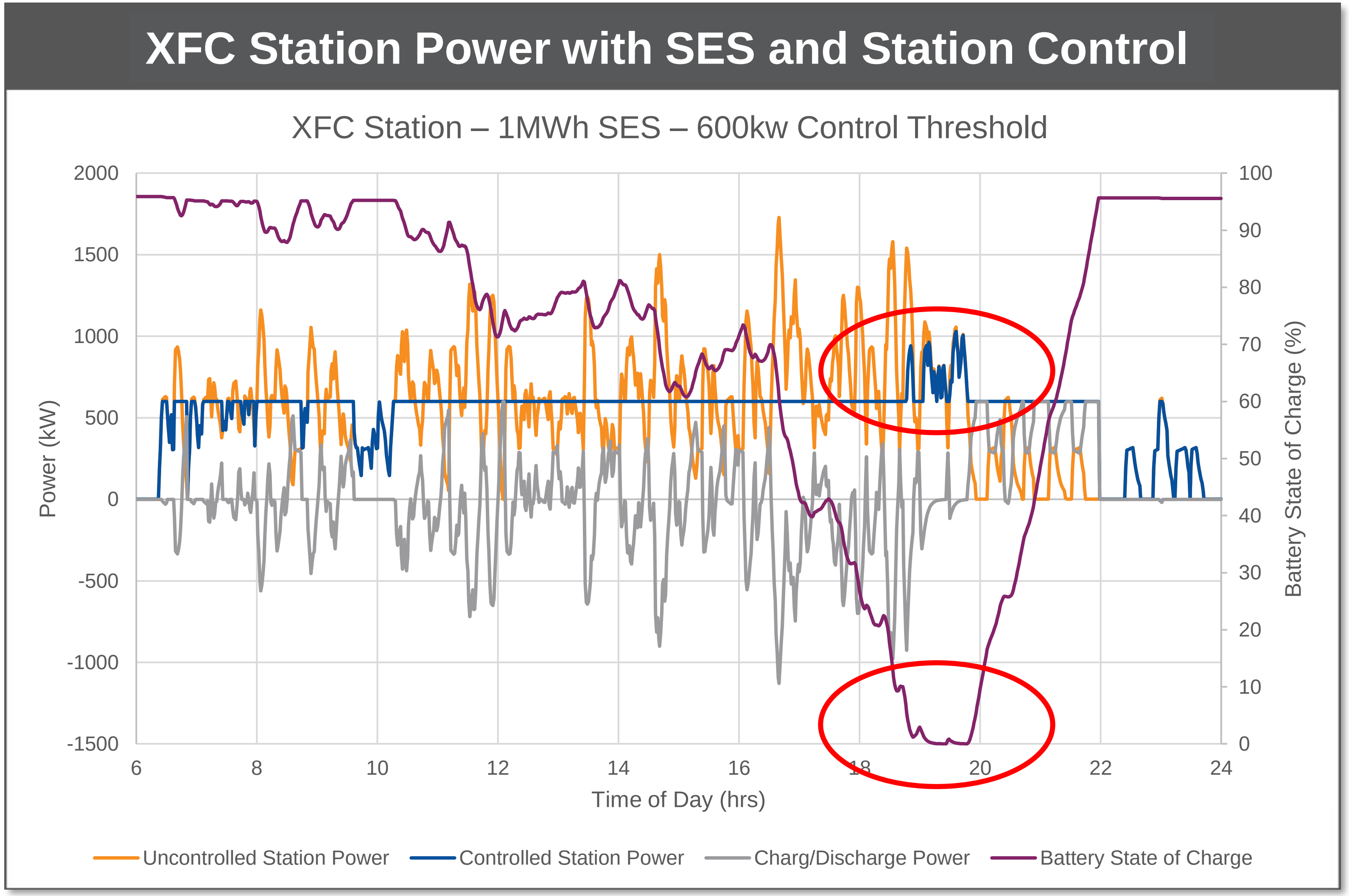
Caldera Simulation of XFC Station:

- 500kWh battery costs ~$500k
- Reduces 1730kW peak to 725kW on this day
- If demand charge were $15/kW SES saves $15,000/month
- SES payback period=33months
- 50kW vehicle population with 50kWh SES reduced 320kW peak to 230kW
- 150kW vehicle population with 250kWh SES reduced 900kW peak to 500kW

- All seem to be financially viable with ~3year pay back
- **BUT THAT IS NOT ENOUGH**

Results from Caldera in DirectXFC DOE Project

How do you predict and set the threshold? What happens when it is broken?



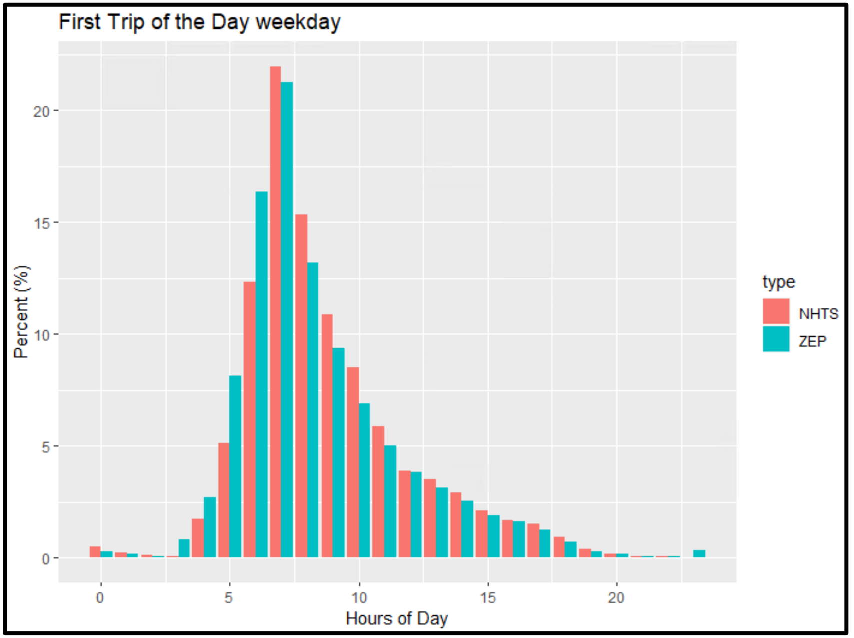
A few extra charges costs a lot:

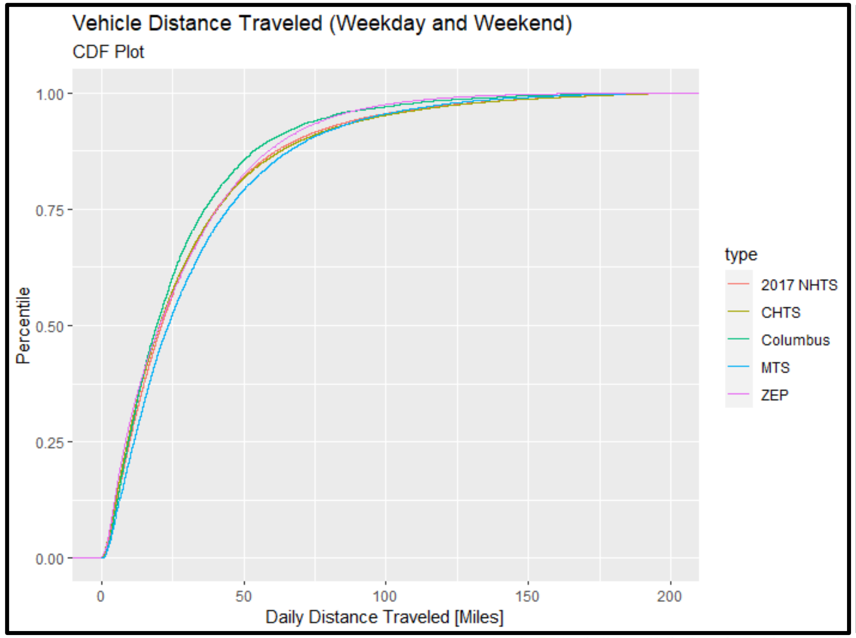
- Machine Learning prediction = very accurate
- But just a few unexpected customers or increases in frequency - deplete the SES and incur substantial costs.
- Example:
- 1MWh SES ($1M)
- Threshold set to 600kW
- 4 or 5 EVs bring peak >1000kW
- Costs > $6000

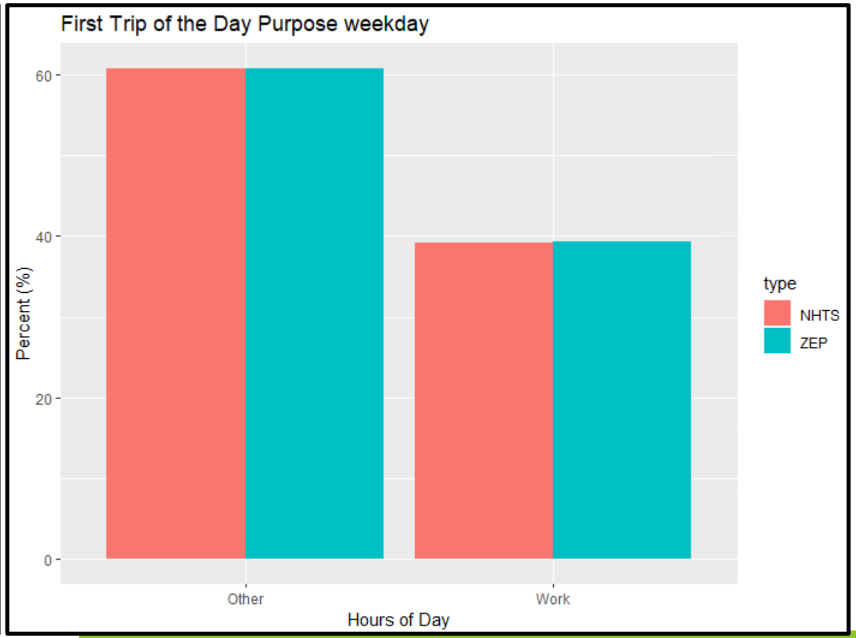
- **SCM MUST DO MORE**
- **Communications & Reservations – DIRECT XFC**

Technical Accomplishments: Vehicle Travel Profiles

- A large vehicle travel dataset was developed to evaluate the charging control strategy's ability to guide user behavior when utilizing high performance XFC vehicle charging.
- NREL developed travel itineraries for Minneapolis vehicle trips
  - ~28 million vehicle trips through the ZEP simulator (38.9% PEV penetration)
  - 84 million miles of simulated vehicle travel reflecting real world origins and destinations
  - Large scale validation of simulation was executed comparing to the NHTS



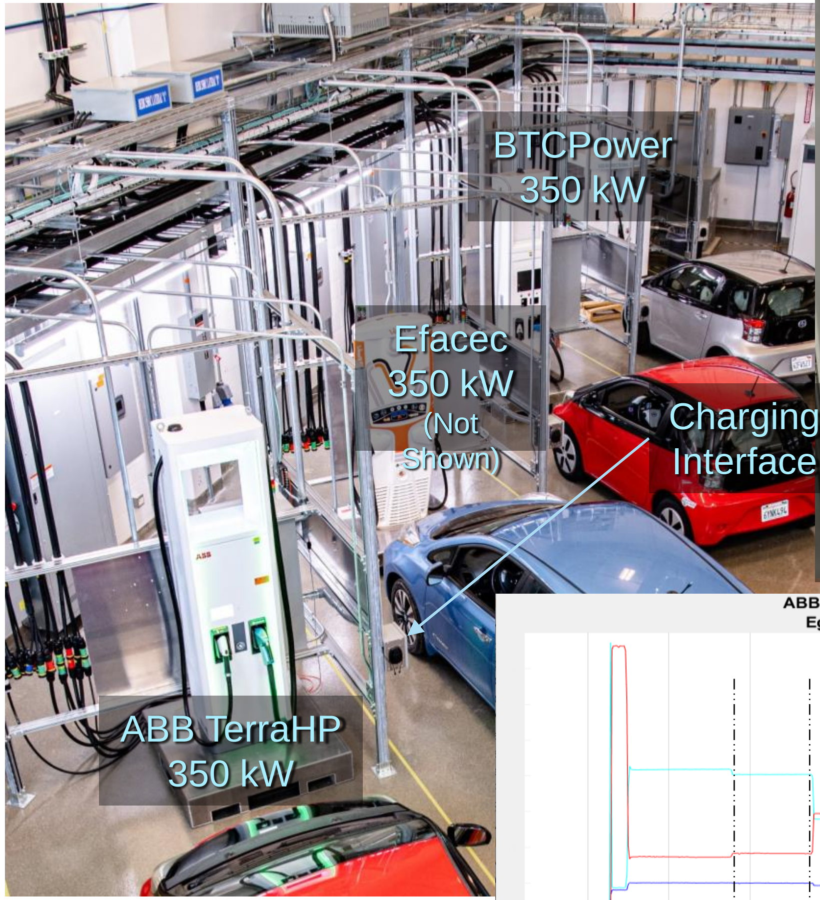


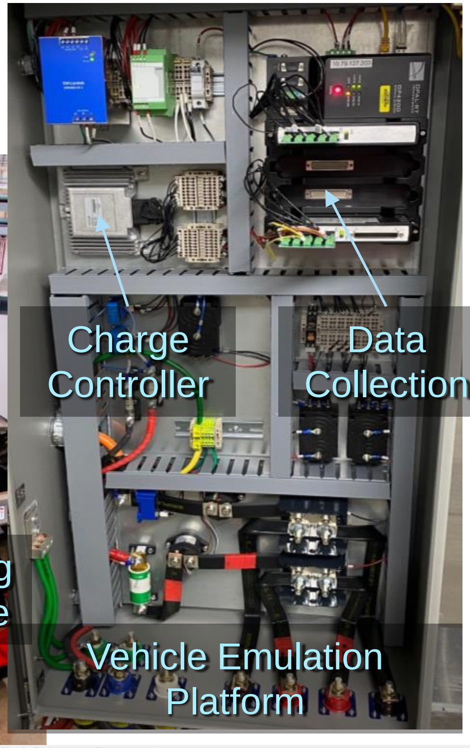


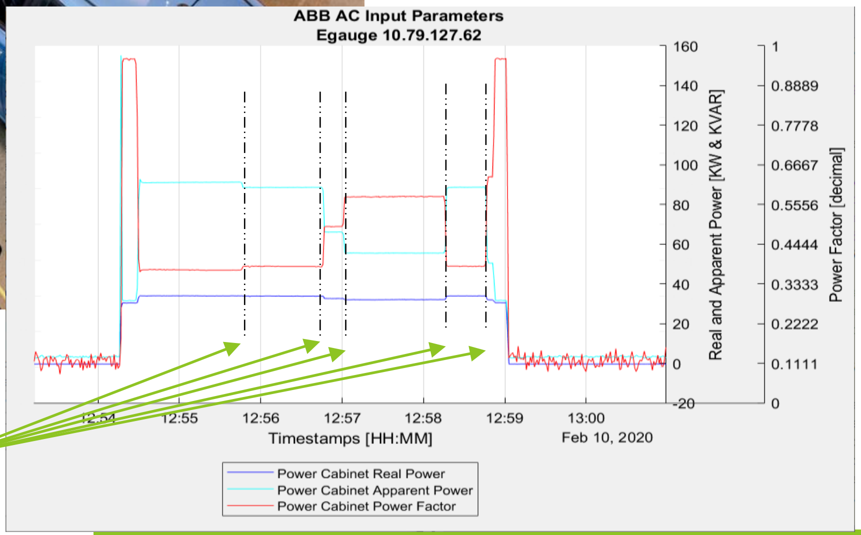
NHTS – National Household Travel Survey
ZEP- Zone Entity Probability

Technical Accomplishments:
Site-level XFC charge Scheduling demonstration

- Three 350 kW chargers installed in the lab
  - ABB, Efacec, and BTCPower
  - Functionality demonstrated by charging an EV
- OCPP capability is currently being integrated
  - OCPP control of ABB and BTCPower chargers are functional and ready for research
    - Demonstrated charge curtailment via OCPP command
  - The Efacec is undergoing initial OCPP setup
- Vehicle emulation is being developed in-house using off-the-shelf components
  - Responsible for communicating with EVSE via PLC and ISO 15118 / DIN 70121 protocols
  - Currently working through DC charging sequence
    - Successfully demonstrated charging sequence up to when EVSE requests charging to commence







Set in-session output power limits

NREL NATIONAL RENEWABLE ENERGY LABORATORY

IDAHO NATIONAL LABORATORY

Technical Accomplishments on Hardware at ANL

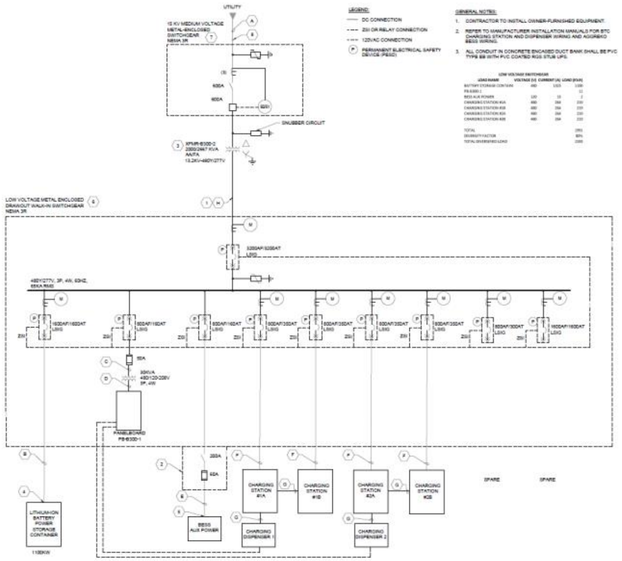
Completed design and implementation of XFC site with co-located battery storage system

Major Components
- (2) BTCPower 350kW XFC EVSE
- Aggreko Y.Cube
  - 660kWh capacity
  - 1MW peak output – 30 minutes sustained

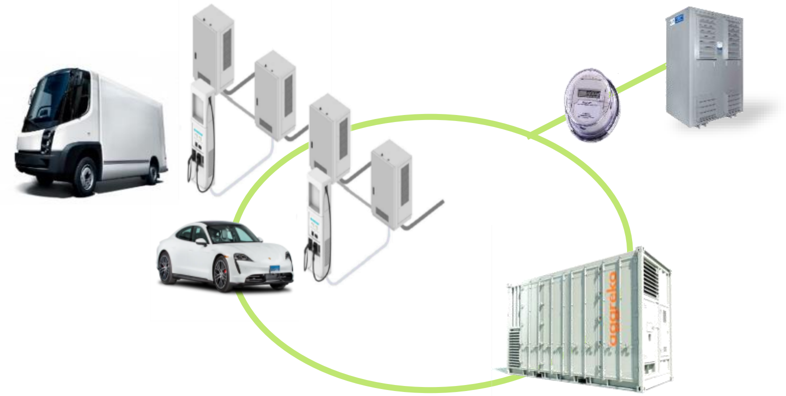
Capability
- 700kW charging available
- Multiple storage dispatching modes
- Integrated sub-metering – major components and aux. loads.

Integration
- CIP.io integration to be completed
- DNM integration to be completed

Design



Concept



Completion

Response to Previous Year Reviewers' Comments

- **Several reviewer comments touched on Human Behaviors:**
  - While DirectXFC was intended simply to show the potential value that XFC management could create through: Avoided Capacity Upgrades, Increased Utilization (reduced capital), and better access (enabling MUD adoption) – We found it necessary to include driver selection of L2 vs XFC, trip changing, driving distances, and price sensitivities. Yes, they were included.
- **Some reviewers asked about Economic Considerations:**
  - Predicting the future cost of charging fees, vehicle costs, infrastructure installation and upgrade are very difficult and inaccurate. Instead DirectXFC will address reduced demand charges to XFC stations in today's dollars, and assess the utility capacity upgrades required and avoided by various systems. Notional charging fees incurred by drivers under dynamic pricing will be shown as % increase.
- **Some reviewers had questions about basis in current transportation realities:**
  - Travel of PEVs was derived from real world Origin-Destination pairs and National Travel Survey data.
  - XFC Station locations use existing Gas Station locations in Minneapolis to ensure compatibility with travel patterns.
  - Validating this kind of future looking simulation result is difficult, but inputs are derived from as much current real world ICE data as possible. Vehicle Miles Traveled and total energy consumed are validated.

Collaboration and Coordination

INL is leading this project and developing the simulation platform – Caldera™, charging load profiles, and charge management control strategies

NREL is creating the simulation scenario inputs, operating their MN OpenDSS model from RECHARGE as well as developing a HIL demonstration of XFC site implementation

ANL is assessing the network-level requirements and impacts of XFC control as well as developing a HIL XFC station for real-time grid impact analysis with their Distributed Network Model used in SmartVGI

DirectXFC has active collaborations and data sharing with several other DOE funded projects: RECHARGE(ELT202), Behind The Meter Storage (BTMS-BAT422), XCEL(BAT462), and VTO Analysis E-drive sales tracking

Xcel Energy has graciously provided their knowledge and their distribution feeder data for grid impact assessment

INL – Idaho National Laboratory
- Tim Pennington
- Don Scoffield
- Zonggen Yi
- Manoj Kumar

NREL – National Renewable Energy Laboratory
- Andrew Meintz
- Chris Neuman
- Kalpesh Chaudhari
- Jesse Bennet
- Shibani Ghosh
- Keith Davidson
- Darren Paschedag

Argonne National Laboratory
- Keith Hardy
- Dan Dobrzynski
- Zhouquan (Owen) Wu

The DirectXFC team also coordinates with other Automotive and Utility partners on the USDRIVE Grid Interaction Tech Team (GITT)

USDRIVE – DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Remaining Challenges and Barriers

- Grid impact and control strategy implementation need to be completed
- Quantifying the benefits of the proposed technology and reservation system is a difficult task involving future cost forecasting and proprietary infrastructure upgrades
- Hardware-in-the-loop (HIL) demonstrations have construction and communication risks, but much reduced from last year
- COVID-19 and the Labs' safety posture have greatly impacted the in-person installation, setup and testing of HIL; but that appears to be easing and much installation work has occurred
- Using HIL for validation is critical but synchronizing details between the model and the available hardware is a challenge

Proposed Future Research

ID	Task	Description
1	**Determine the value of managed XFC for customers and the grid**	
1.1	Uncontrolled XFC charging at scale	Caldera™ simulation of Minneapolis EVs in uncontrolled 2025-2040 scenarios
1.2	Controlled and directed XFC charging at scale	Development and implementation of Site Control Strategies and EV Directed Strategies in Simulation
1.3	XFC grid impact and grid services	Co-Simulation of Caldera™ with OpenDSS model for Minneapolis Feeders to assess impact and services
1.4	Value analysis	Analytical assessment of value offered by each management method and scenario
2	**XFC station/site implementation(s) for optimal energy management**	
2.1	Development of integrated control of XFC site	Planning and development of hardware control for XFC sites
2.2	Requirements for site-level energy services interface	Interface and communication for XFC site and energy services
2.3	Implementation of XFC station management	Demonstrate independent site management strategies through laboratory testing
3	**Network-level requirements and impact of XFC integration**	
3.1	Requirements for network-level interfaces	Development of communication interfaces for networked control of XFC site
3.2	Network-level control hardware-in-the-loop demonstration	Demonstrate network-level control of XFC site through HIL testing between Caldera™ and lab XFCs

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

Summary

- eXtreme Fast Charing (XFC) enables long distance trips and convenient charging when needed, especially for those without access to home charging
- DirectXFC and Caldera™ are assessing the impact of these high-power loads
- A new paradigm for managing fast charging
  - Communication between EV and EVSE to assist in making optimal market-based charge decisions, best for the driver and the grid
  - Communicated decisions (reservations) provide reliable forecasts for optimal management of the stations' energy

- Technical Highlights
  - Coordinated data across projects creates harmonized research for comparable results
  - Caldera™ development offers future benefits to other charging infrastructure research projects
  - Impacts of large adoption on detailed local energy supply can be simulated and then addressed

- Impacts of VTO efforts
  - Value to Grid, XFC Operators, EV owners and Infrastructure System
  - Simulation useful for future planning
  - Site control useful innovation to industry
  - Integrated control useful to utilities

Question?

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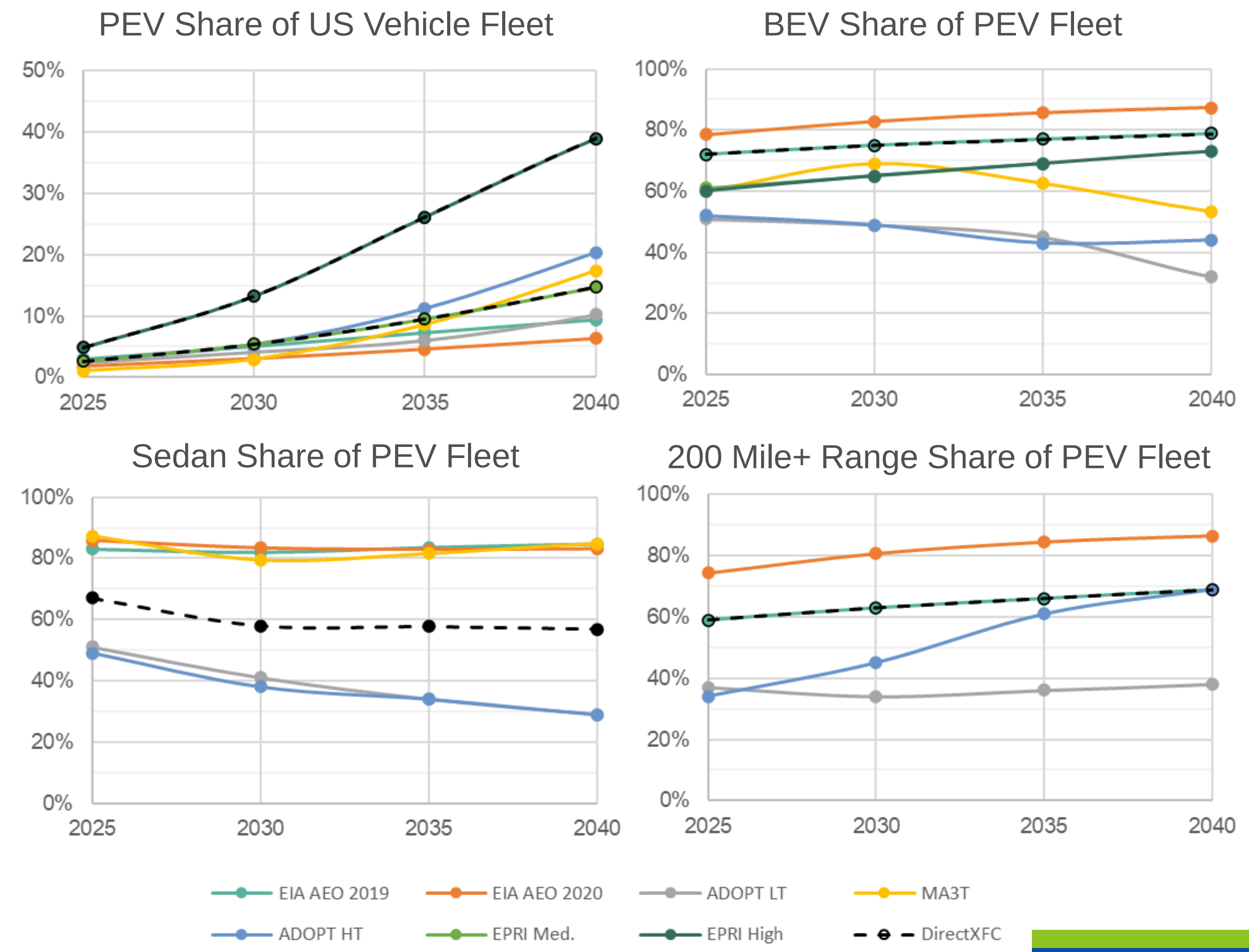
Technical Backup Slides

Idaho National Laboratory

Technical Accomplishments and Progress: Fleet Projections (Task 1.1)

- DirectXFC is utilizing a similar method to RECHARGE (ELT202) in selecting the total EV fleet size and composition based on the following projections:
  - US Energy Information Administration's (EIA) Annual Energy Outlook (AEO)
  - NREL's Automotive Deployment Options Projection Tool (ADOPT)
  - ORNL's Market Acceptance of Advanced Automotive Technologies (MA3T)
  - Electric Power Research Institute (EPRI) Study [1]
- DirectXFC will run 8 simulation scenarios representing the Minneapolis fleet in 2025, '30, '35, and '40 with PEV fleet sizes matching EPRI High and EPRI Medium
- The fleet characteristic selected for each applicable study year are shown in black
- Composition within the PEV fleet is guided by the 3 other graphs here and is detailed on the following slide



[1] Electric Power Research Institute, "Plug-in Electric Vehicle Market Projections: Scenarios and Impacts," EPRI Report #3002011613, https://www.epri.com/#/pages/product/3002011613/, 2017

Technical Accomplishments and Progress: Vehicle Selection (Task 1.1)

- Archetype Vehicles were defined by vehicle type, powertrain, battery capacity/EV range, charge power level, and driving efficiency
- Fleet composition percentages for 2020 are based on cumulative E-drive sales mapped as closely as possible to each vehicle type for relative reference
- Fleet composition percentages for the out years are derived to satisfy Fleet Metrics as shown on previous slide from EPRI, EIA, ADOPT, and MA3T market and consumer preference forecasts (XFC/PEV Share is a derived value)
- Gen 3 XFC charge rates allow 200 miles replenish in 10 minutes, aligning with XCEL(BAT462) goal

	Vehicle Type	EV Range (mi)	Charge Power (kW)	Driving Efficiency (Wh/mi)	Adoption Med High	2.6% 4.8%	5.4% 13.2%	9.5% 26.1%	14.7% 38.9%
	BEV				**2020[2]**	**2025**	**2030**	**2035**	**2040**
XFC Gen3	Sports Car	250	400	350				1%	1%
XFC Gen3	SUV/Truck	300	575	475				6%	8%
XFC Gen3	Midsize Car	300	400	325				4%	15%
XFC Gen2	SUV/Truck	250	350	475			7%	11%	10%
XFC Gen2	Midsize Car	300	300	325			4%	12%	16%
XFC Gen2	Compact Car	150	150	300			5%	6%	10%
XFC Gen1	Sports Car	250	300	350		1%	1%	1%	0%
XFC Gen1	SUV/Truck	200	150	475	7%	25%	24%	13%	9%
XFC Gen1	Midsize Car	275	150	300	32%	27%	23%	19%	10%
DCFC	Compact Car	250	75	300	4%	6%	4%	2%	
DCFC	Compact Car	150	50	300	18%	13%	7%	3%	
	PHEV				**2020**	**2025**	**2030**	**2035**	**2040**
AC Only	SUV/Truck	50	Do not fast charge	475	5%	8%	11%	13%	16%
AC Only	Midsize Car	50	Do not fast charge	310	14%	13%	9%	8%	5%
AC Only	Midsize Car	20	Do not fast charge	250	20%	7%	5%	2%	

[2] E-drive: https://www.anl.gov/es/light-duty-electric-drive-vehicles-monthly-sales-updates

Fleet Metrics	2025	2030	2035	2040
BEV/PEV Ratio	72%	75%	77%	79%
BEV200+/PEV Ratio	59%	63%	68%	69%
Sedan PEV Share	67%	58%	57%	57%
XFC/PEV Share	53%	64%	72%	79%

Individual Charger Granularity (preliminary results)