Behind-the-Meter-Storage (BTMS) Analysis

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DOE Vehicle Technologies Program
2021 Annual Merit Review and Peer Evaluation Meeting

Project ID #bat473

Overview

Timeline

- Project start date: 10/1/2019
- Project end date: 9/30/2022
- Percent complete: 50%

Budget

- VTO Funding for FY 2020: $250k
- VTO Funding for FY 2021: $350k
- Additional funds from BTO and SETO

Barriers addressed

- Development of stationary storage systems to enable extreme fast charging of EVs and energy efficient grid interactive buildings
- Cost and performance

Partners

- A joint project between VTO, BTO, OE, and SETO.
- BTMS Research Project (#bat442)
- Five Laboratory Team lead by NREL:
  - Sandia National Laboratory
  - Argonne National Laboratory
  - Idaho National Laboratory
  - Pacific Northwest National Laboratory

Relevance

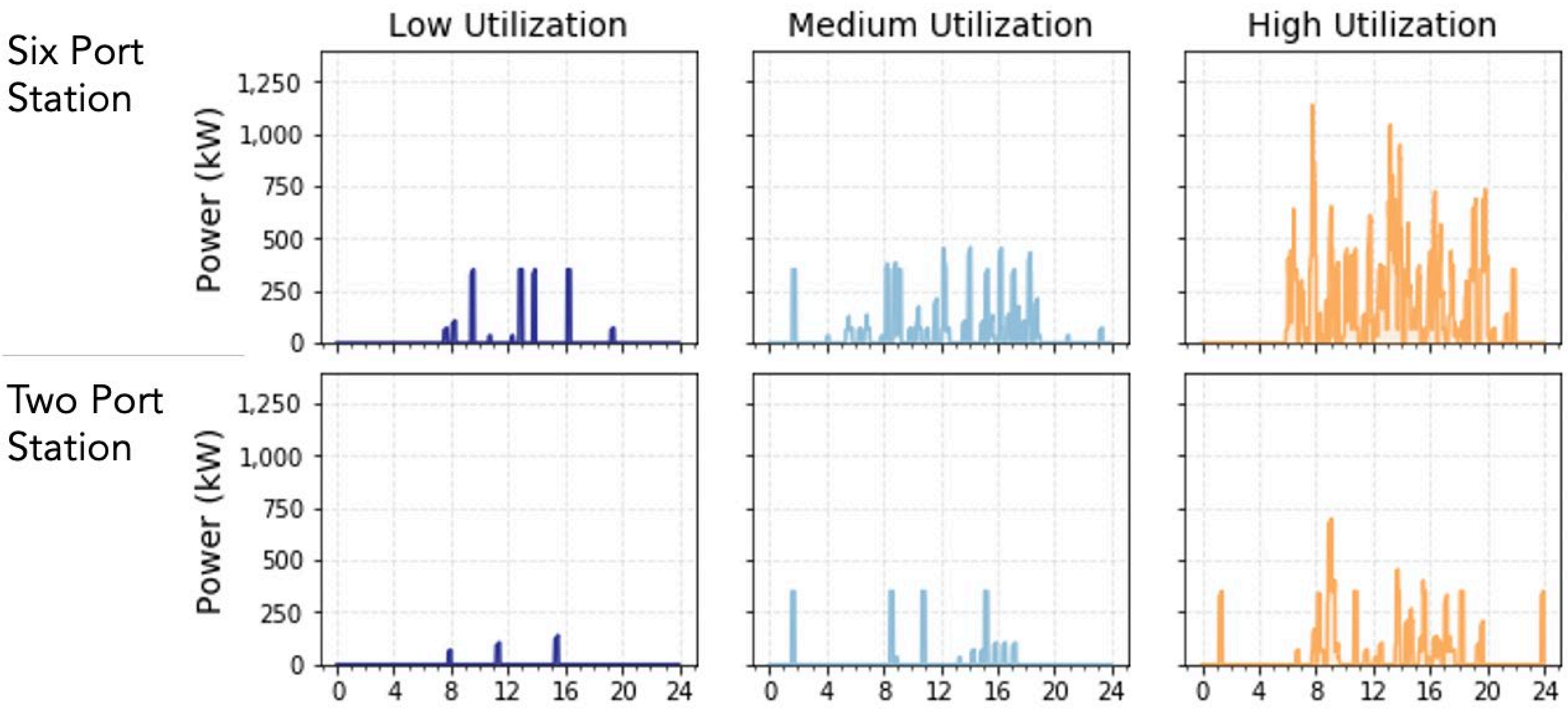
- Rapid electrical vehicle (EV) adoption could have a significant, and potentially negative effect, on grid infrastructure and buildings operations.
- Large penetration of solar photovoltaic (PV) generation installed on buildings is leading to new challenges for building interactions with the electric grid.
- EV charging demand could be very large and irregularly-spaced, particularly for fast EV-charging, resulting in expensive spikes in energy use (demand charges), resulting in delayed adoption of EVs.
- Behind-the-meter energy storage (e.g., batteries and thermal energy), coupled with on-site generation, could be used to:
  - manage dynamic loads and high energy costs
  - provide resiliency and reliability for system operators (EV charging, buildings, and the electric grid)
  - Increase the efficiency of existing and new building structures.

➢ *A detailed physics-level understanding of the interaction of these various components and systems is needed to economically optimize the design and operation of BTMS.*

➢ *The EnStore Model is being developed to identify the most efficient means of deploying BTMS across the U.S. for fast-EV charging at different buildings, in different climates, with PV generation*

Relevance: EV Fast Charging Can Impact the Entire System

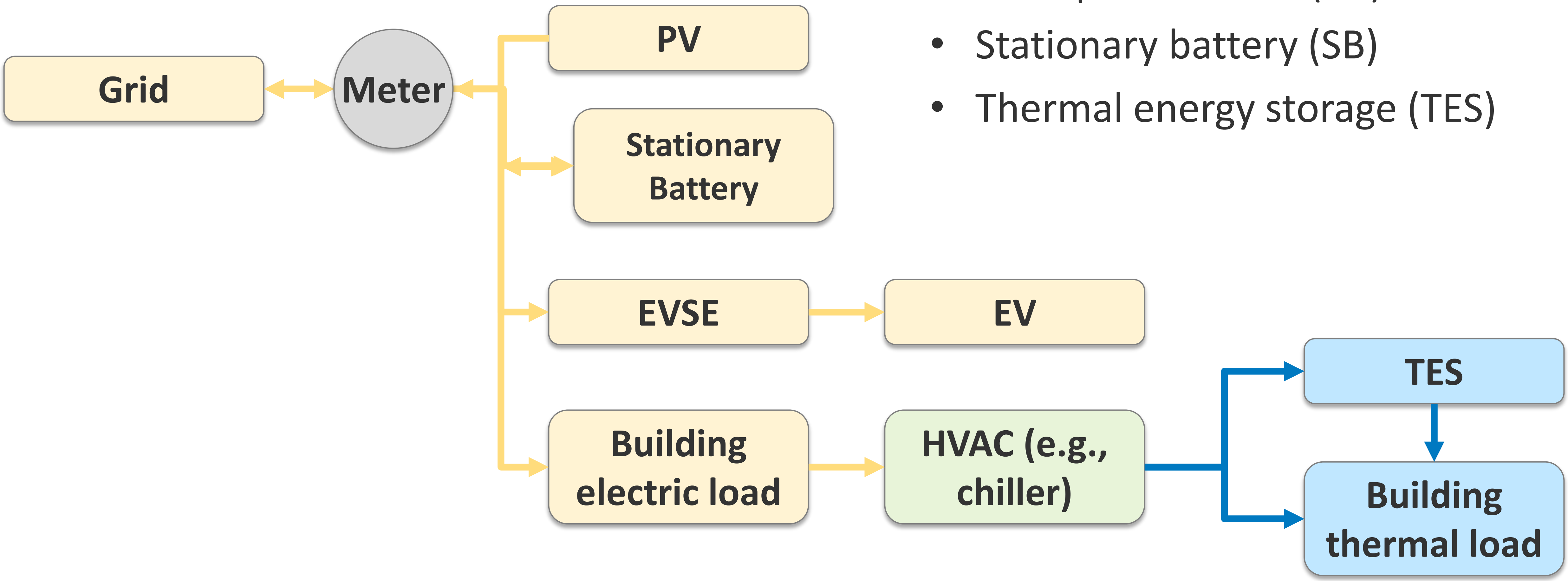
EV fast charging loads, especially when ports deliver 350+ kW, can greatly affect the power demand at a site, as well as grid stability, equipment choices, costs, and infrastructure upgrade requirements



Can behind-the-meter storage (BTMS) mitigate these costs and enable fast EV charging?

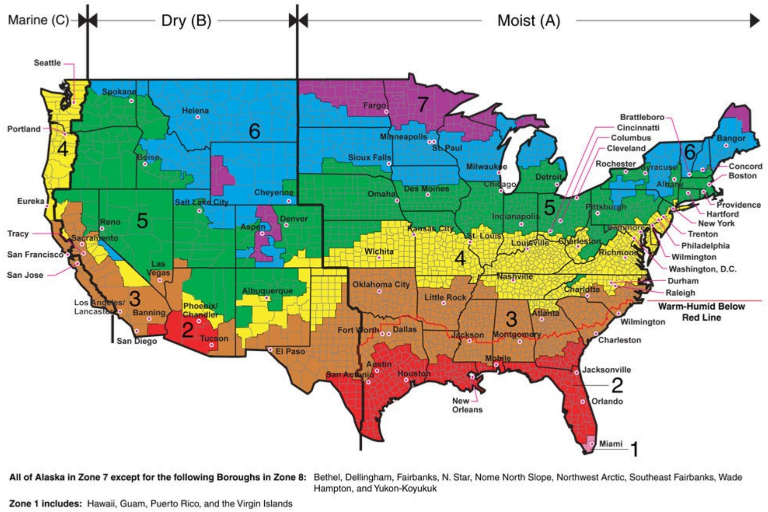
Approach: Optimize BTMS System Design to Minimize Cost and Enable Fast EV Charging

- Solar photovoltaic (PV)
- Stationary battery (SB)
- Thermal energy storage (TES)



Approach: Use Detailed Physics-based Modeling and Predictive Controls to Evaluate the Potential for Behind the Meter Energy Storage (BTMS) to Mitigate Costs and Grid Impacts of Fast EV Charging

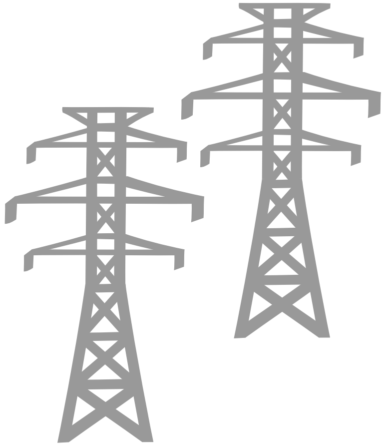
<u>*Key Question:*</u> What are the ***optimal*** **system designs** and **energy flows** for **thermal** and **electrochemical** behind-the-meter-storage with on-site **PV** generation enabling **fast EV charging** for various climates, building types, and utility rate structures?



6 ASHRAE Climate Zones

5 Building Types with Varying EV Charging Demand

Corner charging station, Retail big-box grocery store, Fleet vehicle depot, Commercial office building, Multi-family residential



Thousands of Utility Rate Structures Across U.S. (and changes very likely)

Approach: Other Important Questions

1. What is the sensitivity of analysis results to the variability of location, building loads, EV charging demands, and component costs, and combinations of each case within those categories?

2. What research achievements (e.g., material characteristics for thermal energy storage, battery material costs and lifetime, PV deployment) would increase the economic viability of the various configurations of BTMS at multiple locations?

3. What level of improved iterative feedback modeling (controls), informed by BTO research on TES and VTO research on battery degradation, would be necessary to optimize sizing and designs for subsystem components (PV, battery size and operation, thermal storage)?

4. What is the potential energy savings, GHG emissions reduction, PV energy generation, and EV demand coverage in different locations across the U.S., as a function of technical and cost improvements?

Approach – Sensitivity Analysis is Critical for Understanding Important Cost Levers and Optimal Configurations

The design and configuration of a BTMS system depends on many factors:

- Climate: building energy use, battery conditioning, battery lifetime, efficiency of EVs
- Utility rate structures: demand and time-of-use charges, cost of energy
- Connection to the grid: infrastructure improvement costs (and can BTMS help reduce or defer these costs)
- Building type energy demand profiles, space limitations, population served
- Capital costs – batteries, thermal energy storage (TES), EVSEs, PV, power electronics
- Controls algorithm – when to dispatch stationary battery and TES; EnStore now uses supervisory model predictive controls (MPC)
- Storage operation - battery and TES state-of-charge, discharge/charge rate, temperature

Parameters are varied separately and in combination, leading to tens-of-thousands of simulations, necessitating high-performance-supercomputing and advanced visualization techniques

Approach: The EnStore Model High-Level Model Architecture

Utilize existing models where appropriate and expand to evaluate the interaction between components at physics-based resolution

Pre-Process

- Generate the baseline building load profile using **EnergyPlus**
- Generate the electric vehicle charging station load profile using **EVI-EnSite**
- Specify component costs, weather data, utility rate tariffs.

EnStore

Seed

- Use **REopt** to limit the initial parameter space with simplified models and idealized controls.
- Suggest initial sizes for stationary battery and solar PV.

Explore

- Model parameter variations with greater fidelity.
- Use **EnergyPlus** for building loads and thermal energy storage.
- Implement supervisory predictive controls to dispatch storage
- Vary selected parameters to explore impact on LCOC.

Model Report

- Store key system characteristics, e.g., stationary battery, solar PV, and thermal storage sizes for each run.
- Provide time-series outputs for post-processing.
- Use **SAM** to calculate financial metrics.

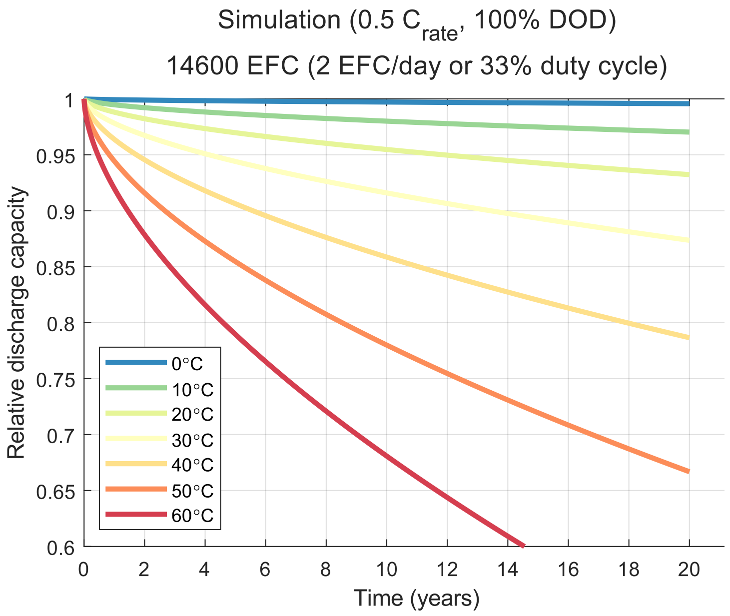
Post-Process

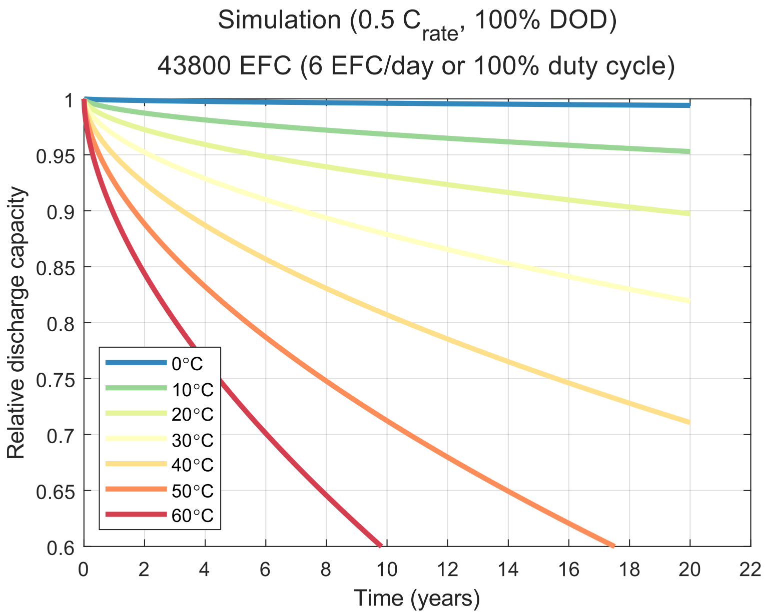
Use data analytics and advanced visualizations

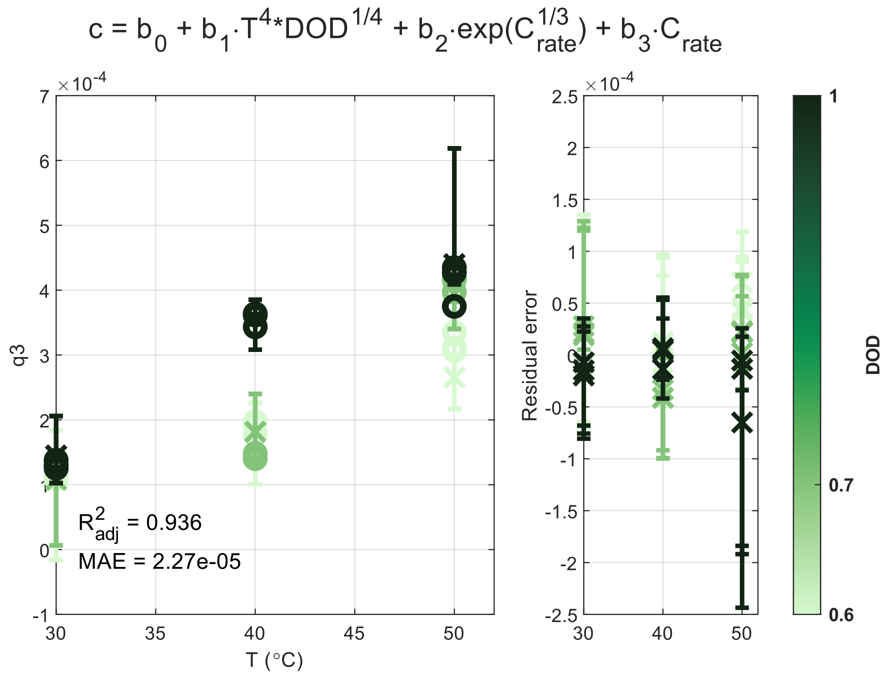
- Analyze which parameter variations yield the lowest LCOC.
- Analyze sensitivity of results to key input parameter values.
- With each set of insights, refine & define new scenarios

Approach: Include Data-Derived Battery Lifetime Data in EnStore (Q3 milestone)

The BTMS R&D Project is developing cobalt-free batteries and evaluating their lifetime characteristics
Curves & equations developed by Matt Shirk (INL), Paul Gasper (NREL), & Kandler Smith (NREL), under project #bat442, for LMO/LTO battery chemistry. EnStore now uses standard lifetime curves for currently commercial batteries.







Model predictions for T ≥ 40 °C are potentially believable, given the convex behavior of the experimentally-observed degradation at those conditions. Above 40 °C, predictions are very optimistic given mismatch with concave degradation observed at 30 °C

Cycling degradation rate is predominantly a function of temperature and depth of discharge (DOD). *More data will help to identify a more complex model, capturing both convex and concave fade behaviors.*

Approach: Assess Optimal Design with Financial Metrics

EnStore uses the standard financial approach known as discounted cash flow (DCF), which takes into account the time value of money throughout the project lifetime

- **Levelized Cost of Charging (LCOC) - ¢/kWh to vehicle owner**
  - The minimum levelized revenue per unit of electricity generated in the **EV charging station** required to recover the costs of the BTMS equipment over its financial life
  - <u>Research Question</u>: *What is the minimum cost of electricity that needs to be charged to EV owners in order to pay back all of the capital and operating costs over the lifetime of the operation. How does this compare with the cost of charging without BTMS or elsewhere?*

- **Levelized Cost of Electricity (LCOE) - ¢/kWh to building owner**
  - The average revenue per unit of electricity generated in the **building** that would be required to recover the costs of the BTMS equipment over its financial life
  - <u>Research Question</u>: *If we installed the BTMS assets, what would the relative (energy-cost) impact to the building owner be?*

- **Net Present Cost (NPC) - $**
  - The present value of all the costs the system incurs over its project lifetime
  - <u>Research Question</u>: *What will it cost (in today's dollars) to install and operate a BTMS system?*

** Future EnStore assessments can include the ability to assess the lowest carbon-emitting configuration*

Approach: Evaluate the Impact of Utility Rate Tariffs

There are over 7,000 utility rate tariffs in the U.S. These rates were chosen as **examples** to represent various types of tariffs and **demonstrate BTMS response** to differing time of use (TOU)/demand charges and electricity prices

CONED

Consolidated Edison: monthly demand charges that range **5.36 - 16.7 $/kW** and TOU demand charges up to **23.89 $/kW**; flat energy rates

Demand Charge Schedule

Weekday Schedule

	12 am	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm
Jan	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
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Oct	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
Nov	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
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PGE

Pacific Gas & Electric: flat demand charges of **15.97 $/kW** and TOU demand charges up to **20.62$/kW;** TOU energy charges

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XCEL

Xcel Energy: constant demand charges at **5.63 $/kW**, but energy charges vary much more than those of CONED

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Results preview: Utility rate schedules have a significant impact on LCOC and system configuration.

Project Milestones

FY2020

- Build initial modeling capability (complete)
- Gather data and define cases (complete)
- Define methodology for one or more use cases (complete)
- Begin running pre-integrated model (model is now fully integrated)
- Apply initial capability to select cases

FY2020

- Improve model
- Improve input generation methods (completed in FY20)
- Explore results space with early visualizations and data analysis

FY2022

- Finalize scenarios and run model
- Create visualizations of results (moved to FY21)
- Release user interface to DOE/industry/public to explore results
- Validate results with equipment at scale

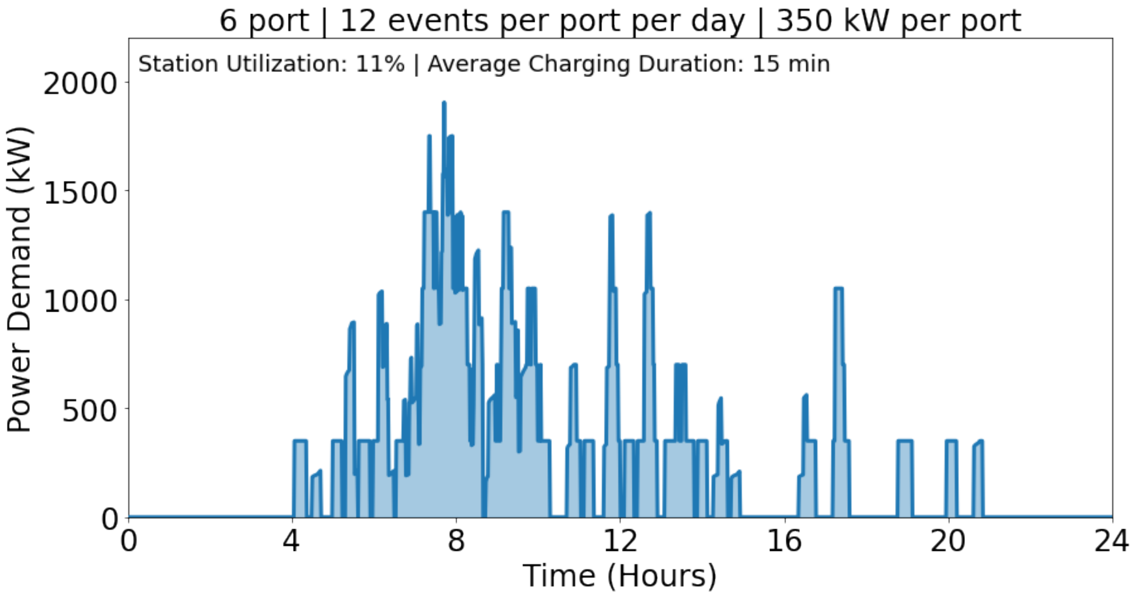
FY2021 – milestone details

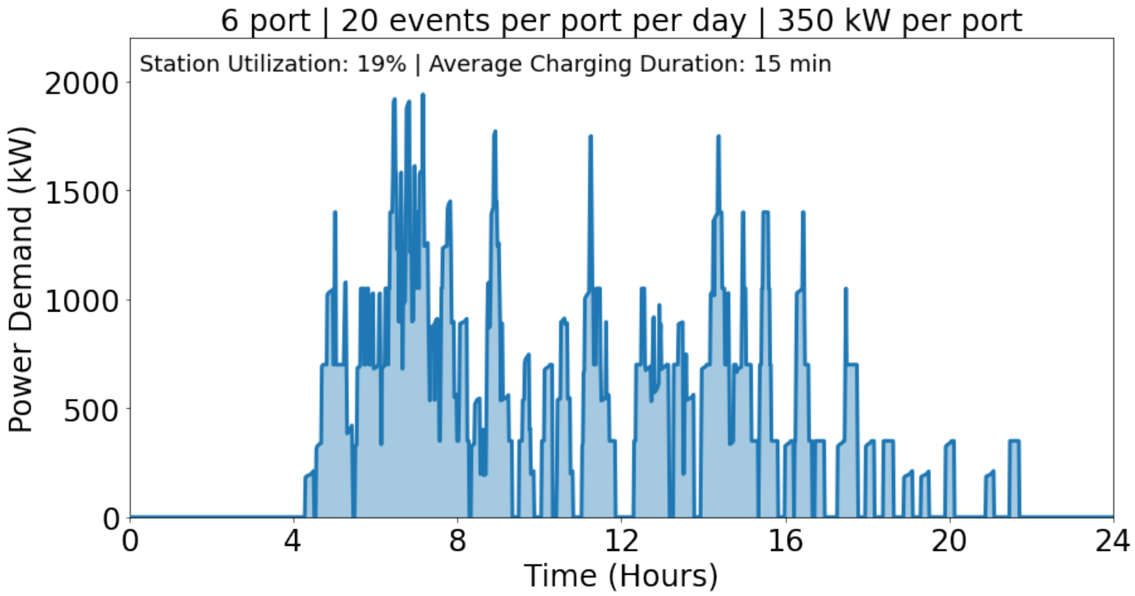
Milestone Description	Due Date	Status
Summary of results and insights from EnStore runs of *initial scenarios, focusing on the sensitivity of analysis* results to the variability of location, building loads, EV charging demands, and component costs, and combinations of each within these categories.	FY21 Q1 12/31/2020	Complete
Summary of the incorporation of *different controls strategies* and the effects on results and insights.	FY21 Q2 3/30/2021	Complete
Summary of EnStore results of *incorporation of data* from the VTO-funded BTMS research project on *battery testing* and validation and data from the BTO-funded research project on *thermal energy storage (TES).*	FY21 Q3 6/31/2021	In-progress; on-track
Interactive visualization tools for scenario exploration by audiences outside of project team such as DOE and industry advisors.	FY21 Q4 9/30/2021	In-progress; on-track

Accomplishments: Detailed EV Charge Profile Creation
Fast EV-charging station without demand management

The charging demand profile is calculated for each scenario using the EVI-EnSite Tool. The shape and power requirements depend on station size, events per day, charging power level, charge per vehicle, vehicle arrival time, building type, charge demand management, & fleet management.

Example day





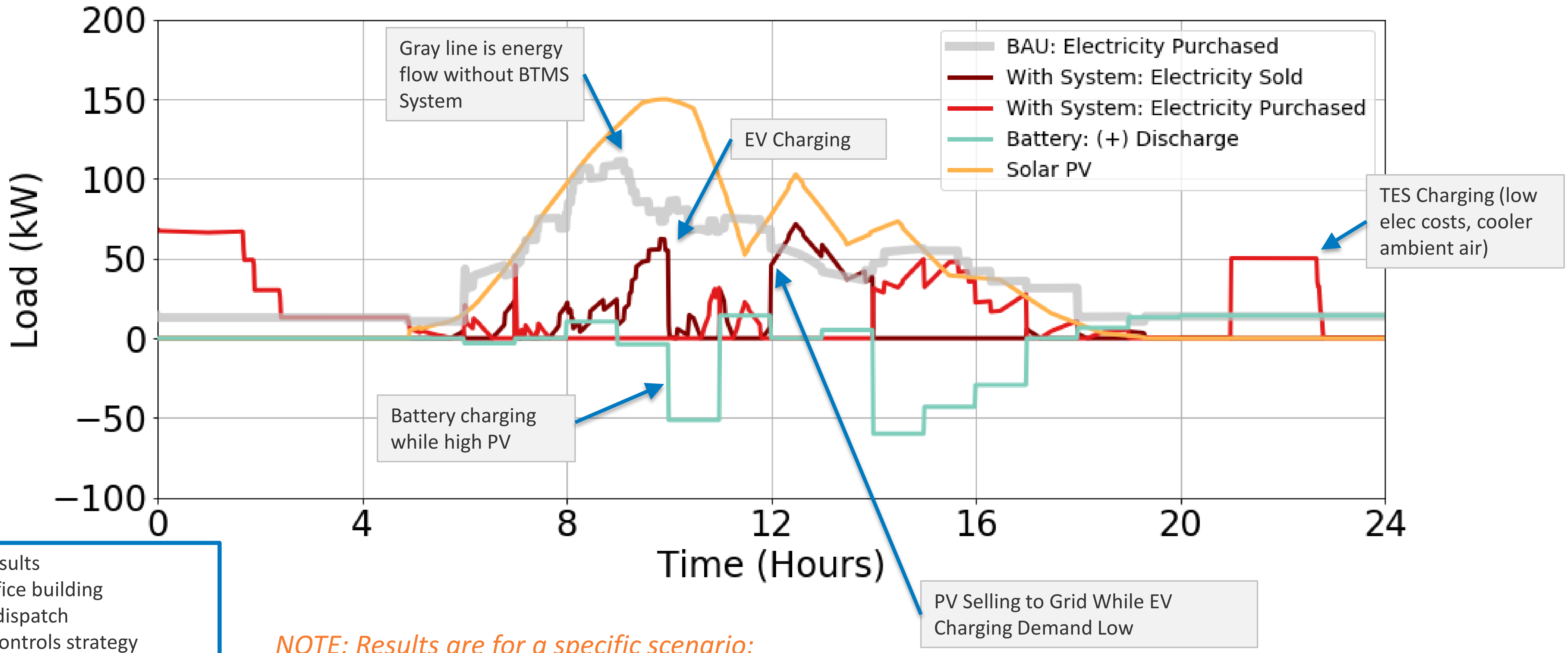
NOTE: Results are for a specific scenario; do not generalize to other cases

Six-port station with 350 kW per port, 12 & 20 charging events per port per day; peak power demand of ~2 MW; *similar to today's gas station*

EVI-EnSite Tool: https://www.nrel.gov/transportation/evi-ensite.html

Technical Accomplishments – The Multiple BTMS Components Interact Throughout Each Day

Energy flows within the BTMS system are complex.
Simplified controls algorithm does not dispatch battery quickly enough, necessitating the development of supervisory model predictive controls (see Q2 milestone)



Example Results
Medium office building
15-minute dispatch
Simplified controls strategy

NOTE: Results are for a specific scenario; do not generalize to other cases

Technical Accomplishments: Optimal LCOC and design across 4 climates and 3 utility rate schedules

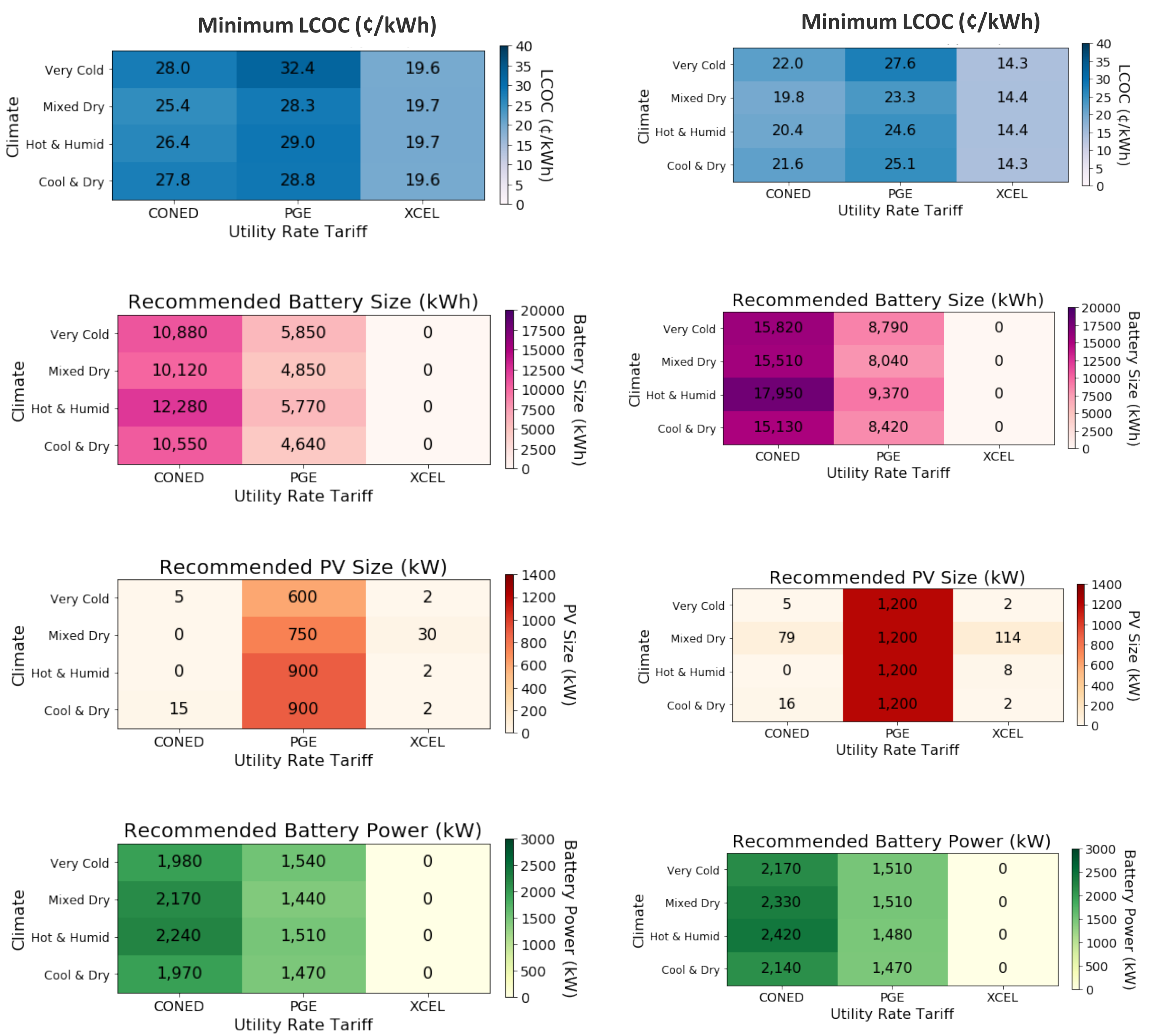
For a corner charging station, the utility rate structure has a more significant impact on results than climate. This is largely due to the low energy use of the building.

Other buildings, especially grocery stores, will have greater location impacts.

<u>Related to the figures on this slide:</u>
Utility rate has a big impact on LCOC, battery size, PV size, and battery discharge power
Location (climate), while important, has a smaller impact because EV charging demand dominates costs

Corner-type Charging Station
Battery Unit Cost = $120/kWh |$ 540/kW
PV Unit Cost: $1600/kW
EVSE cost per port: $185,000

Medium Station Utilization | High Station Utilization



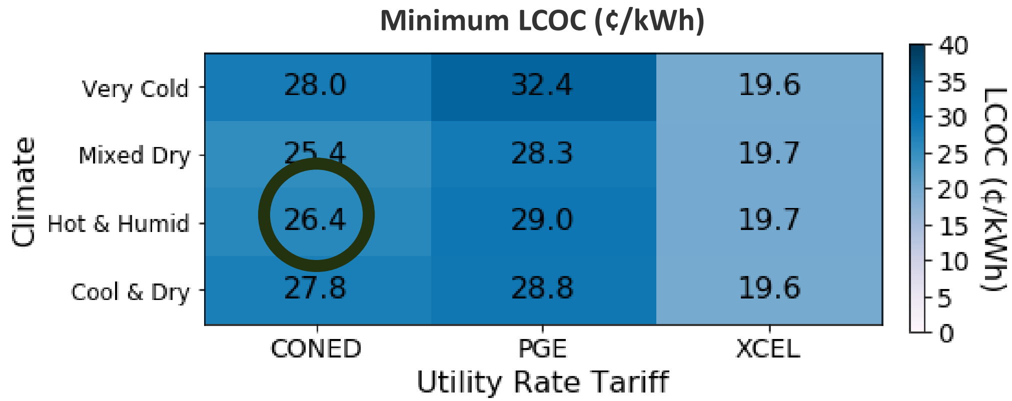
NOTE: Results are for a specific scenarios; do not generalize to other cases

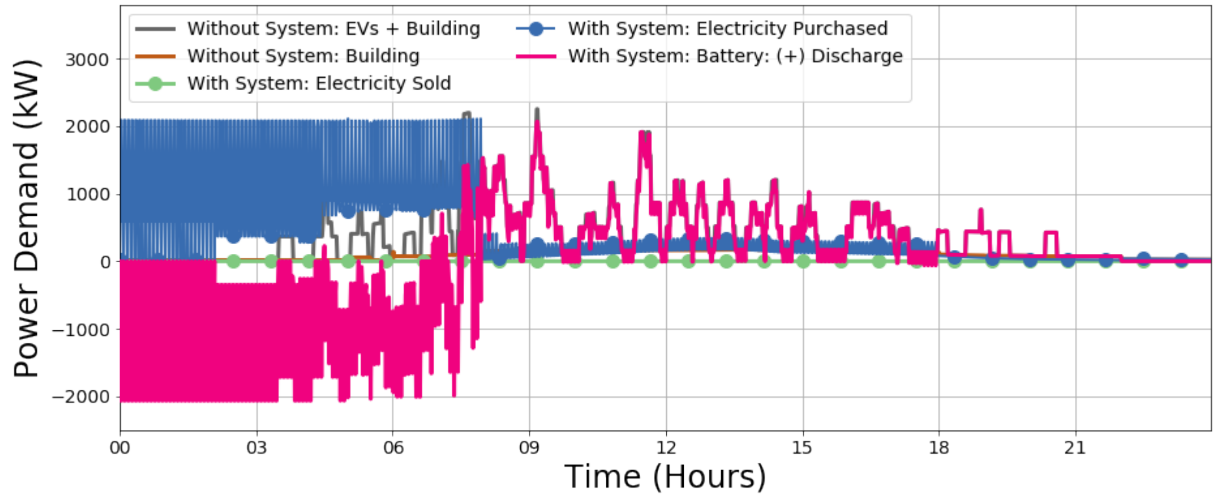
Accomplishments: Determination of Optimal LCOC & System Design

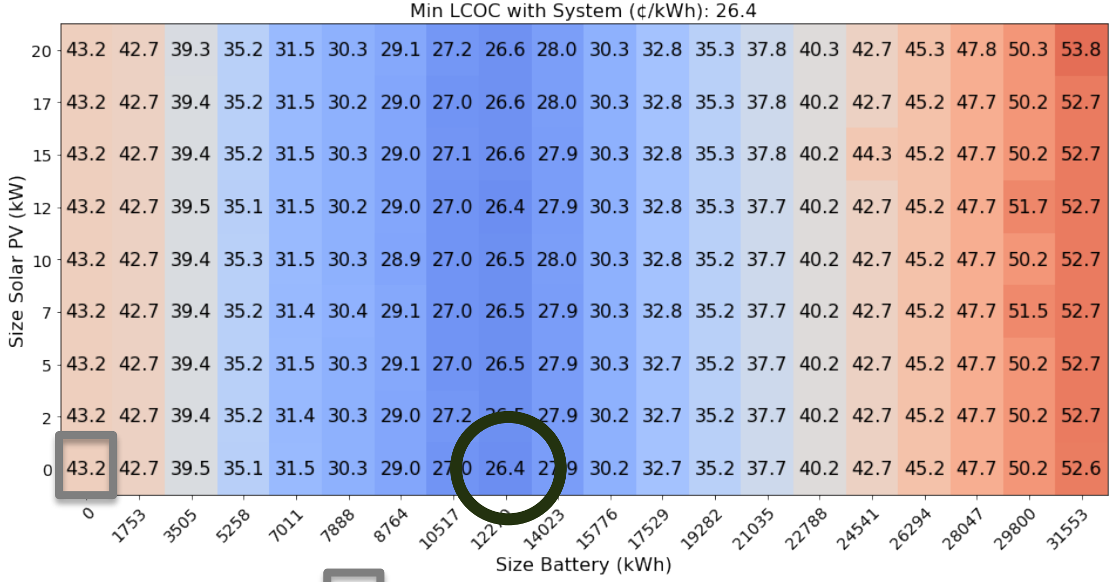
- The next three slides show the following results for a corner charging station:
  - Energy flows for one day of operations
  - Optimum LCOC (¢/kWh) for each scenario
  - LCOC for varying PV and battery sizes
  - LCOC without PV and stationary batteries (no BTMS)
- For the following conditions:
  - Corner charging station with 6 ports, 12-events per port per day (medium vehicle charging demand)
  - 350 kW fast EV charging
  - 4 climates
  - 3 utility rate structures
- Key insights from these scenarios:
  - When PV and batteries are economic, LCOC is reduced by ~30%-40%
  - BTMS battery charges mostly at night but not always
  - BTMS battery discharges to help meet EV charging demands, but not always to meet *all* charging demands
  - Utility rate structure has a very significant impact on the optimal system design

Minute-by-minute Predictive Supervisory Controls are Necessary to Cost-Effectively Dispatch Energy Storage

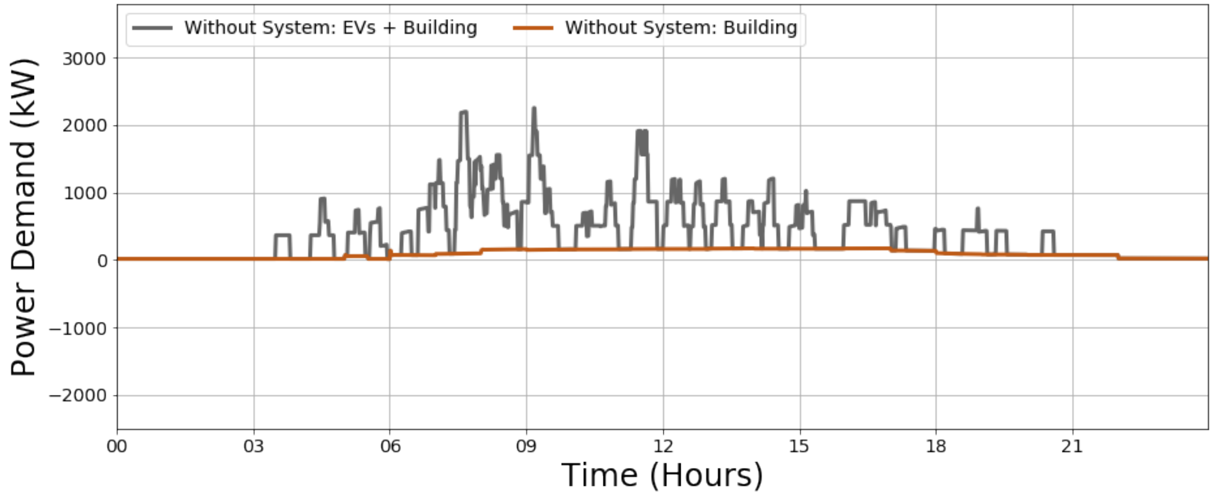
Utility Rate: CONED: HIGH DEMAND CHARGES
Location: TAMPA: HOT & HUMID







LCOC without System (¢/kWh): 43.2

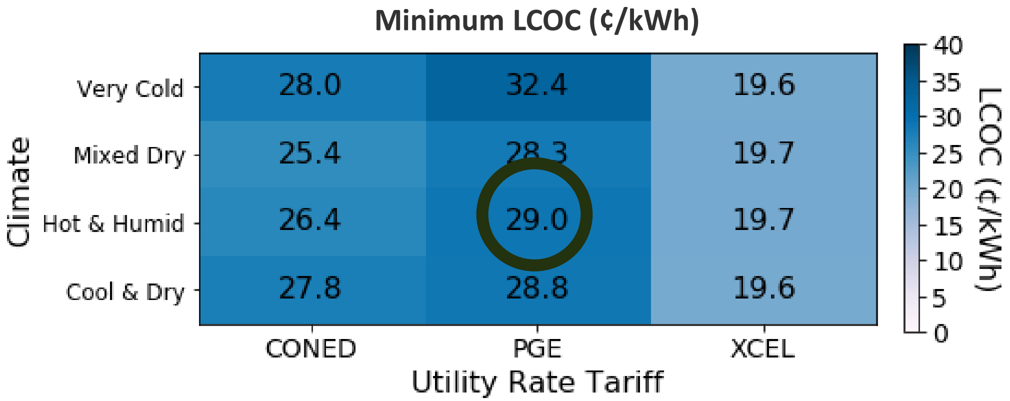


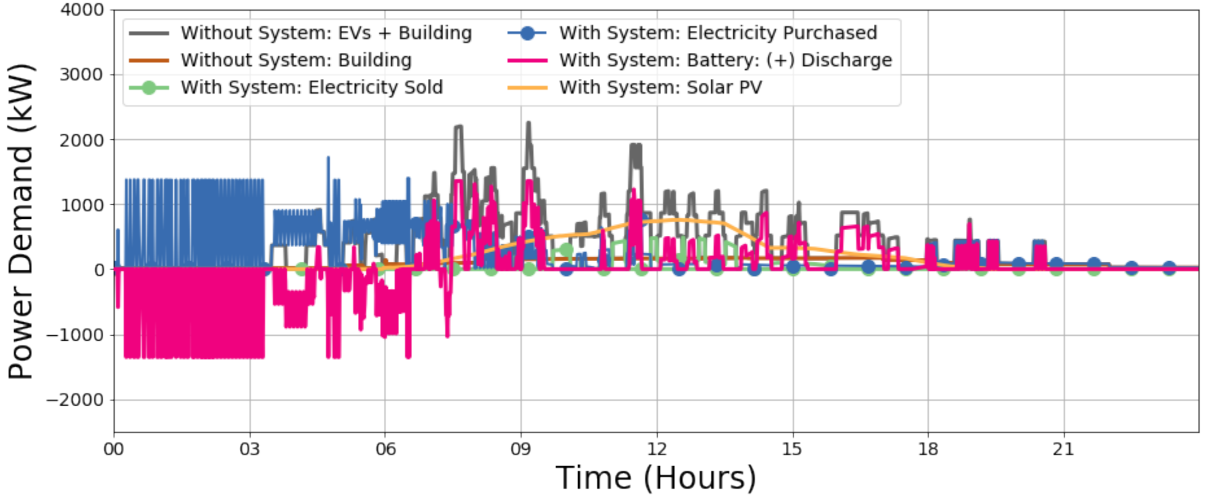
NOTE: Results are for a specific scenario; do not generalize to other cases

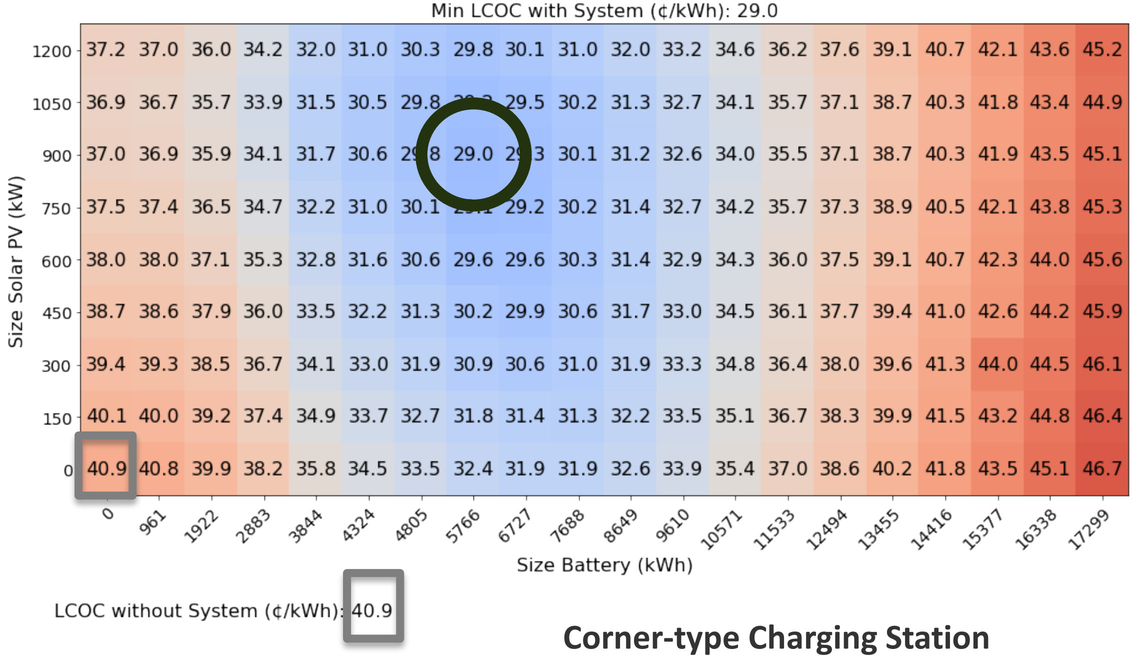
Corner-type Charging Station
EV Load Profile: 6 PORT 12 EVENT 350 KW
EVSE $/port = $185,000
Battery = 120 $/kWh, 540 $/kW
Season of Interest: Summer
PV Unit Cost = $600/kW

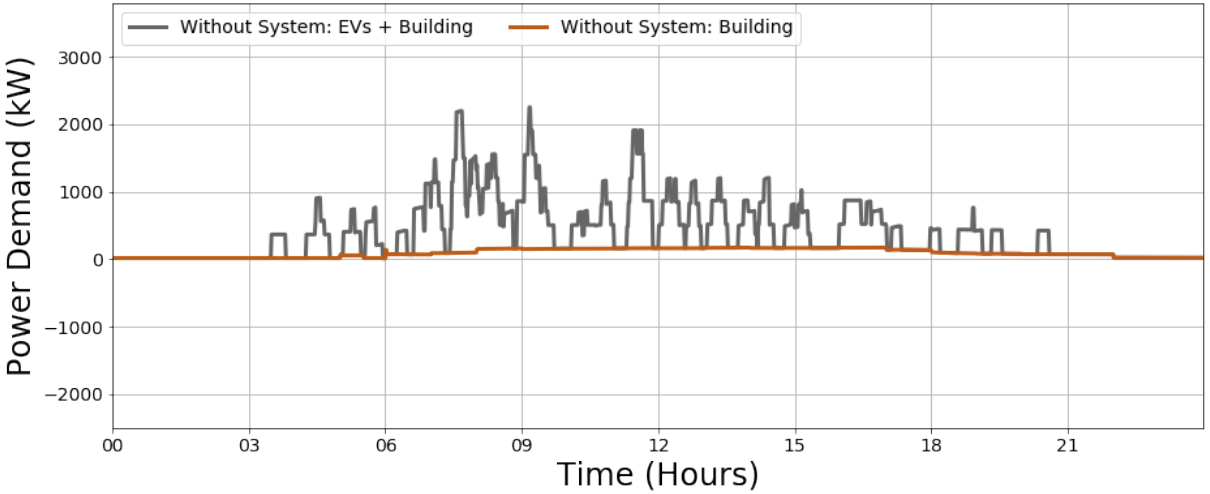
Minute-by-minute Predictive Supervisory Controls are Necessary to Cost-Effectively Dispatch Energy Storage

Utility Rate: PG&E: TOU DEMAND & ENERGY CHARGES
Location: TAMPA: HOT & HUMID







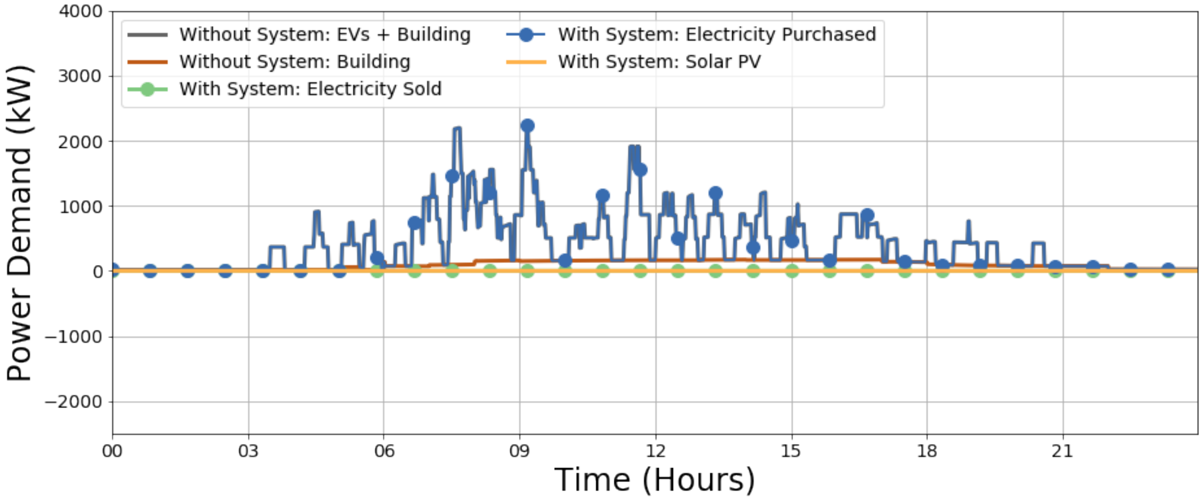


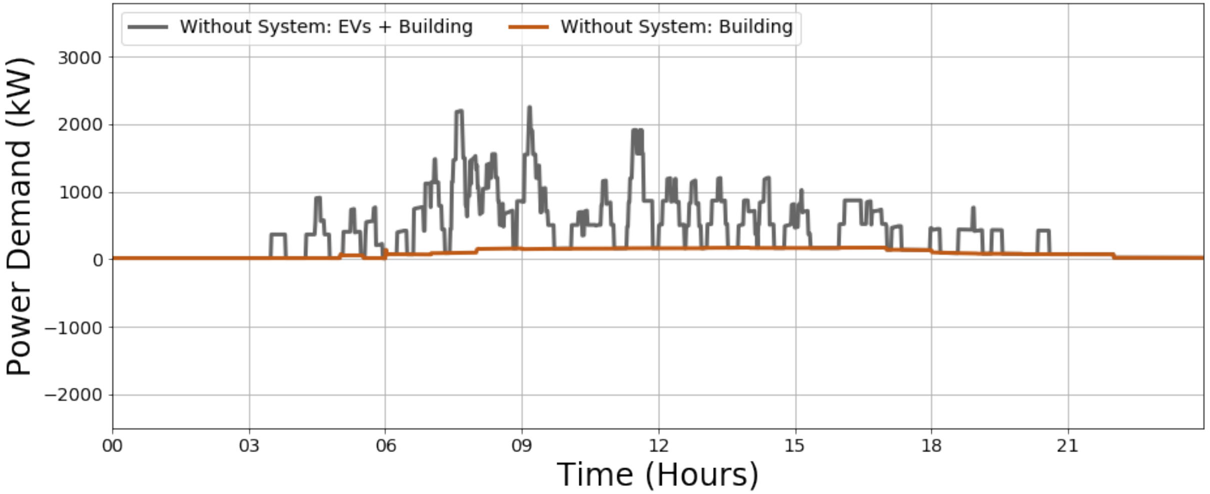
NOTE: Results are for a specific scenario; do not generalize to other cases

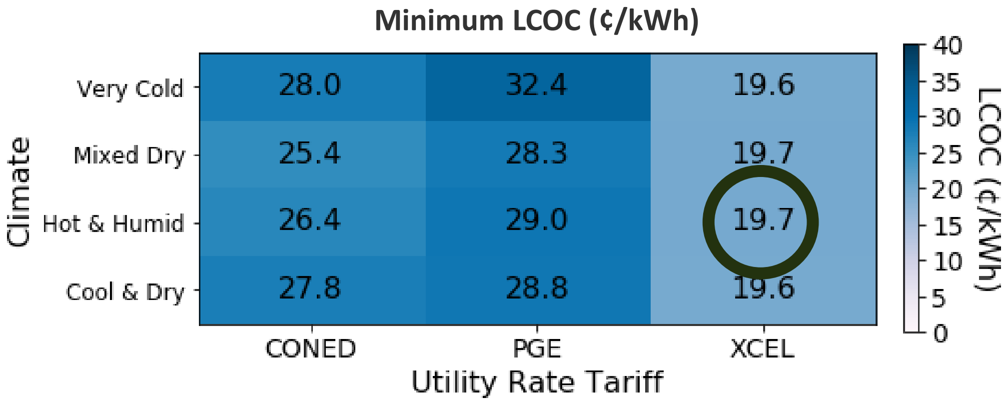
Corner-type Charging Station
EV Load Profile: 6 PORT 12 EVENT 350 KW
EVSE $/port = $185,000
Battery = 120 $/kWh, 540 $/kW
Season of Interest: Summer
PV Unit Cost = $600/kW

Minute-by-minute Predictive Supervisory Controls are Necessary to Cost-Effectively Dispatch Energy Storage

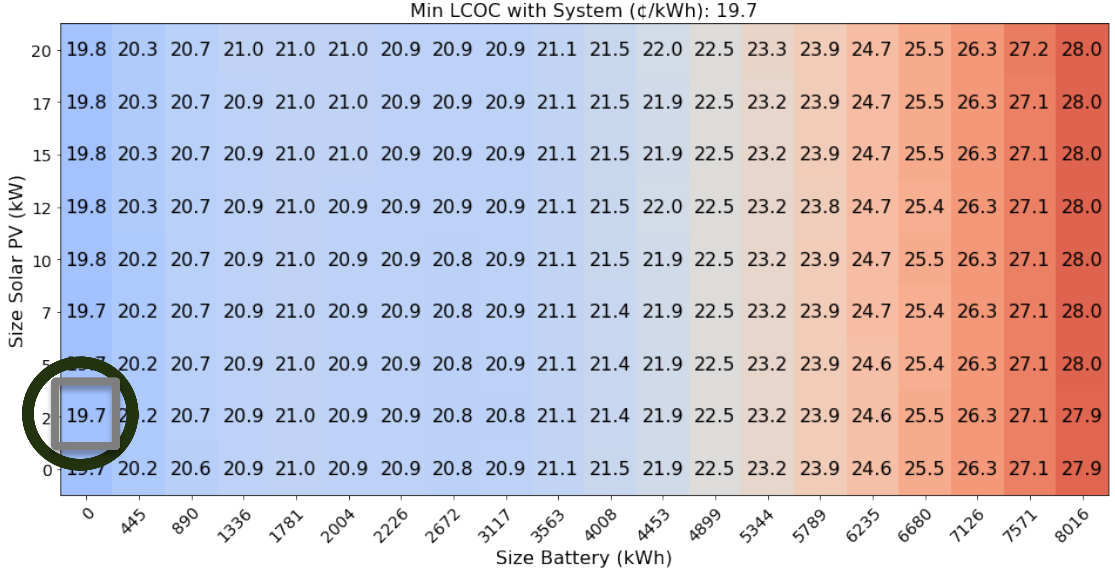
Utility Rate: XCEL: TOU BUT LOW-COST ENERGY
Location: TAMPA: HOT & HUMID







Climate	CONED	PGE	XCEL
Very Cold	28.0	32.4	19.6
Mixed Dry	25.4	28.3	19.7
Hot & Humid	26.4	29.0	19.7
Cool & Dry	27.8	28.8	19.6



Size Solar PV (kW) \ Size Battery (kWh)	0	445	890	1336	1781	2004	2226	2672	3117	3563	4008	4453	4899	5344	5789	6235	6680	7126	7571	8016
20	19.8	20.3	20.7	21.0	21.0	21.0	20.9	20.9	20.9	21.1	21.5	22.0	22.5	23.3	23.9	24.7	25.5	26.3	27.2	28.0
17	19.8	20.3	20.7	20.9	21.0	21.0	20.9	20.9	20.9	21.1	21.5	21.9	22.5	23.2	23.9	24.7	25.5	26.3	27.1	28.0
15	19.8	20.3	20.7	20.9	21.0	21.0	20.9	20.9	20.9	21.1	21.5	21.9	22.5	23.2	23.9	24.7	25.5	26.3	27.1	28.0
12	19.8	20.3	20.7	20.9	21.0	20.9	20.9	20.9	20.9	21.1	21.5	22.0	22.5	23.2	23.8	24.7	25.4	26.3	27.1	28.0
10	19.8	20.2	20.7	20.9	21.0	20.9	20.9	20.8	20.9	21.1	21.5	21.9	22.5	23.2	23.9	24.7	25.5	26.3	27.1	28.0
7	19.7	20.2	20.7	20.9	21.0	20.9	20.9	20.8	20.9	21.1	21.4	21.9	22.5	23.2	23.9	24.7	25.4	26.3	27.1	28.0
5	[illegible]	20.2	20.7	20.9	21.0	20.9	20.9	20.8	20.9	21.1	21.4	21.9	22.5	23.2	23.9	24.6	25.4	26.3	27.1	28.0
2	19.7	[illegible]	20.7	20.9	21.0	20.9	20.9	20.8	20.8	21.1	21.4	21.9	22.5	23.2	23.9	24.6	25.5	26.3	27.1	27.9
0	19.7	20.2	20.6	20.9	21.0	20.9	20.9	20.8	20.9	21.1	21.5	21.9	22.5	23.2	23.9	24.6	25.5	26.3	27.1	27.9

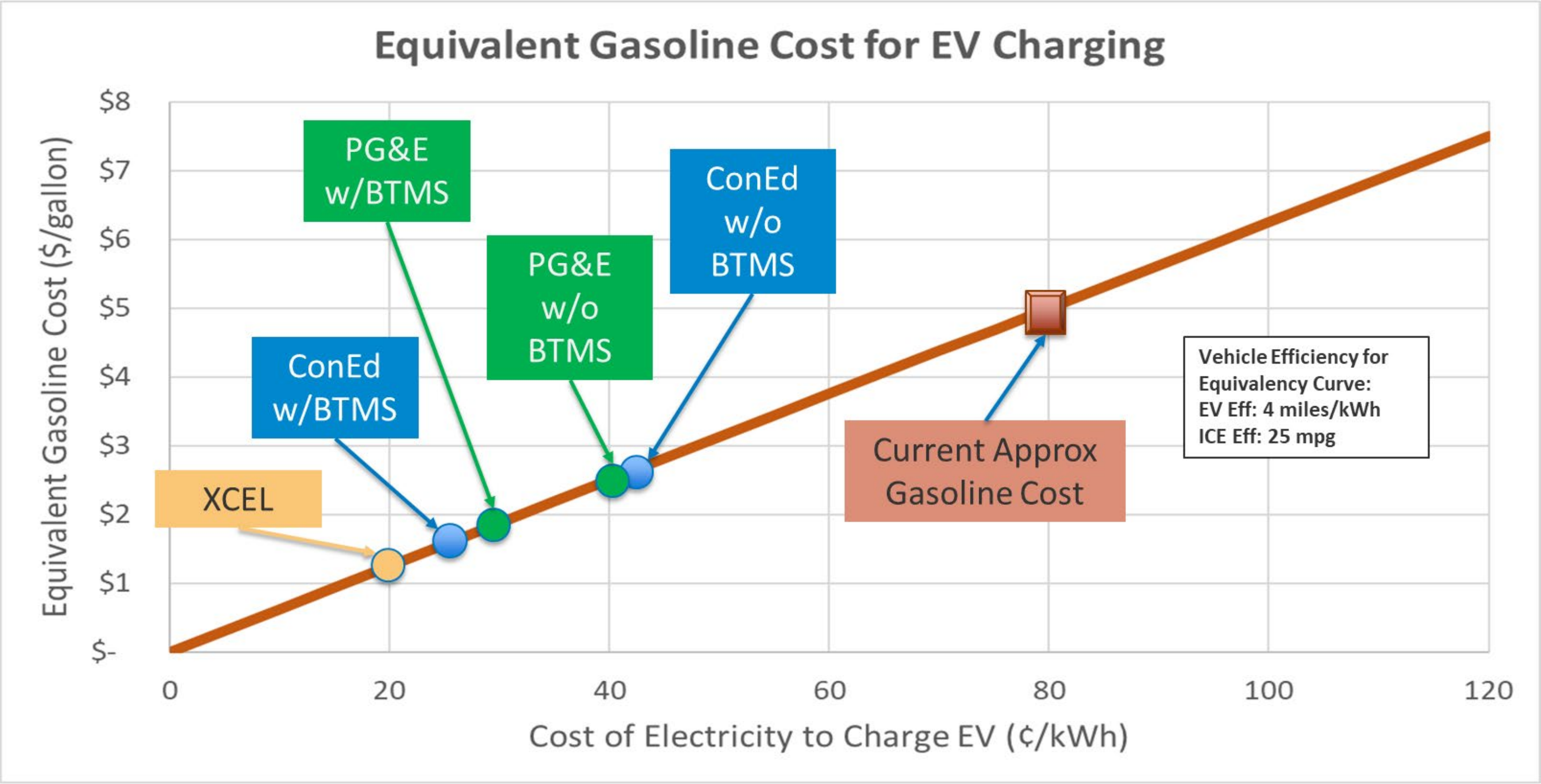
LCOC without System (¢/kWh): 19.7

NOTE: Results are for a specific scenario; do not generalize to other cases

Corner-type Charging Station
EV Load Profile: 6 PORT 12 EVENT 350 KW
EVSE $/port = $185,000
Battery = 120 $/kWh, 540 $/kW
Season of Interest: Summer
PV Unit Cost = $600/kW

Accomplishments: BTMS Can Reduce the Costs of Fast EV-Charging

What's the value of these BTMS cases relative to fueling a vehicle with gasoline?



Stay tuned for the results of more scenarios (being examined now)

For a corner charging station with 6 ports, 12-events per port per day, with 350 kW fast EV charging:

- *Charging an electric vehicle at "reasonable" electricity rates is cheaper than driving with gasoline*
- *BTMS reduces the cost of fast EV-charging*
- *BTMS can be an economic means of reducing impacts of fast EV-charging*

Important caveats:

- Results are for the specific scenarios shown; may not hold for different building types, utility rates, and capital costs
- Utilities are very likely to change their rate structures as more variable renewables are added to the grid

Responses to Previous Year Reviewers' Comments

- This project was not reviewed at last year's Annual Merit Review

Summary

- Several fundamental and watershed changes in the transportation, electrical, and buildings sectors are happening simultaneously. Understanding the intersection of these changes is essential for optimizing the economic, social, and climate benefits.
  - Rapid (EV) adoption could have a significant, and potentially negative effect, on grid infrastructure and buildings operations.
  - Large penetration of solar photovoltaic (PV) generation installed on buildings is leading to new challenges for building interactions with the electric grid.
  - New wind and solar electric generation installation and operating costs are now market competitive
  - Storage energy costs are rapidly declining, enabling greater use of clean energy
- *The EnStore Model dynamically evaluates, at the physics-based level, how batteries and thermal energy storage can reduce costs for fast EV charging for multiple buildings in different locations*

- The EnStore Model has been used to evaluate the optimal design and costs of BTMS for fast EV-charging at corner charging stations, medium office buildings, and package fulfillment warehouses, with PV, battery storage, and thermal energy storage, in different climates, and with different utility rate schedules.
  - When PV and batteries are economic, LCOC is reduced by ~30%-40% for specific corner charging station scenarios
  - BTMS battery charges mostly at night but not always; detailed controls are necessary to get this right
  - BTMS battery discharges to help meet EV charging demands, but not always to meet *all* charging demands
  - Utility rate structure has a very significant impact on the optimal system design
- Current work is aimed at evaluating the benefits and economic viability of BTMS across U.S.

Remaining Challenges and Barriers

- Automatically-generated visualization and data “wrangling” are needed to more quickly analyze EnStore results. Team is working with visualization experts to bring this to the project by the end of summer.
- Time on the high-performance supercomputer is sometimes limited. Requests for FY22 allocations are being made now.
- The large number of variables requires thousands of runs. By the end of FY21, cases will be run across all variables using the NREL high-performance supercomputer (Eagle). More sensitivity analyses will be conducted in FY22.

Proposed Future Research

Will be addressed by end of FY21:

- Finalize scenarios and run model across full parameter space.
- We have run scenarios for 3 of 5 building types, 4 of 6 climate regions, battery costs, PV costs, battery lifetime, and impact of battery chemistry

To be addressed in FY22*:

- Impact of deferred electric distribution upgrades on financial viability
- More detailed visualization of results
- Public-facing visual interface for exploring the potential of BTMS under changing scenarios

Other proposed research*:

- Greenhouse gas emissions savings compared to no BTMS at locations across U.S. and at different levels of EV deployment
- Validate EnStore energy-flow results on charging systems at commercial scales; improve model predictive controls algorithms
- Partner with charging & vehicle industries to validate market results

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

Collaboration and Coordination

- This project is part of the wider BTMS R&D project (# bat442)
  - Team of Five National Laboratories: *Sandia National Laboratory, Argonne National Laboratory, Idaho National Laboratory, Pacific Northwest National Laboratory*
- This project is funded by VTO, BTO, and SETO, leading to collaboration with researchers in the vehicles, buildings, and solar energy fields
  - In particular, this project regularly works with building researchers focusing on thermal energy storage for grid-interactive buildings and battery researchers
- These collaborations are ongoing, with weekly, monthly, and quarterly meetings, as well as informal project discussions
- *These collaborations are essential* for the partnership between analysis and R&D research. The research project provides input data and technical context for EnStore scenarios. The EnStore analysis project provides insight into the critical technical levers and research targets needed to meet the objectives of greater electrification of transportation and fast EV charging.

CONTRIBUTORS AND ACKNOWLEDGMENT

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NREL Transforming ENERGY | Idaho National Laboratory | Sandia National Laboratories | Argonne NATIONAL LABORATORY | Pacific Northwest NATIONAL LABORATORY

Thank You

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For additional information or to contribute to this project, please contact margaret.mann@nrel.gov

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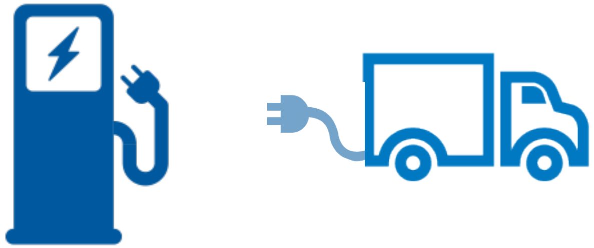
NREL Transforming ENERGY

Technical Back-Up Slides

Calculation of LCOC (for vehicle focus)

Electric Vehicle Focus



$$LCOC_{baseline} = \left(\frac{\boldsymbol{C'}_{EVSE+building} - \boldsymbol{C'}_{baseline\ building\ only}}{\boldsymbol{E'}_{BEV}} \right)$$

$$LCOC_{BTMS} = \left(\frac{\boldsymbol{C'}_{EVSE+building+\boldsymbol{BTMS}} - \boldsymbol{C'}_{baseline\ building\ only}}{\boldsymbol{E'}_{BEV}} \right)$$

$\boldsymbol{C'}_i = vector\ of\ discounted\ cash\ flows\ (costs)\ for\ system$
$\boldsymbol{E'}_i = vector\ of\ discounted\ energy\ flows\ going\ to\ item\ i$
$BEV\ = \ battery\ electric\ vehicle$

The LCOC should only account for costs associated with the EV Station

The building must pay its “fair share”

Thus, the **costs (energy bill) of the baseline building** without the EVSEs must be subtracted from the combined building and EVSE or EVSE+BTMS

This makes the **LCOC reflect only the EV Station and charging costs** rather than also incorporating building electricity costs

Calculation of LCOE (for Buildings-focus)

Building Focus

$$LCOE_{baseline} = \left(\frac{\boldsymbol{C'}_{baseline\ building\ only}}{\boldsymbol{E'}_{building}}\right)$$

$$LCOE_{BTMS} = \left(\frac{\boldsymbol{C'}_{EVSE+building+BTMS} - \left[\boldsymbol{C'}_{EVSE+building} - \boldsymbol{C'}_{baseline\ building\ only}\right]}{\boldsymbol{E'}_{building}}\right)$$

$\boldsymbol{C'}_i = vector\ of\ discounted\ cash\ flows\ (costs) for\ system$
$\boldsymbol{E'}_i = vector\ of\ discounted\ energy\ flows\ going\ to\ item\ i$

Analogous to the LCOC computation except all benefits of BTMS system are accrued to the building owner as opposed to the EV owner and ***levelization is by energy usage of the entire system*** through the building as opposed to energy usage of the EVSE

Key Input Assumptions for Charging Station Scenarios

Climate Zone	Description	Location	Nickname
2a	Hot & Humid	Tampa, Florida	TAMPA
4b	Mixed Dry	Albuquerque, New Mexico	ABQ
5b	Cool & Dry	Aurora, Colorado	AURORA
7	Very cold	International Falls, Minnesota	INTL FALLS

System Costs

Battery

$120/kWh | $270/kWh | $420/kWh

$540/kW | $690/kW | $840/kW

Solar PV

$1600/kW

EVSE (equipment and installation)

50 kW: $30,000 | $56,000 | $84,000 per port

150 kW: $94,000 | $121,000 | $148,000 per port

350 kW: $154,000 | $185,000 | $216,000 per port

Financials

Discount Rate

8.6%

Building type

Medium office

EV Station type

6 port | 350 kW | 12 charging events per port per day (medium utilization station)

6 port | 350 kW | 20 charging events per port per day (high utilization station)

Utility Nickname	Utility Full Name	Characteristics
ConEd	Consolidated Edison	ConEd has monthly demand charges that go 5.36 - 16.7 $/kW and TOU demand charges that go up to 23.89 $/kW; and flat energy rates
PG&E	Pacific Gas & Electric	PG&E has flat demand charge of 15.97 $/kW and TOU demand that goes up to 20.62$/kW AND TOU energy
Xcel	Xcel Energy	Xcel's demand is constant at 5.63 $/kW, but energy varies much more than for CONED

Sensitivity Analysis of Battery Cost

One climate zone & one utility rate tariff; *EVSE cost kept constant*

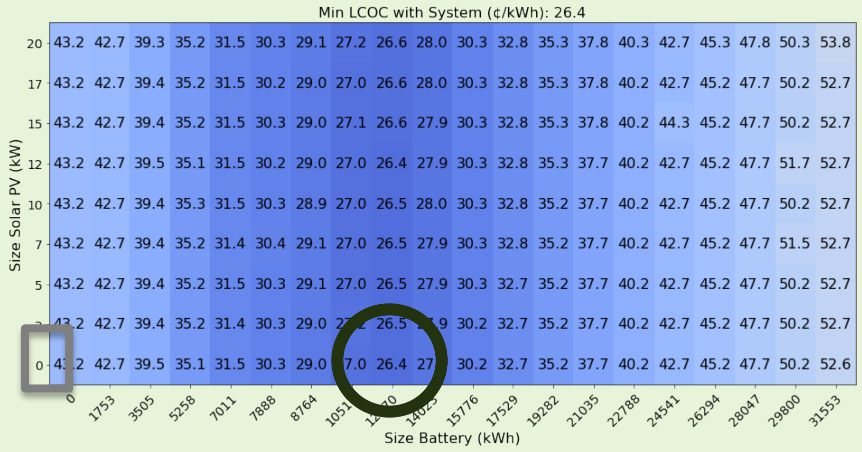
Utility Rate: CONED
Location: TAMPA
EV Load Profile: 2 PORT 16 EVENT 350 KW
EVSE $/port = $185,000 per port
Battery $/kWh = 120 | 270 | 470
Battery $/kW = 540

Here, optimal battery size varies drastically (from **12,271 kWh** to **10,518 kWh** to **7,012 kWh**), based on input battery price

The "LCOC without System" or LCOC without any PV or battery stays constant at **43.2 ¢/kWh**

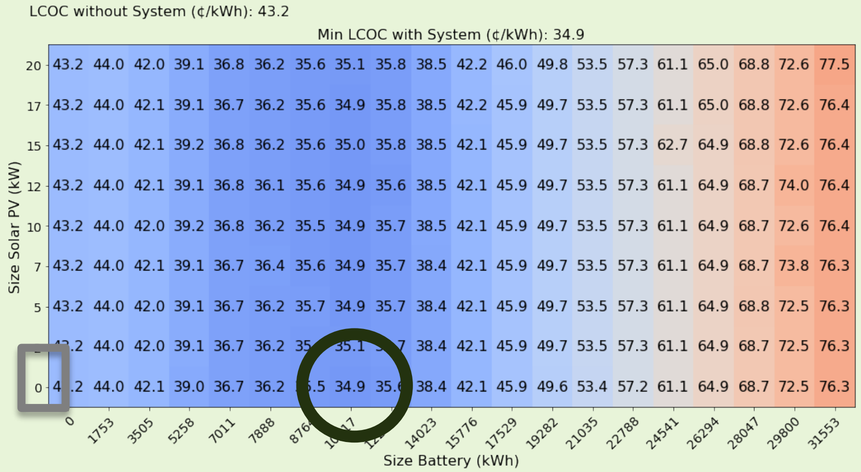
Battery Cost: $120/kWh
Min LCOC:
51.9 ¢/kWh

Battery size:
12,271 kWh



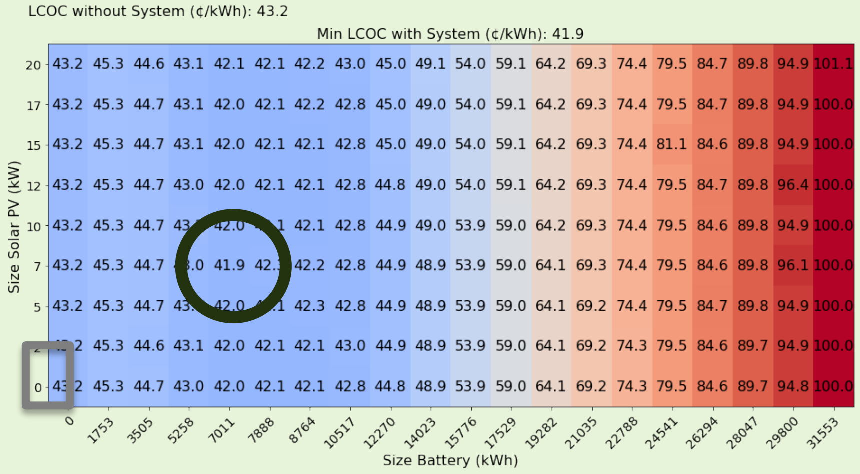
Battery Cost: $270/kWh
Min LCOC:
34.9 ¢/kWh

Battery size:
10,518 kWh



Battery Cost: $470/kWh
Min LCOC:
41.9 ¢/kWh

Battery size:
7,012 kWh



Sensitivity Analysis of EVSE Cost

One climate zone & one utility rate tariff; *battery cost kept constant*

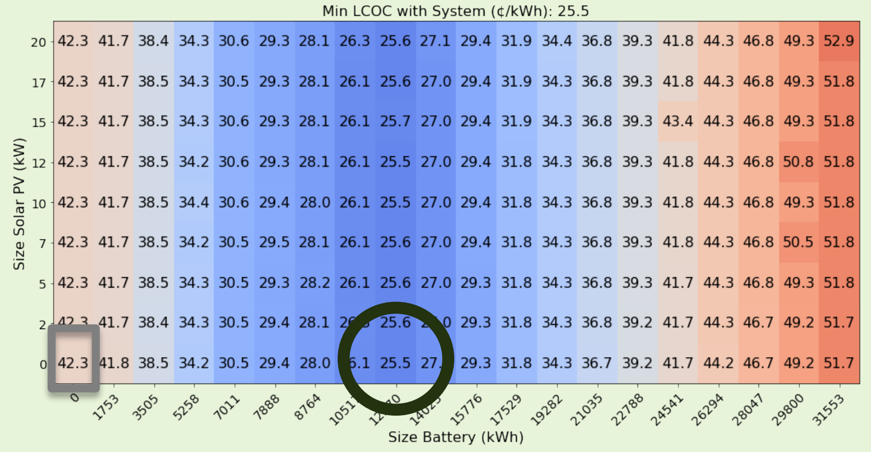
Utility Rate: CONED
Location: TAMPA
EV Load Profile: 6 PORT 12 EVENT 350 KW
EVSE $/port = **$154,000 | $185,000 | $216,000 per port**
Battery $/kWh = 120
Battery $/kW = 540

Here, optimal battery size stays constant **(12,271 kWh)** regardless of EVSE input cost

EVSE costs affect the absolute value of LCOC. EVSE cost variation does not have very large impacts on LCOC.

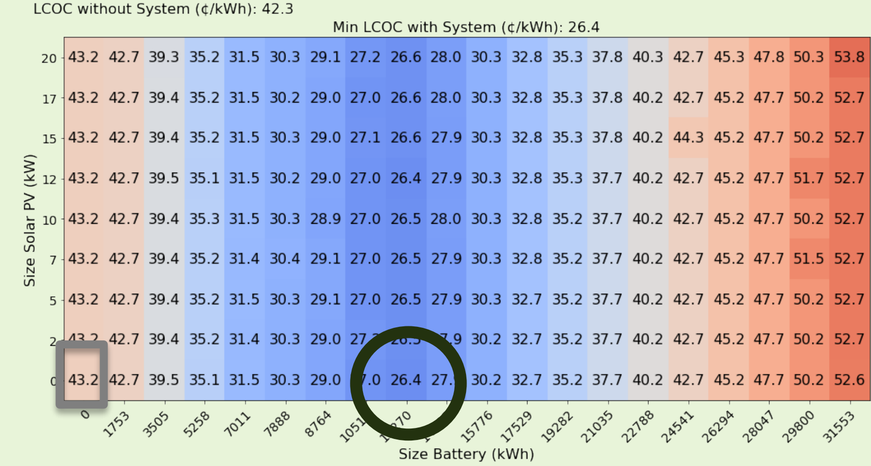
EVSE Cost: $154,000

Min LCOC: 25.5 ¢/kWh



EVSE Cost: $185,000

Min LCOC: 26.4 ¢/kWh



EVSE Cost: $216,000

Min LCOC: 27.4 ¢/kWh