Behind-the-Meter Storage

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Project Introduction

This initiative, referred to as Behind-the-Meter-Storage (BTMS), will focus on novel critical-materials-free battery technologies to facilitate the integration of electric vehicle (EV) charging, solar power generation technologies, and energy-efficient buildings while minimizing both costs and grid impacts. For extreme fast-charging at levels of 350 kW or higher, novel approaches are required to avoid significant negative cost and resiliency impacts. However, it is reasonable to assume that BTMS solutions would be applicable to other intermittent renewable energy generation sources or short-duration, high power-demand electric loads. BTMS research is targeted at developing innovative energy-storage technology specifically optimized for stationary applications below 10 MWh that will minimize the need for significant grid upgrades. Additionally, avoiding excessive high-power draws will eliminate excess demand charges that would be incurred during 350-kW fast-charging using current technologies. The key to achieving this is to leverage battery storage solutions that can discharge at high power but be recharged at standard lower power rates, acting as a power reservoir to bridge to the grid and other on-site energy generation technologies such as solar photovoltaics (PV), thereby minimizing costs and grid impacts. To be successful, new and innovative integration treatments must be developed for seamless interaction between stationary storage, PV generation, building systems, and the electric grid.

Key components of BTMS will address early-stage research into new energy-generation and building-integration concepts, critical-materials-free battery energy-storage chemistries, and energy-storage designs with a focus on new stationary energy-storage strategies that will balance performance and costs for expanded fast-charging networks while minimizing the need for grid improvements.

Objectives

A cohesive multidisciplinary research effort to create a cost-effective, critical-materials-free solution to BTMS by employing a whole-systems approach will be taken. The focus of this initiative is to develop innovative battery energy-storage technologies with abundant materials applicable to EVs and high-power charging systems. Solutions in the 1–10 MWh range will eliminate potential grid impacts of high-power EV charging systems as well as lower installation costs and costs to the consumer.

Although many lessons learned from EV battery development may be applied to the BTMS program, the requirements for BTMS systems are unique—carrying their own calendar-life, cycle-life, and cost challenges. For example, EV energy-storage systems need to meet very rigorous energy-density and volume requirements to meet consumer transportation needs. Despite that, current stationary storage systems use batteries designed for EVs due to high volumes driving down costs. This creates another market demand for EV batteries, further straining the EV battery supply chain and critical-material demand.

By considering BTMS electrochemical solutions optimized for these applications with less focus on energy density in mass and volume, the potential for novel battery solutions is very appealing. Furthermore, the balance-of-plant for a BTMS battery system, or the cost of everything minus the battery cells, is thought to be upwards of 60% of the total energy-storage system cost. In contrast, the EV's balance-of-plant costs make up roughly 30% of the total battery cost. Therefore, BTMS will also need to focus on reducing balance-of-plant cost through system optimization to realize desired cost targets.

The design parameters are needed to optimize the BTMS system for performance, reliability, resilience, safety, and cost.

The objectives for the project are:

- Produce behind-the-meter battery solutions that can be deployed at scale and meet the functional requirement of high-power EV charging.
- Battery storage: Utilize a total-systems approach to develop and identify the specific functional requirements for BTMS battery solutions that will provide novel battery systems in the 1–10 MWh range at $100/kWh installed cost and able to cycle twice per day, discharging for at least 4 hours, with a lifetime of roughly 20 years or at least 8,000 cycles.

Approach

A cohesive multidisciplinary research effort, involving NREL, INL, SNL, and ORNL, will create a cost-effective, critical-materials-free solution to BTMS by employing a whole-systems approach. The focus of this initiative is to develop innovative battery energy-storage technologies with abundant materials applicable to PV energy generation, building energy-storage systems, EVs, and high-power charging systems. Solutions in the 1–10 MWh range will enable optimal integration of PV generation from a DC-DC connection, increase energy efficiency of buildings, eliminate potential grid impacts of high-power EV charging systems, and lower installation costs and costs to the consumer.

Although many lessons learned from EV battery development may be applied to the BTMS program, the requirements for BTMS systems are unique—carrying their own calendar-life, cycle-life, and cost challenges. For example, EV energy-storage systems need to meet very rigorous energy-density and volume requirements to meet consumer transportation needs. Despite that, current stationary storage systems use batteries designed for EVs due to high volumes that drive down the costs. This creates another market demand for EV batteries, further straining the EV battery supply chain and critical-material demand.

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Integration of battery storage with PV generation, energy-efficient buildings, charging stations, and the electric grid will enable new and innovative control strategies. The design parameters are needed to optimize the BTMS system for performance, reliability, resilience, safety, and cost.

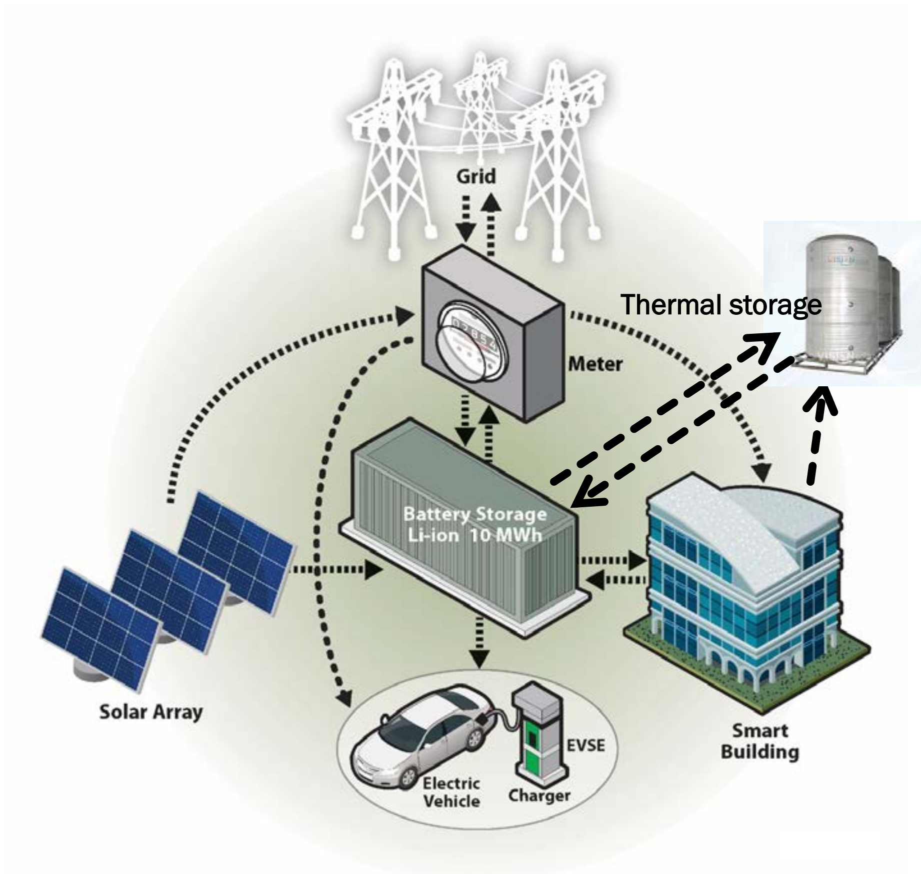

Figure 1. Overview of BTMS relevance.

BTMS Analysis (NREL)

Contributors: INL, SNL, NREL, ORNL

Background

The Behind-the-Meter Storage (BTMS) project goal is to create a cost-effective, critical-materials-free solution to BTMS by employing a whole-systems approach. The solutions are targeted in the 1–10 MWh range, with the goal of eliminating potential grid impacts from high-power EV charging systems. In addition to the 1–10 MWh size, the project is targeting $100/kWh installed battery system cost with a 20-year lifetime.

Electrical vehicle adoption is currently growing at a rapid pace. This adoption rate requires expansion and improvement of charging infrastructure or electronic charging stations (ECSs). Increasing the rapid-charging infrastructure places increased demand needs on the grid. A design change to ECSs to incorporate batteries could reduce or smooth these demands, but the cost tradeoffs are not currently known. This analysis will examine the tradeoff and benefits of incorporating battery storage solutions with EV supply equipment (EVSE) to understand the costs that drive this charging infrastructure. The overall purpose is to define the highest cost inputs and quantify the impacts of research accomplishments and goals on the entire system.

Results

The first step in the modeling was to outline the design and determine the components in each segment. The component costs considered are boxed in Figure 2.

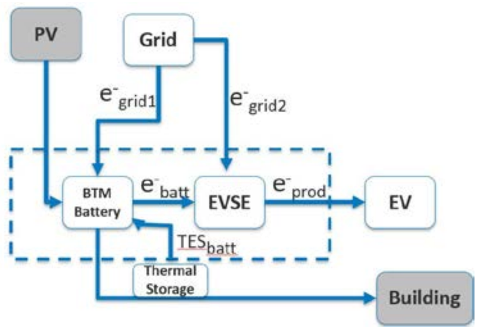

Figure 2. Overview of modeled system.

The location is a model input because rate and demand charges vary significantly by utility service territory, in addition to time of year. Therefore, energy rate structures are a critical input to evaluating system economics for EV charging systems. Figure 3 shows the geographically disaggregated nature of energy rates.

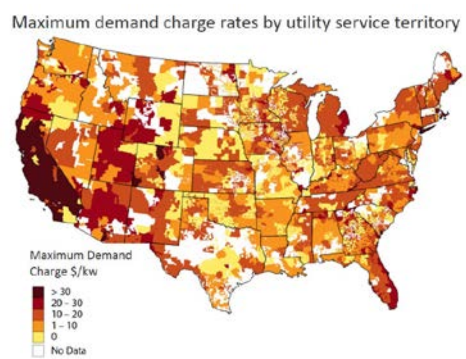

Figure 3. Contiguous 48 states energy rates.[1]

Figure 4 shows how the location can have both a tiered energy-usage charge structure coupled with a seasonal/monthly demand structure. The figure serves as an example of the rate complexity.

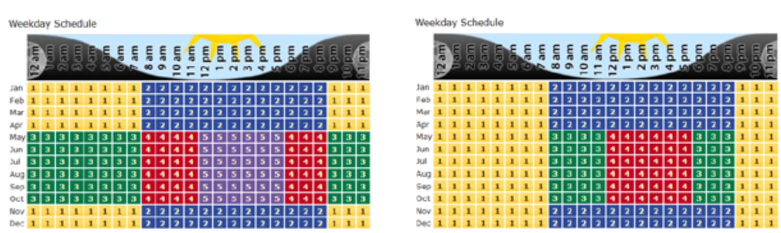

Figure 4. (Left) Price per kW. (Right) Price based on demand.[2]

The next step was to simulate the charging profile that the system would need to meet. Electric Vehicle Infrastructure Projection Tool (EVI-Pro[3]) was used. The project focused on DC fast-charging at 350 kW. The scenario was a “gas” station, so it was decided that six chargers would be available. This scenario would be transferable later to a “big box” store retailer. Figure 5 graphically represents the anticipated demand modeled by EVI-Pro for this scenario.

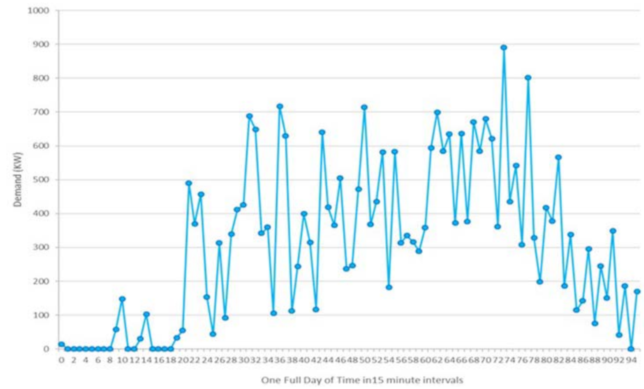

Figure 5. Six EVSE (350 kW each) power-station demand profile.

The next step was to then model the scenario to offset the demand and peak electricity pricing charges. It is understood that the current electricity price structure is not indicative of the future. However, for the purposes of the analysis, this assumption was made. A model was created to determine when to dispatch and charge the battery to minimize electricity cost. Figure 6 shows the three periods of demand and price change for the region chosen overlaid with the EV demand. The light blue is the original demand, and the dark blue shows how that is lowered when the battery is used. Note in the furthest left quadrant the increased demand when the battery is charging during the time of lowest cost.

Figure 6. Demand change with the use of battery storage.

The component costs that undelay the cartoon shown in figure one were modeled using a bottom-up model with the end result establishing the minimum sustainable price (MSP) that energy could be sold from the system. The MSP was calculated using a discounted cash-flow rate of return methodology. MSP is the price for which something can be sold and pay back all the investment and cost within the analysis period. The model was designed to be agnostic regarding technology and location to allow maximum sensitivity analysis. Assuming the six chargers from the EVSI-Pro modeling, three initial scenarios where run; the MSP was then used to calculate the lifetime costs of the systems. The three scenarios were: 1) meeting the demand without a battery, 2) meeting demand with a 5 MWh battery, and 3) assuming that the battery system achieved the \$100/kWh installed cost. With current component costs, there is only a small lifetime savings if a battery is used to offset peak demand and electricity cost. But when the battery system achieves the installed target cost, a ~40% lifetime savings would be achieved.

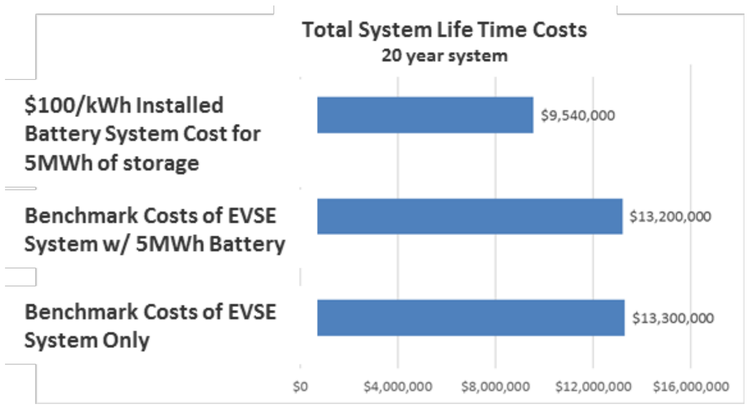

Figure 7. Total lifetime time cost estimates based upon 20 year life, relative to demand current demand charges and current battery cost vs $100KWh targets.

Conclusions

The equipment costs, energy load, and energy rate data have been collected. The models have been constructed to allow initial scenarios and to provide insight into the impact of research accomplishments and goals. We are able to model:

- Multiple charging demand scenarios
- Multiple rate structures
- Multiple EVSEs
- Varying battery sizes
- Varying performance
  - Depth of charge
  - Round-trip efficiency

The next steps are to:

1) Improve the model details, specifically increasing the component resolution.
   - Continue updating the model with team feedback.
2) Perform multivariate sensitivity analysis.
3) Begin geographically disaggregated modeling and visualization.

References

1 *Behind-the-Meter Battery Energy Storage: A Survey of US Demand Charges,* No. NREL/BR-6A20-68963. National Renewable Energy Laboratory (NREL), Golden, CO (USA) 2017.

2 https://openei.org/apps/USURDB/

3 Wood, E.; Raghavan, S.; Rames, C.; Eichman, J.; Melaina. M. (2017). Regional Charging Infrastructure for Plug-In Electric Vehicles: A Case Study of Massachusetts. NREL/TP-5400-67436. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy17osti/67436.pdf

BTMS Testing Section

Background

Cell testing is an important part of understanding the performance and life capabilities of state-of-the art energy-storage technologies, particularly with respect to the distinct technical and functional requirements posed by the BTMS program. Test procedures must be created to test energy-storage components and systems against these requirements. System-usage scenarios are concurrently being developed with testing of baseline cells intended to illustrate their capabilities relative to a broad set of initial system assumptions. The results from these early performance tests and aging procedures, although only loosely framed by a baseline 1 MWh BTMS system supporting six 350-kW DC fast charging units, will produce both slow and accelerated cycle-life aging information through a mix of empirical observations and modeling.

Results

Three parameters—temperature, rate, and state-of-charge window—were varied to accelerate aging and support modeling to estimate cycle-life capabilities, as shown in Figure 8. Calendar aging at 55°C was also added as an accelerated calendar-aging condition, compared to the expected system operating conditions closer to room temperature.

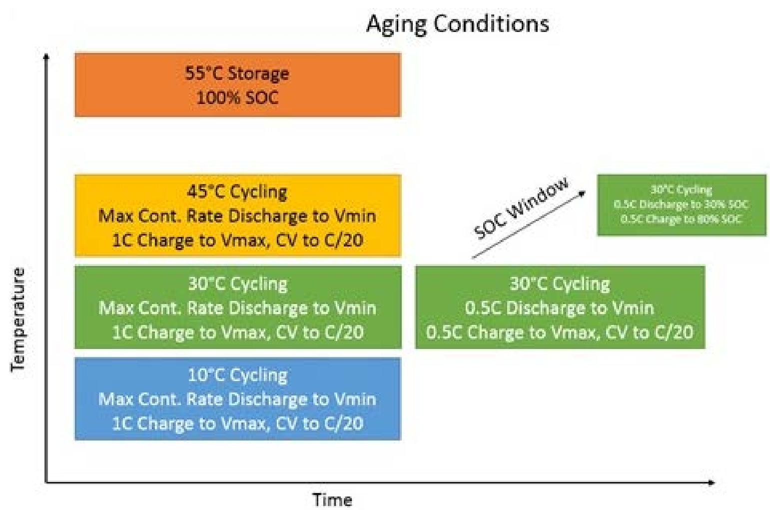

Figure 8. Test matrix for cells under baseline scenario.

The 2-hour discharge capacity and pulse-power capability of each cell will be measured monthly in a reference performance test. Every third performance test will include a set of 20-h charge and discharge cycles that can be analyzed to understand differences in aging mechanisms among test conditions, in addition to the characterization of performance loss through time and cycling.

Performance and life testing has commenced in Q2 for three baseline lithium-ion chemistries at INL and SNL. NMC-LTO cells from XALT Energy, NMC-graphite cells from LG Chem, and LFP-graphite cells from K2 Energy were put into testing using the methodology described. Figure 9 shows a test setup within a thermal chamber. These large cells are resource-intensive to test, so resource sharing was carefully planned for available tester channels and chambers.

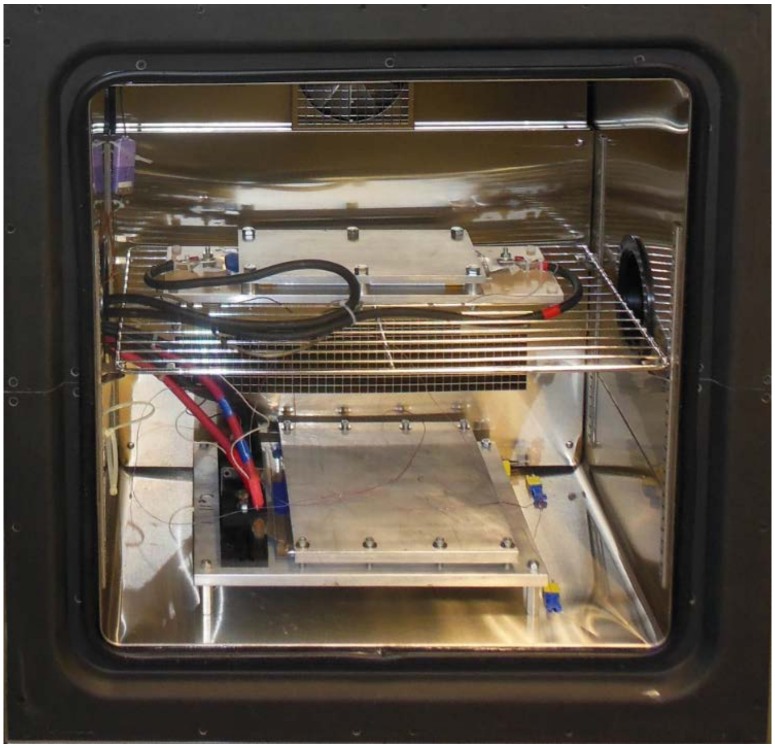

Figure 9. LG Chem cell (top) and XALT cell (bottom) sharing 45 °C test chamber.

With these few baseline chemistries testing under an early baseline scenario, most data analysis will be forthcoming. The beginning-of-life performance characterization tests yield some early information on cell-only volumetric energy density. This information is not useful by itself because the balance-of-plant of an energy-storage system will certainly be substantial. This does, however, allow us to picture the relative footprint impact among systems of widely varying energy density, as shown in Figure 10.

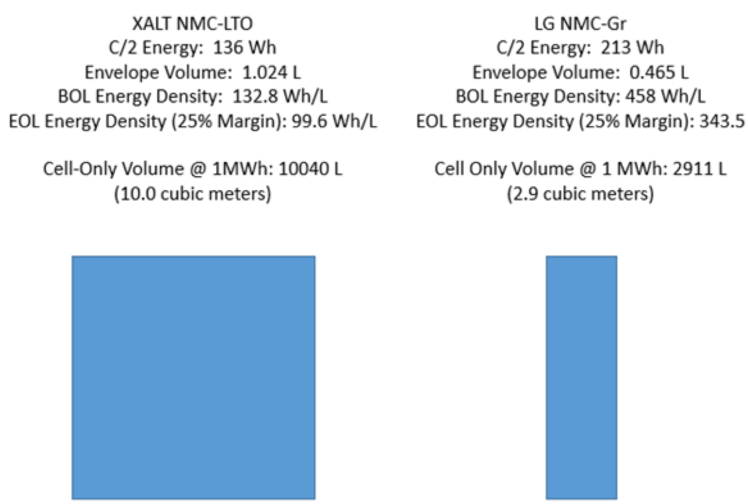

Figure 10. Comparison of energy density of two cell technologies being tested.

Summary

Results from the testing discussed above will help to refine methods used for forthcoming testing of articles that are more closely aligned with BTMS goals—particularly the critical-materials-free mandate. As system modeling progresses, a clearer set of goals will be established, and test procedures will be developed to emulate the operation of such a system. These procedures, alongside tests designed to yield accelerated aging, will provide data that allows prediction of a technology's ability to meet the long cycle-life and calendar-life goals of the program.