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Behind-the-Meter Storage Overview

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Project ID #bat442

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

- October 1st 2018 - September 30th 2025.
- Percent complete: 40%

Budget

- Funding for FY 21: $2400K

Barriers

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

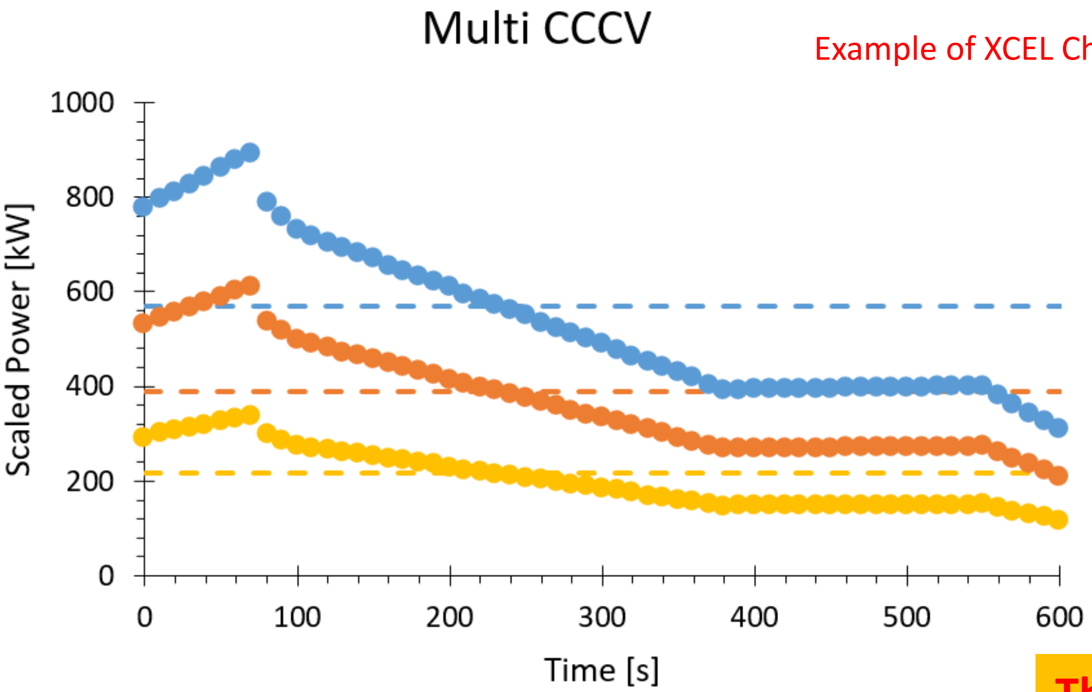
Partners

- A joint project between VTO, BTO, OE and SETO.
- Five Laboratory Team lead by NREL:
  - Sandia National Laboratory
  - Argonne National Laboratory
  - Idaho National Laboratory
  - Pacific Northwest National Laboratory

BTMS: Milestones VTO

- Define critical parameters for enabling an advanced rack and battery management system design incorporating new sensors, controls, electronics, and thermal control strategies for BTMS storage chemistries. **Q1 Complete**
- Report on the degradation of cells under two cycling regimes and delineate the aging effects induced by the two protocols. **Q2 Complete**
- NREL will use the EnStore Model to evaluate the economic feasibility of BTMS with cobalt-free battery chemistries using testing data from BTMS chemistries at a representative fulfilment center for package deliveries using medium-duty vehicles. Q3
- Have critical-material-free pouch cells (2 Ah) prepared and on test using BTMS protocols. Q4

NEED: Fast charging is a goal for VTO target (aggressive) ~ 200 miles in 10 minutes



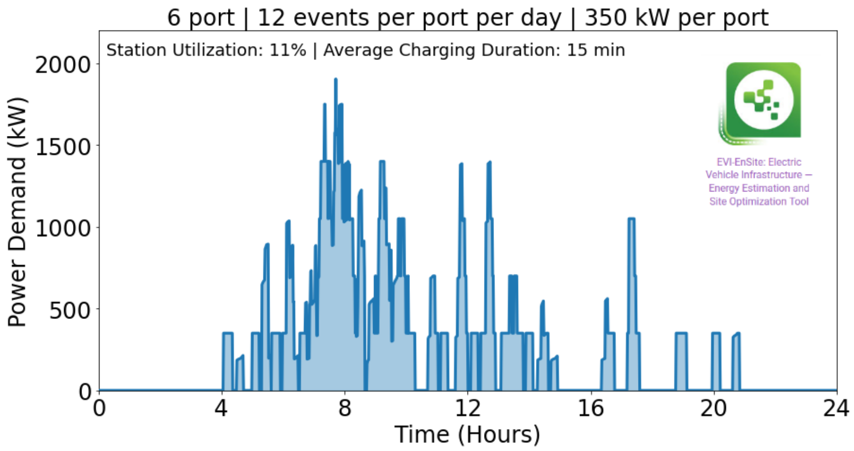
Example of XCEL Changing profile.

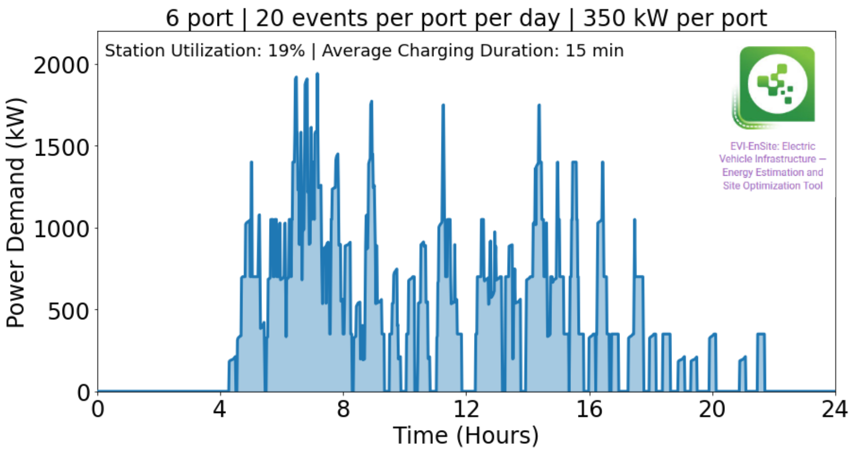
These charging levels will have impacts on the grid and demand charges may result.

EV Profile Example: charging station without demand control

Example day

Six-port station with **350 kW** per port and **12** charging events per port per day; peak power demand of ~**2 MW**





Charging profile depends on station size, events per day, charging power level, charge per vehicle, vehicle arrival, building type, charge demand management allowed

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

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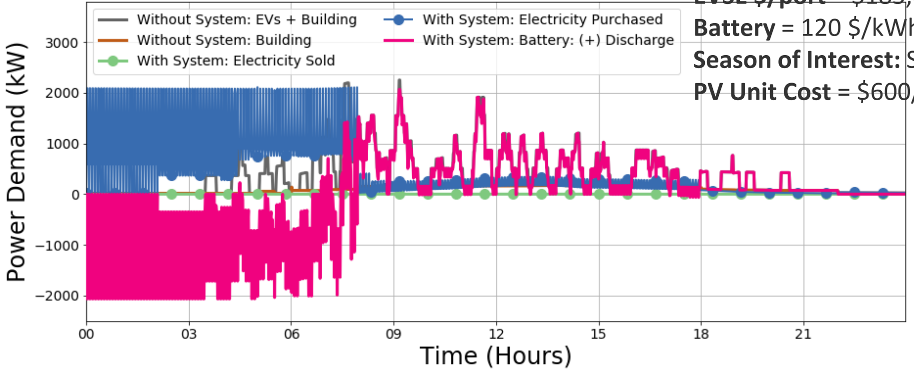
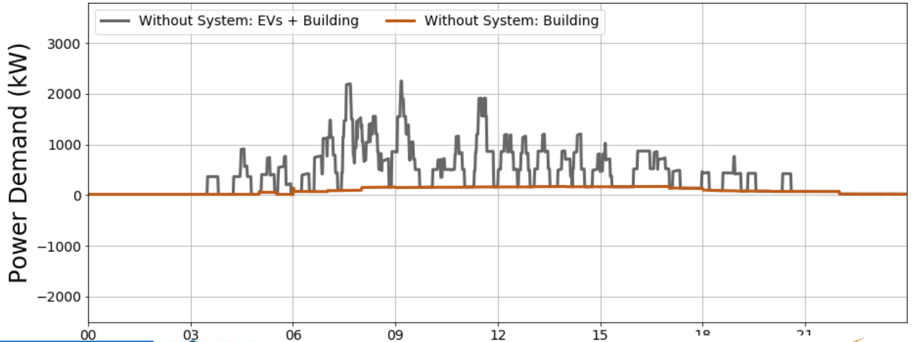
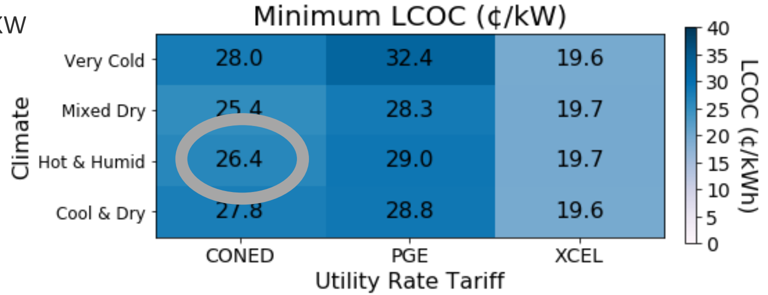
BTMS: **THE PROBLEM – fast charging gas station**

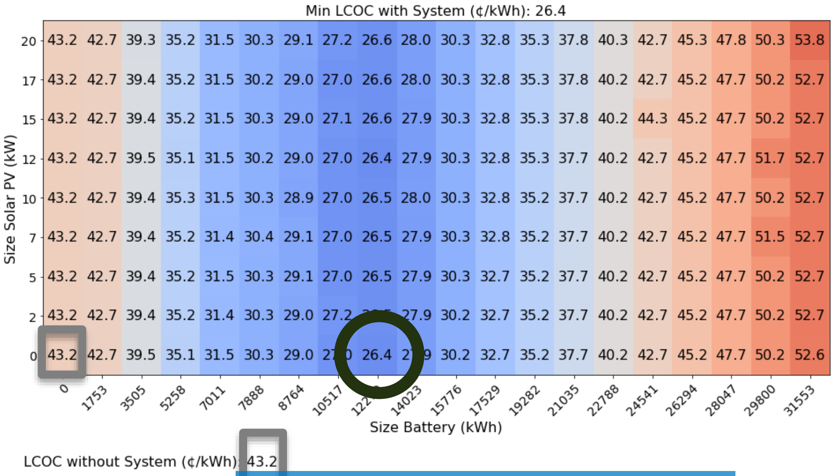
Utility Rate: CONED: HIGH DEMAND CHARGES
Location: TAMPA: HOT & HUMID

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









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BTMS: Basic Premise

What do we need?

- Battery systems designed for the task:
  - Cost - upfront vs total cost
  - Performance
  - Lifetime
  - Safety

Cells capable of
20 year lifetimes
Cycle life greater than 8,000
Cell cost of < $100 KWh
Volume mined minerals only

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Ongoing and Upcoming BTMS Cell Testing – began in FY20

- **NMC622/Graphite*** cells were cycled to EOL using 2-hr constant-current rates
  - Lifetime energy throughput was extended by 33% using a shallow, mid-50% SOC window
- **NMC/LTO*** cells were cycled to ~13000 cycles with less than 2% capacity fade measured at the 2-hr rate, across various rate conditions
- **LMO/LTO** cells are on test as a benchmark and to evaluate the cycle life test developed, along with an extended test matrix to support ML activities.
- **Ni-Zn** cells on test using the BTMS cycle life protocol.
- **Pb Acid** systems under evaluation.
- **Graphite/LFP** multiple cells being evaluated.

Ongoing effort to identify energy storage options research that would enable BTMS.

*baseline used to assess state of the art

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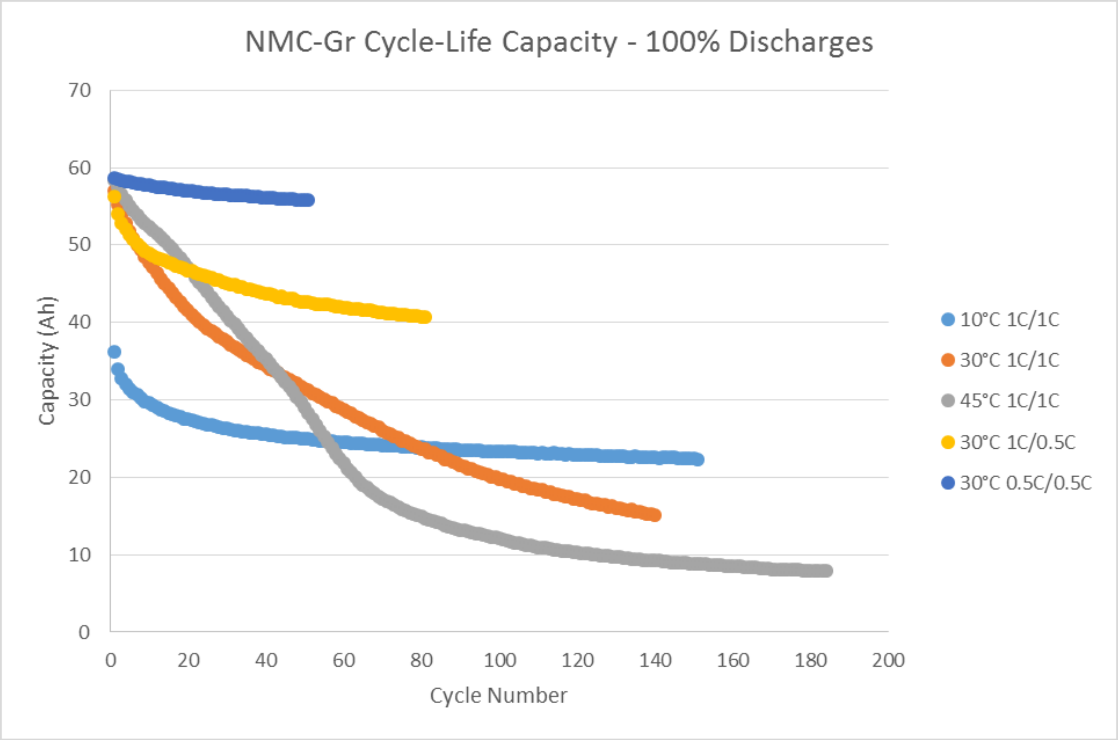
Battery chemistries developed for vehicle may not lead to the best outcome



Even in high quality cells variation in power requirements have impact on cell lifetime performance.

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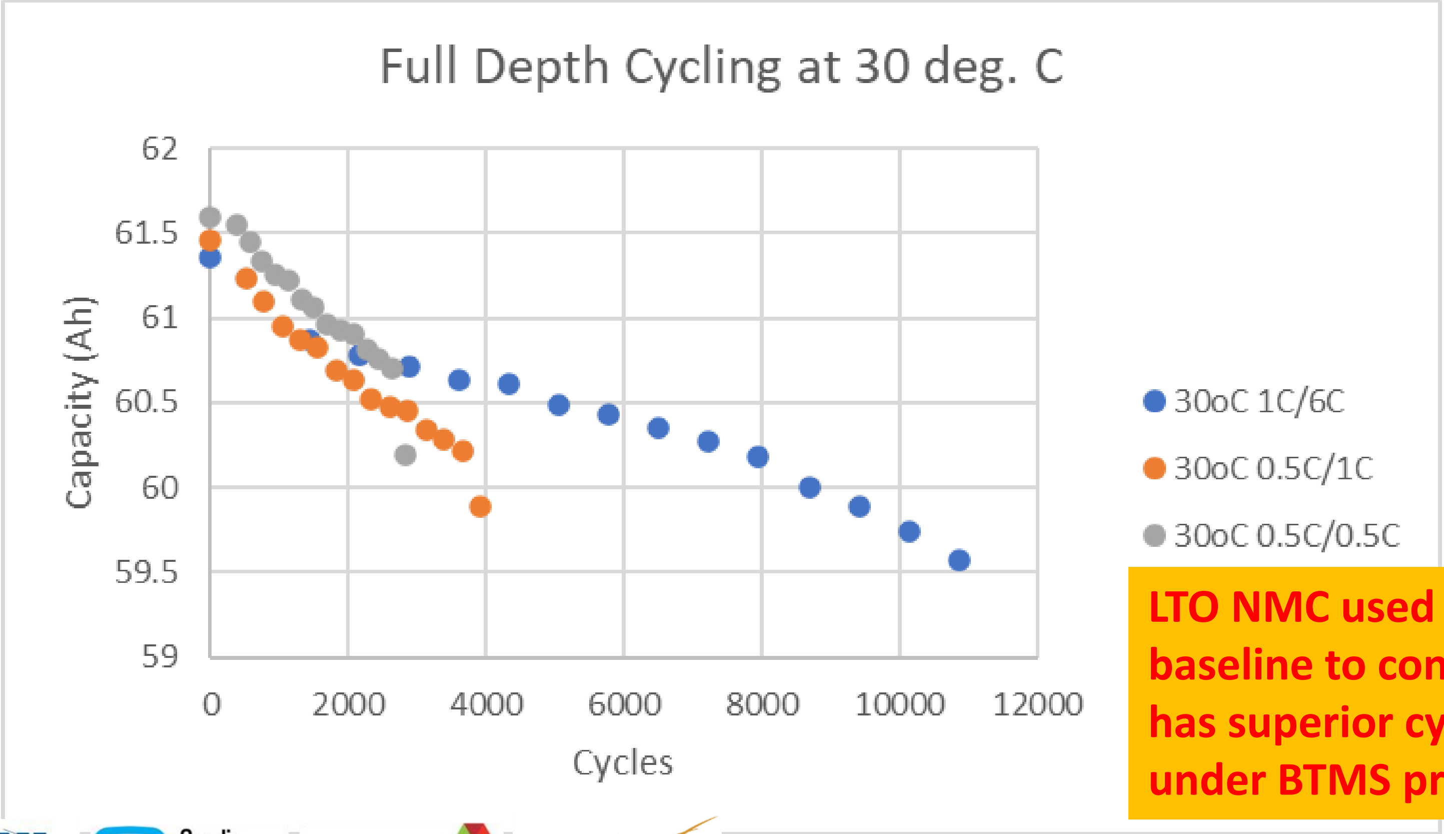
Possible solution to long cycle life under BTMS protocols: LTO anodes



LTO NMC used as baseline to confirm LTO has superior cycle life under BTMS protocols.

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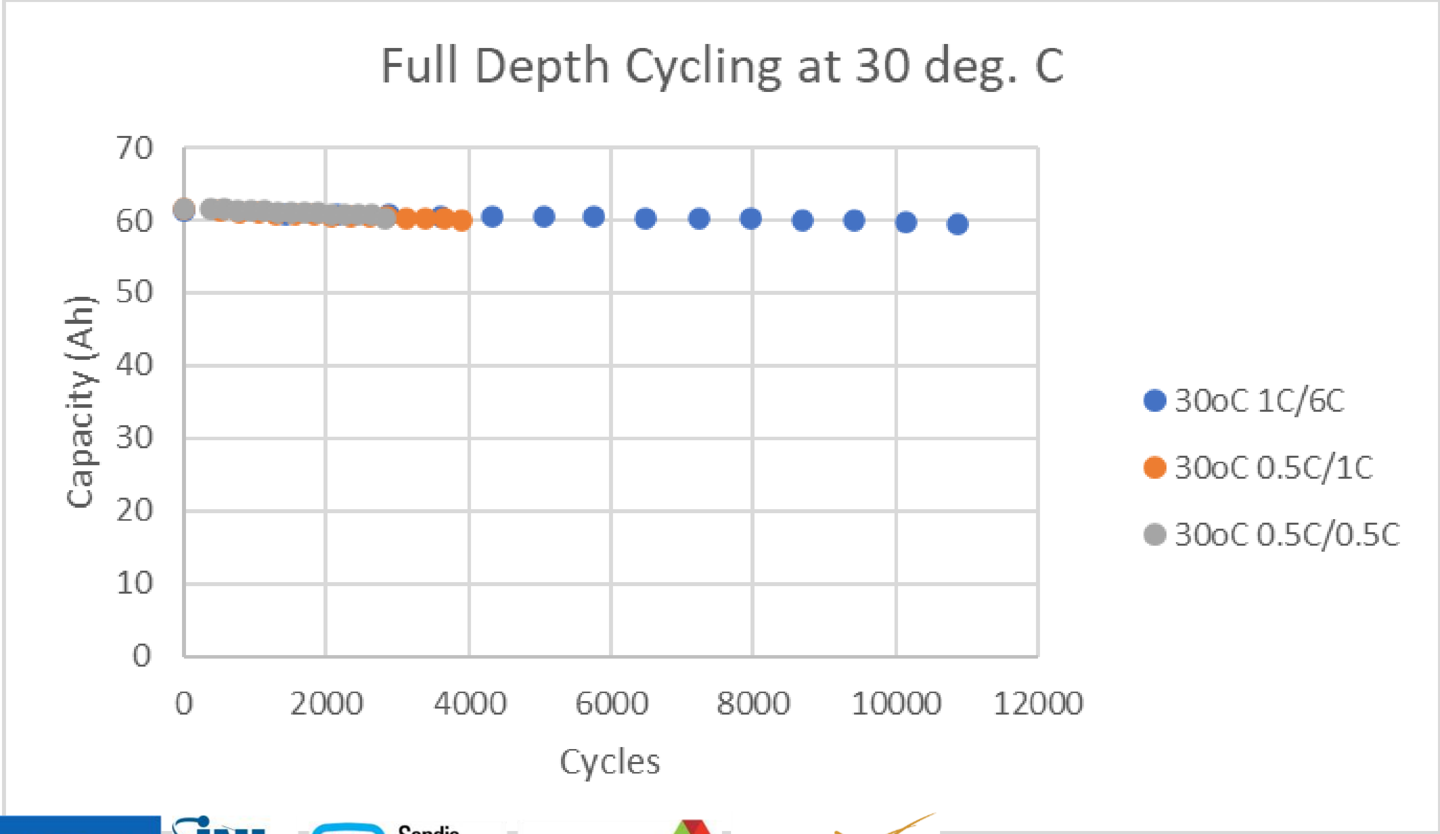
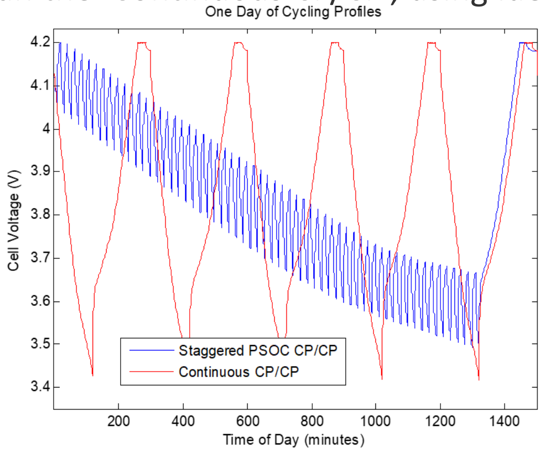
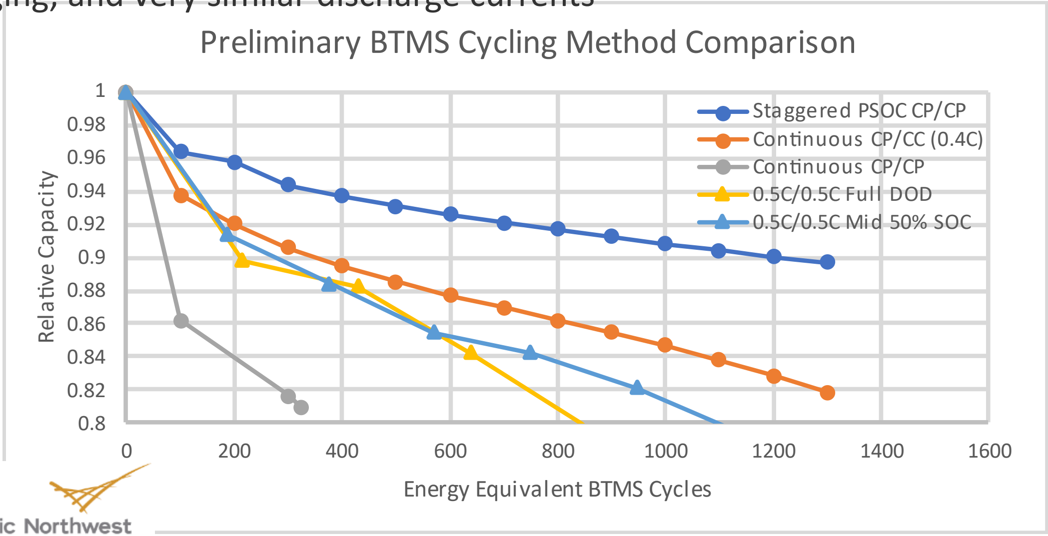


LTO NMC used as baseline to confirm LTO has superior cycle life under BTMS protocols. (future work – determine the cobalt options that meet the BTMS targets)

BTMS Cycling Protocol Evaluation with Surrogate Cells

- The effects of Continuous Discharge vs Staggered Discharge/Recharge were investigated by cycling cells and comparing to previous years' CC cycling on the same cell type. To accelerate data, this cycle had a faster recharge rate than the BTMS 24/12 routines
- **The 'Continuous CP/CP' cycle degraded the most quickly, the Staggered PSOC CP/CP degraded the least quickly.** Each cell design and chemistry will have different sensitivities to these differences in cycling, but this illustrates the need for both 'bookend' cycling routines.
- An Additional case of CP charging and CC discharging was added, and that case, 'Continuous CP/CC' fared much better than the 'Continuous CP/CP', using identical charging, and very similar discharge currents



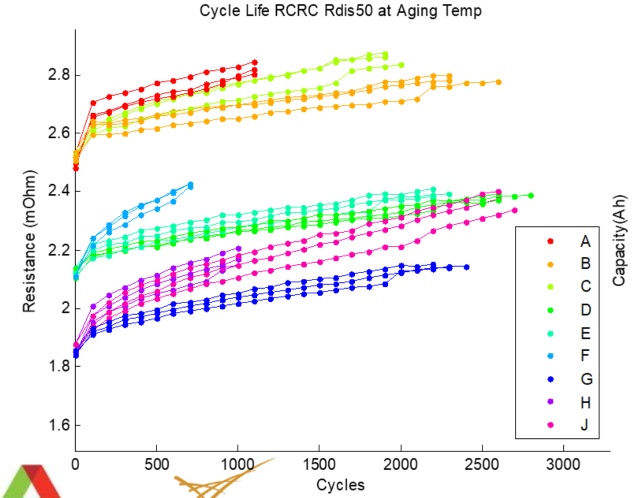


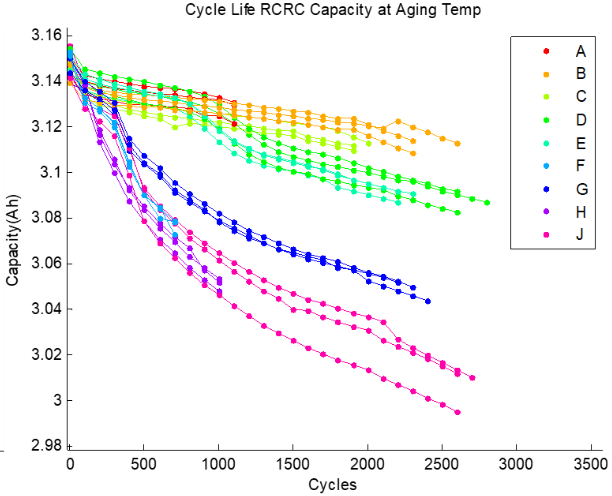
Accelerated Life prediction: LMO/LTO Testing for ML and Life Prediction

- First three 30-day periods of calendar life testing and associated reference performance tests completed
  - Automatically updated database created and is actively warehousing a rapidly growing dataset
- Data shared with NREL ML team, to advance life prediction models for BTMS
- This dataset and ML-focused analysis is planned to serve as a platform for the advanced sensing & control rack design task in FY22
- LMO and LTO half cell builds from harvested electrode completed, and cycling has commenced, including GITT tests
  - These data will yield the correct cell profile for more precise incremental capacity analysis to join ML analysis to degradation mechanisms

Group	Temperature	Aging Type	C-rate	Vmax,cycle	Dischg End	Cell Numbers		
A	30	Cycle	1	V80	1.74 Ah	35	37	43
B	30	Cycle	10	V90	2.03 Ah	73	46	60
C	30	Cycle	5	Vmax	Vmin	11	12	48
D	40	Cycle	10	V80	1.74 Ah	58	39	10
E	40	Cycle	5	V90	2.03 Ah	44	71	52
F	40	Cycle	1	Vmax	Vmin	36	74	89
G	50	Cycle	5	V80	1.74 Ah	87	86	38
H	50	Cycle	1	V90	2.03 Ah	29	72	7
J	50	Cycle	10	Vmax	Vmin	81	30	51

Group	Temperature	Aging Type	Aging V	Cell Numbers		
K	30	Calendar	V90	78	28	66
L	30	Calendar	V80	41	65	5
M	30	Calendar	V20	45	1	69
N	40	Calendar	V90	77	49	21
P	40	Calendar	V80	19	33	88
Q	50	Calendar	Vmax	3	34	20
R	50	Calendar	V90	83	16	23





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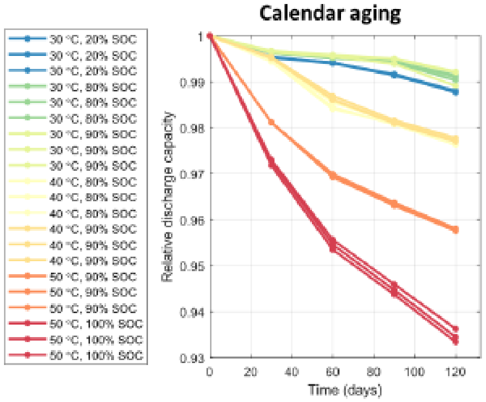
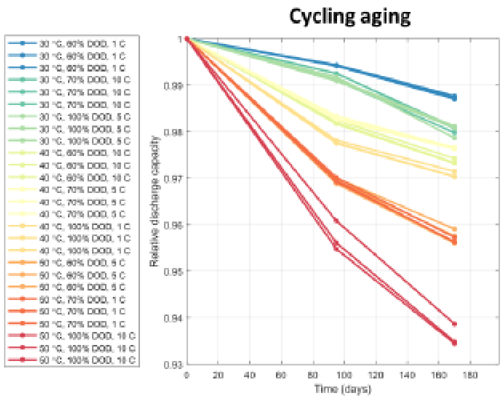
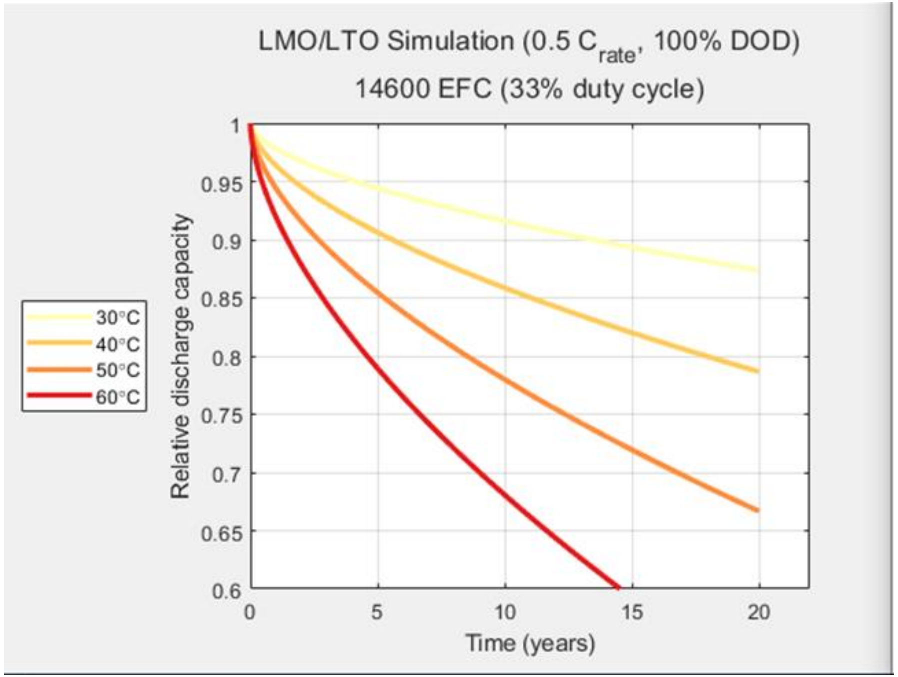
Preliminary Predictions for LTO/LMO

Initial projections from the ML/AI project indicate that LTO based cells, specifically LTO-LMO can meet the BTMS lifetime and cycle targets.







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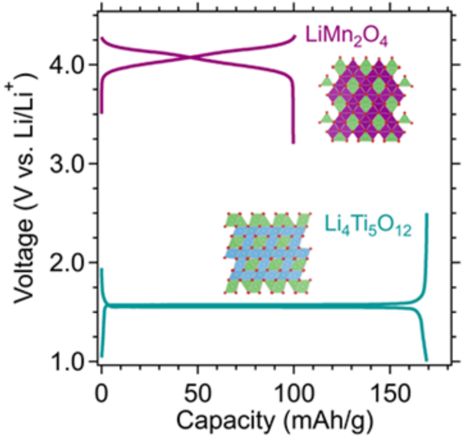
Development of LMO//LTO Chemistry for BTMS application

Key Requirements for BTMS Batteries

- Non-critical materials
- Long lifetime
- Safety

→ LTO/LMO Chemistry



Approach

- Coin cell cycling at 45°C
- dQ/dV analysis
- Postmortem characterizations (SEM, XPS, TOF-SIMS)

Experimental Details

- LTO and LMO electrodes provided by CAMP (N/P~1.2)
- Electrolyte: 1 M $LiPF_6$ in EC or PC
- Coin cells fabricated with GF/F separator
- Echem protocol:
  C/10(x2)→1C(x1000)→C/10(x2)
  Same charge/discharge rates
  1.5 – 3.0 V cutoffs

LMO//LTO

↓ *Energy Cell*

Thicker Electrode

↓

Higher Operating Temp. *45 °C*

↓

New Electrolyte *EC vs. PC Vs ??*

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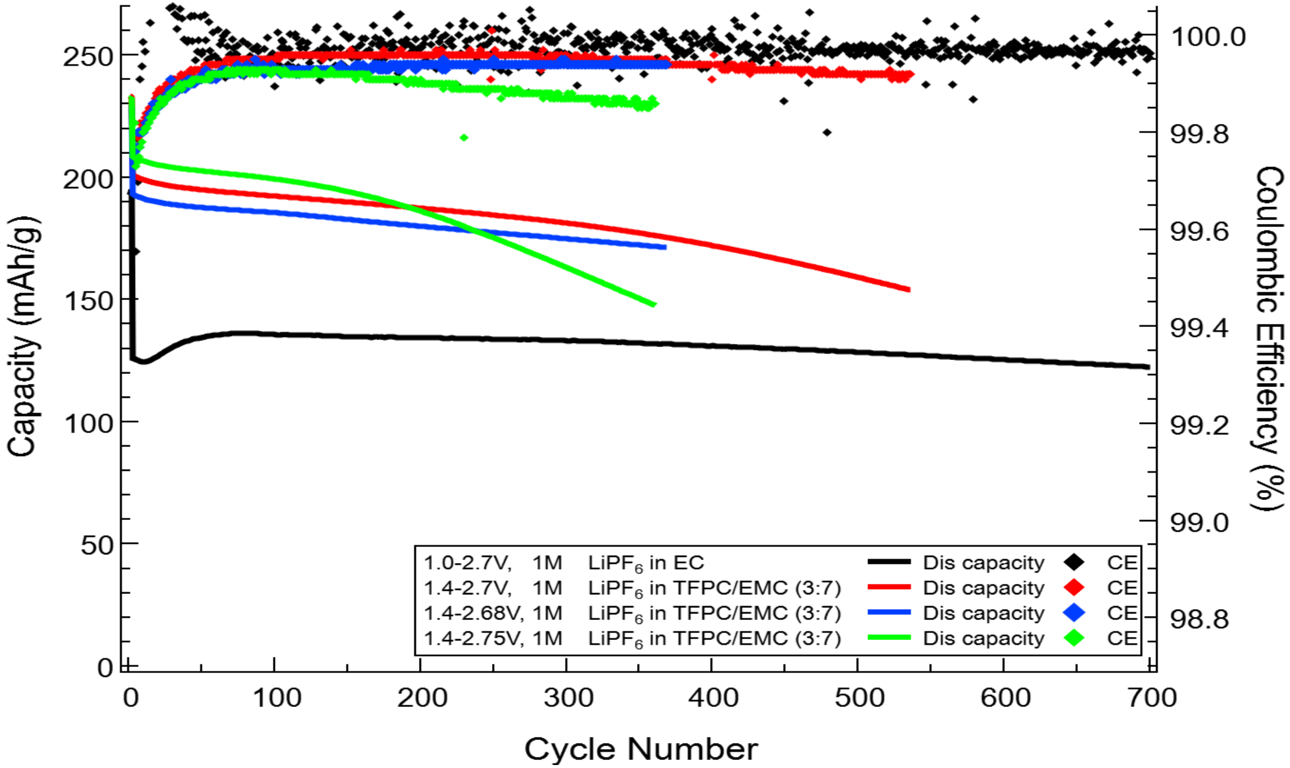
Higher Energy Cathodes like no-Co $Ni_{0.9}Mn_{0.1}$ chemistries show promise



LTO Ni9Mn1 using the initial BTMS survey conditions identified cycling stability for the cell but with high polarization (black). Alternative electrolyte systems show promise (blue and Red) under the BTMS survey protocols.

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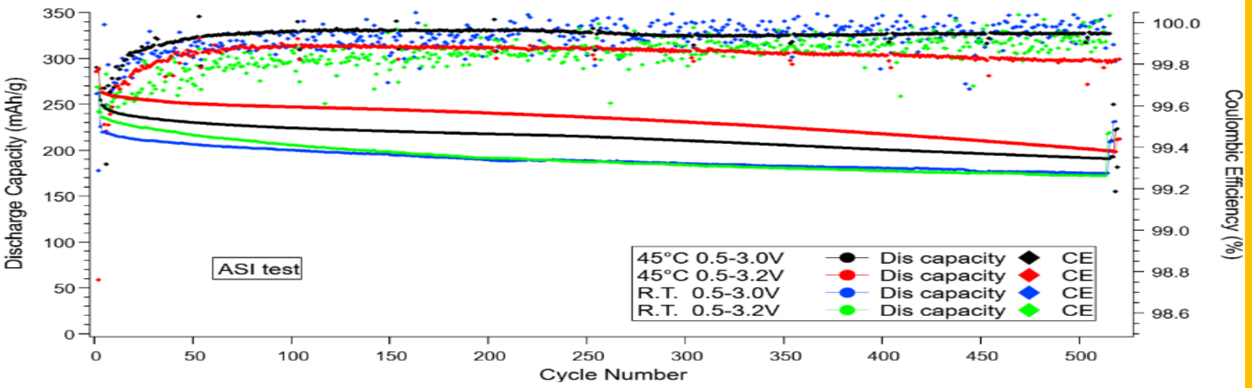
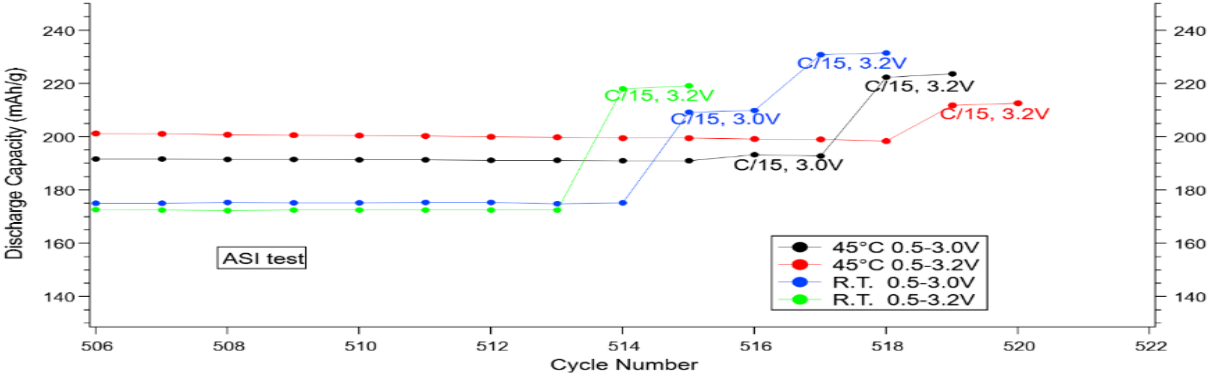
LMR-NM Materials also show promise – Higher capacity cathodes





Higher energy cathodes will enable lower system costs. Fewer cells = less balance of plant. However, lifetimes must still make targets. (future work – determine the electrolyte options that enable BTMS targets based upon the BTMS testing protocols).

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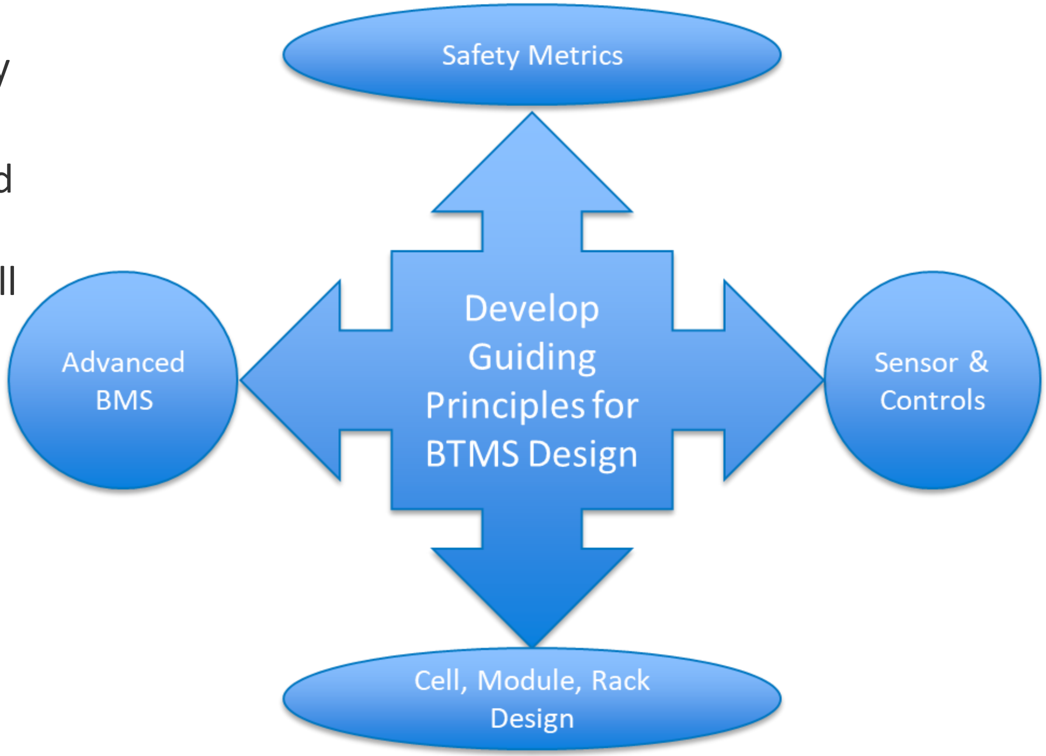
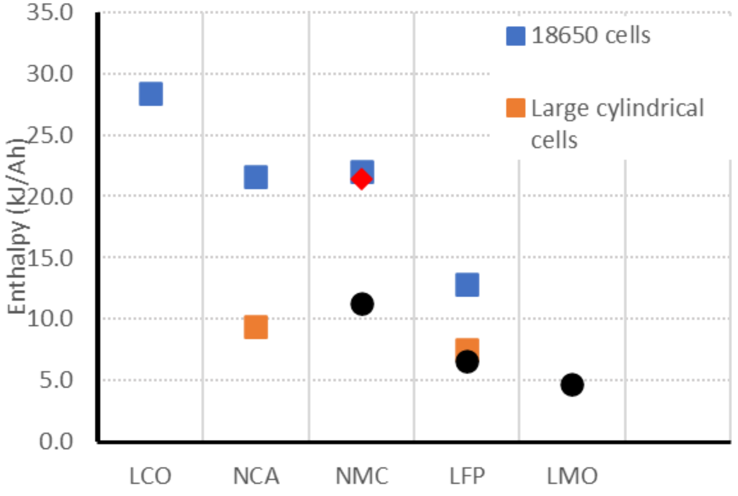
Enabling Technologies for Advanced Rack Design

- Need to address the hazards associated with lithium-ion batteries used in stationary applications for BTMS to become a reality.
- BTMS program is assuming that existing and future quality control measures at battery manufacturing facilities will not eliminate all single cell thermal runaway events.
- We are developing a strategy to enable a fail-safe rack design over a three-year period. “Fail-safe” is defined as preventing cell to cell propagation in a best-case scenario and preventing rack to rack propagation in a worst-case scenario.



Safety - Thermal Runaway Characteristics

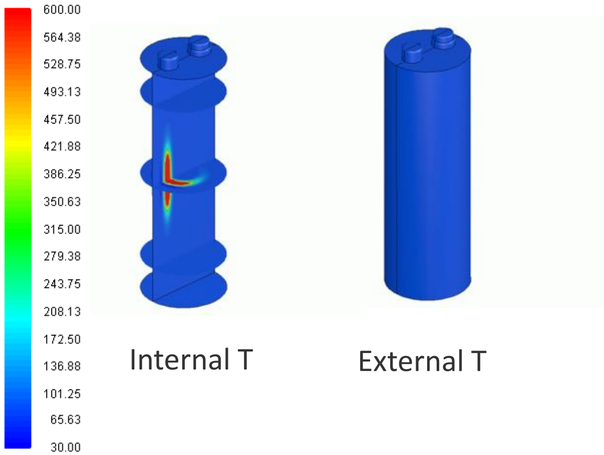
Target would be no rack-to-rack propagation of thermal runaway. No cell to cell would be perfection, but we need to assess cost implications.



- Thermal runaway (TR) heat produced by both short circuits and decomposition reactions
- Key parameters and chemistries
  - Onset temperature
  - Self-heating rate
  - Thermal runaway enthalpy
- Abuse tolerance response of a cell mainly determined by cell energy density.

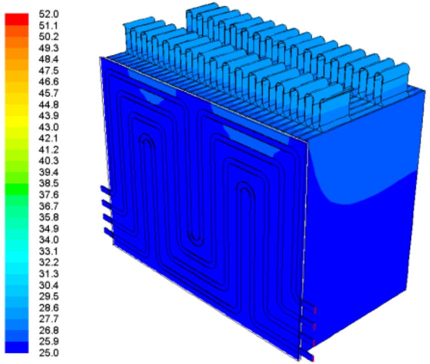
1. Daniel D. Vehicle battery safety roadmap guidance. United States: N. p., 2012. Web. https://doi.org/10.2172/1055366.
2. Christopher Orendorff, Joshua. Lamb, Leigh. Anna. Steele, Scott. W. Spangler, Jill. Langendorf. Quantification of Lithium-ion cell thermal runaway energetics. SANDIA REPORT, SAND2016-0486, January 2016.
3. Boxia L; Wenjiao Z; Carlos Z; Nils U; Magnus R; Hans S. Experimental analysis of thermal runaway in 18650 cylindrical Li-ion cells using an accelerating rate calorimeter. Batteries 2017; 3(2):14. https://doi.org/10.3390/batteries3020014
4. William W, John D, Donal F, Gary B, Kenneth J, Eric D, Steven R. Decoupling of heat generated from ejected and non-ejected contents of 18650-format lithium-ion cells using statistical methods. Journal of Power Sources 2019; 415:207-218. https://doi.org/10.1016/j.jpowsour.2018.10.099.

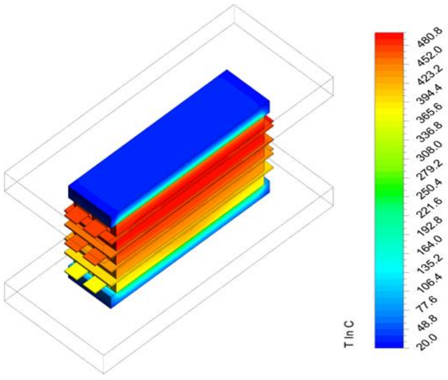
Safety – Need to understand LTO thermal issues



Internal T

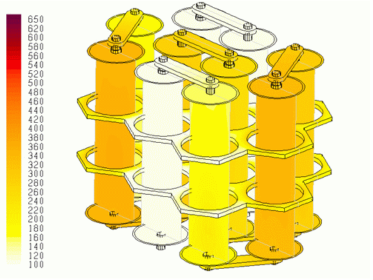
External T





Thermal management design

Our current thermal analysis modeling suite will help us assess the thermal design space, but we need to update the models using BTMS chemistries. (future work – collect the thermal characteristics for the new chemistries)



Thermal runaway propagation

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Multi-level Fail-Safe Design – Next FY

Fail-safe design

Safety: Thermal runaway Hazard

BMS: modular rack design

Sensors/controls : early detection

Cell and Module Thermal Management

- Cell size
- Form factor
- Chemistry
- Energy efficiencies
- Thermal runaway enthalpy
- Onset temperature
- Rates
- Electrical configuration
- Thermal control strategy
- Cooling techniques
- Thermal management materials

Fail-safe design +

The team will assess "all" options for a fail-safe design and generate a cos-advantage determination.

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Conclusions

- Fast charging will require a “gas station” approach to EV charging.
- The cost of charging may be excessive if demand charges are not mitigated.
- The utility costs dominate changing station costs.
- Onsite BTMS can reduce costs.
- Standard EV cells are not optimized for stational storage.
- LTO based anode systems have the possibility to meet all the targets.
- Safety consideration need to be addressed from the cell chemistry through to the rack/system design.
- Reducing the costs of the BTMS is a major priority.

Proposed Future work

- Full cell evaluations at >2 Ah in different cell geometry's (hard casing, cylindrical and pouch cells) assessment.
- Assessment of no-cobalt cathode chemistries from the Low-cobalt VTO project.
- Electrolyte development for higher energy density chemistries (LMNO, LMR-NM etc).
- Cell design (size and format) to be finalized for system design.
- Cell energy assessment for cost vs safety for LTO chemistry.
- Power electronics design for rack options.
- Competition of design for cost/safety/lifetime targets.

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