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Battery Thermal Characterization

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RELEVANCE

Life, cost, performance, and safety of energy storage systems are strongly impacted by temperature.

OBJECTIVES

- To thermally characterize cell and battery hardware and provide technical assistance and modeling support to DOE/U.S. DRIVE, USABC, and battery developers for improved designs
- Identify how changes to the battery chemistry and cell design affect the cells' efficiency and performance
- To quantify the impacts of temperature and duty cycle on energy storage system life and cost
- Work with the cell manufacturers to identify new thermal management strategies that are cost effective.

SUMMARY

- NREL collaborated with U.S. DRIVE and USABC battery developers to obtain thermal properties of their batteries.
- We obtained heat capacity and heat generation of cells under various power profiles.
- We obtained thermal images of the cells under various drive cycles.
- We used the measured results to validate our thermal models.
- The data has been shared with the battery developers to improve their designs.
- We developed innovative thermal management strategies in partnership with the battery manufacturers.
- We identified additives and cell architecture that improved the high and low temperature performance of the cell.
- Thermal properties are used for the thermal analysis and design of improved battery thermal management systems to support and achieve life and performance targets.

APPROACH

Cells, Modules, and Packs

Tools
- Calorimeters
- Thermal imaging
- Electrical cyclers
- Environmental chambers
- Dynamometer
- Vehicle simulation
- Thermal analysis tools

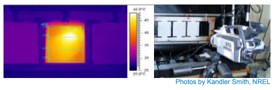
Test Profiles
- Normal operation
- Aggressive operation
- Driving cycles
  - US06
  - UDDS
  - HWFET
- Discharge/charge rates
  - Constant current (CC)
  - Geometric charge/discharge
  - U.S. DRIVE profiles

Measurements
- Heat capacity
- Heat generation
- Efficiency
- Thermal performance
  - Spatial temperature distribution
  - Cell-to-cell temperature imbalance
  - Cooling system effectiveness

NREL provides critical thermal data to the battery manufacturers and OEMs that can be used to improve the design of the cell, module, and pack and their respective thermal management strategies.

Cell-Level Testing

Thermal Imaging
- Temperature variation across cell
- Profiles: US06 cycles, CC discharge/charge
- Unique testing method reducing environmental impacts



Photos by Kandler Smith, NREL

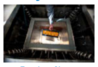
Thermal Management Performance

- Temperature variation across pack under realistic conditions
- Assessing vapor compression, air, and liquid cooling systems
- Profiles: US06 cycles, CC discharge/charge

Photo by Kandler Smith, NREL

Heat Generation and Efficiency

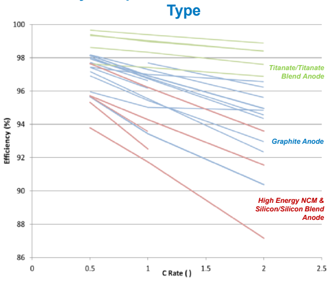
Using state-of-the-art isothermal battery calorimeters
- Heat generation, heat capacity, and efficiency
- Test Temperature Range: -35°C to +90°C
- Profiles: USABC and US06 cycles, Discharge/Regen CC



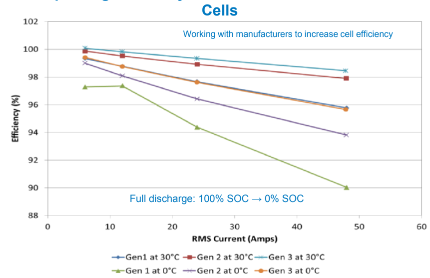
Top view of large calorimeter test chamber
Photo by Dennis Schroeder, NREL

Cell Thermal Studies

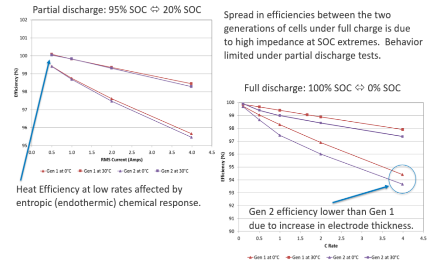
Efficiency Comparison as a Function of Anode Type



Improving Efficiency of Successive Generations of Cells

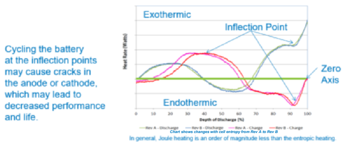


Efficiency Varies as a Function of State-of-Charge (SOC)

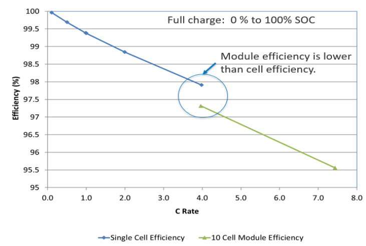


Calorimetry Testing Can Identify Entropic Heating/Cooling

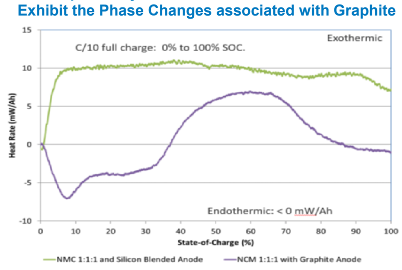
Heat in a cell is produced by:
- The resistance of the various cell components (electrode, cathode, anode, etc.); this is known as Joule heating, which can be minimized by cycling the cells at low currents
- Entropic reactions within the cell—exothermic and endothermic reactions within the cell due to the transfer of ions and electrons.



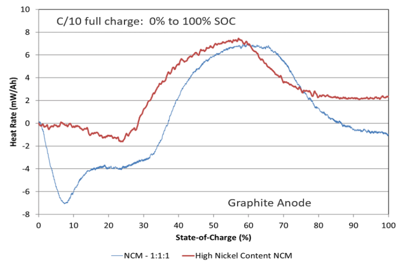
Interconnects Affect Efficiencies of Modules



Entropic Study – Silicon Blended Anodes do not Exhibit the Phase Changes associated with Graphite

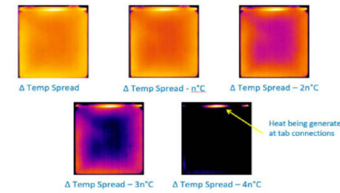


Entropic Signature Varies for Different Cathodes



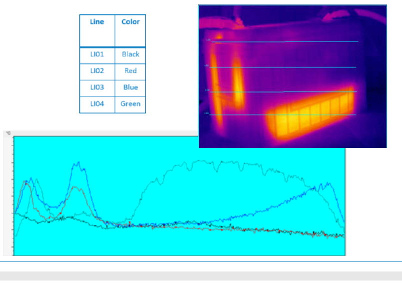
Infrared Imaging Studies

Infrared Imaging of Cell Connections



Infrared (IR) imaging pinpoints where the heat is being generated in the cell.

Infrared Imaging of Battery Module

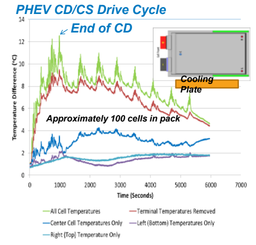


Pack Thermal Temperature Studies

Photos by Dirk Long, NREL

Measured temperature rise, temperature uniformity, and parasitic losses versus temperature and duty cycle, extrapolating calendar life for different scenarios with and without active cooling

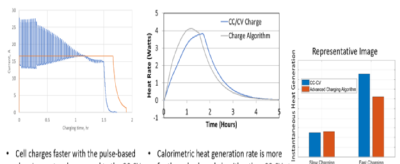
Thermal Management System Performance
PHEV CD/CS Drive Cycle



CD = charge depleting; CS = charge sustaining

- *The recent U.S. DRIVE RFPI limits cell-to-cell temperature in a PHEV pack to less than 3°C; in this pack, cell-to-cell temperature spread is greater than 12°C.*
- *If not properly designed, thermal management systems can cause a large cell-to-cell temperature spread; these temperature differences affect the cycle life of each cell, potentially resulting in warranty issues.*

Advanced Algorithms Decrease Charge Time



- Cell charges faster with the pulse-based charging protocol compared to the CC-CV
- CC-CV takes 114 mins to charge here compared to 104 for the pulse-based protocol (**8% faster to charge**)
- Calorimetric heat generation rate is more for the pulse-based algorithm than CC-CV at low C-rates
- At higher average C-rates, pulse charging will result in less temperature rise compared to CC-CV

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