Battery Extreme Fast Charge: A Thermal Prospective

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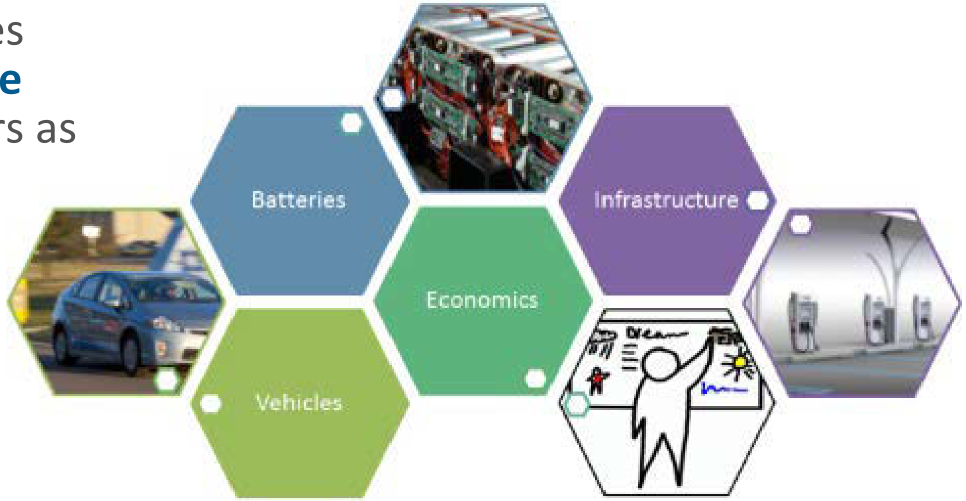
Extreme Fast Charge (XFC) Potential Impact

Impact:

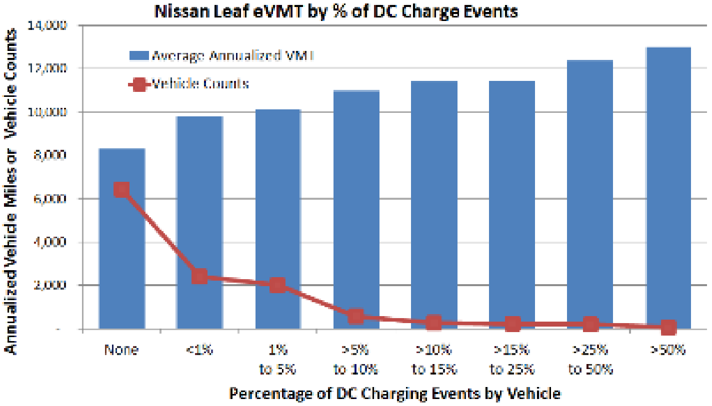
- **Fast charge** can help promote market penetration by **improving** the utility or electric vehicle miles traveled (**eVMT**) of battery electric vehicles (BEVs), thus **alleviating** the **"range anxiety"** often cited by consumers as a barrier to adopting electric technology.



Why XFC

Direct Current Fast Charge (DCFC) Increases BEV Utility

- Yearly **eVMT increases with** the use of 50 kilowatt (kW) **fast charging**
- Nearly **25% more miles** are driven annually **when DCFC is used** for 1%–5% of total charging events.



	Level 1 (110 V, 1.4 kW)	Level 2 (220 V, 7.2 kW)	DC Fast Charger (480 V, 50 kW)	Tesla SuperCharger (480 V, 140 kW)	XFC (1,000 V, 400 kW)
Range Per Minute of Charge (miles)	0.082	0.42	2.92	8.17	23.3
Time to Charge for 200 Miles (min)	2,143	417	60	21.4	7.5

- ## Electric Vehicle Supply Equipment (EVSE) Comparison
  - XFC should be able to **charge** a BEV in less than **10 minutes** and provide approximately **200 miles** of driving range during that charge time.

Source: McCarthy, Michael. "California ZEV Policy Update." SAE 2017 Government/Industry Meeting, Society of Automotive Engineers, 25 January 2017, Walter E. Washington Convention Center, Washington, DC. Conference Presentation.

Objective of NREL's XFC Battery Work

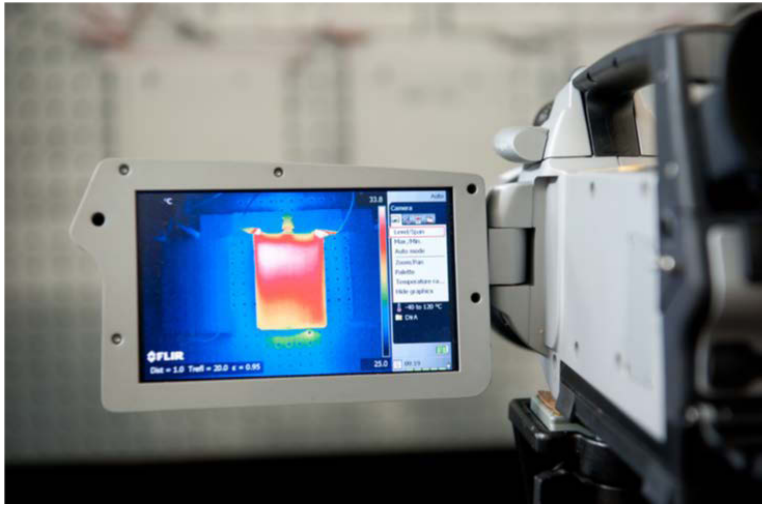
Life, cost, performance, and safety of energy storage systems are strongly impacted by ***temperature***

- Provide industry feedback on the battery thermal challenges associated with XFC
- Identify limitations of using high specific-energy density cells
- Identify state-of-the-art thermal management strategies and how these can be applied to future BEVs
- Identify thermal areas of concern with present battery systems
- Identify how changes to the battery chemistry and cell design affect the cells' **efficiency** and **performance**
- Understand what areas need to be developed to make XFC a reality.

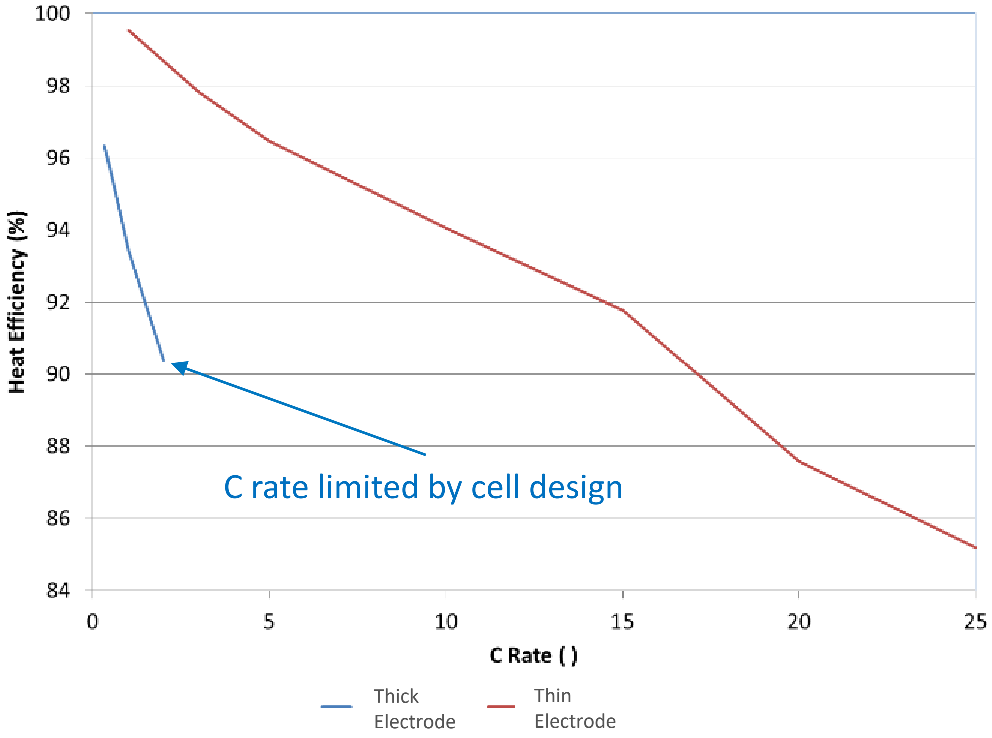
Cell Level Thermal Analysis

Sources of Heat Within Cell

- Lithium-ion batteries have very good coulombic efficiencies that are as high as 99.7%. The small drop in efficiency is often traced back to mismatched properties among the different battery components.
- The source of heat occurs in three areas:
  - Heat generation in the cell due to **Joule heating** is usually 50% of the heat budget of the cell
  - Heat generation from **electrode reactions** contributes 30% – 40% of the heat losses
  - **Entropic heat generation** contributes approximately 5% – 15% of the heat losses.



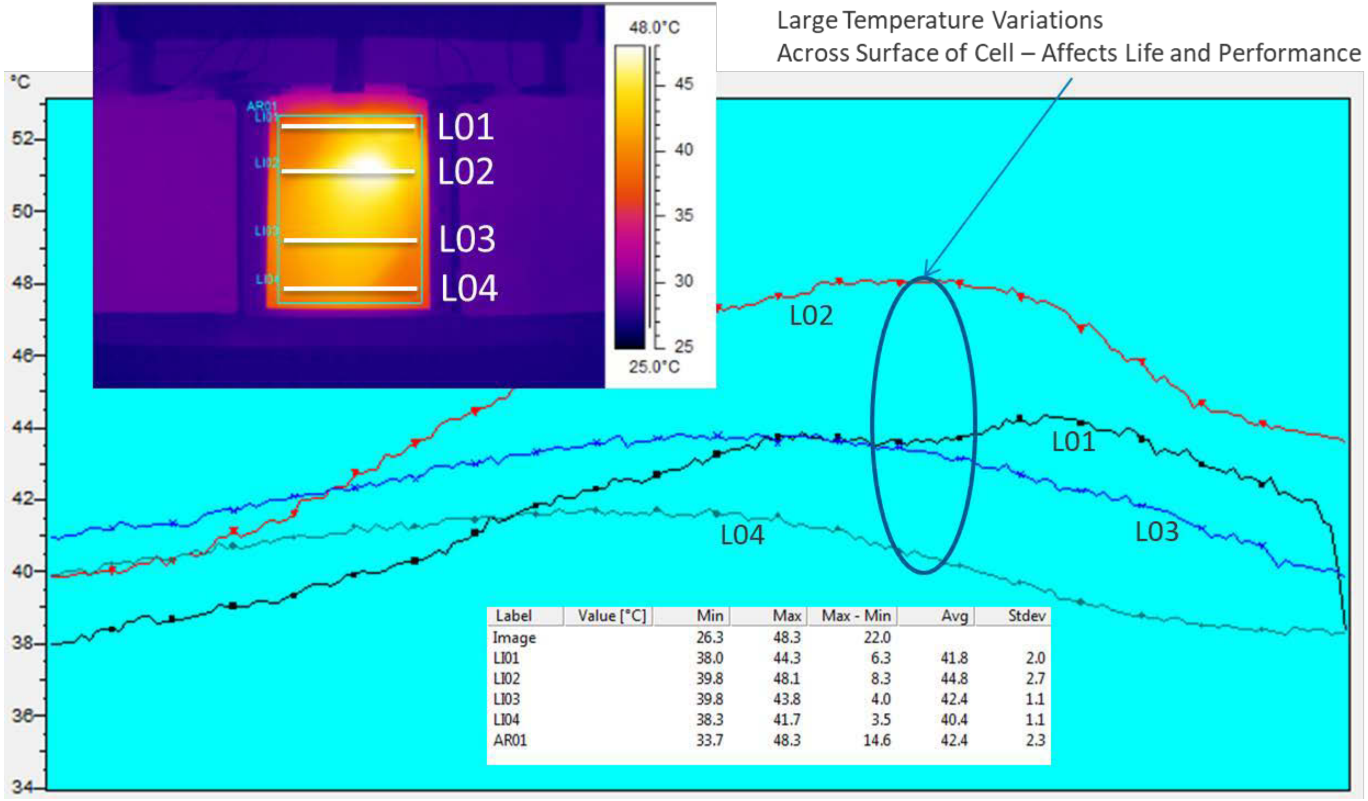
Electrode Thickness Impact on Efficiency



Thermal Image of NMC/Graphite Cell

(End 2C Discharge)

Large Temperature Variations
Across Surface of Cell – Affects Life and Performance



Label	Value [°C]	Min	Max	Max - Min	Avg	Stdev
Image		26.3	48.3	22.0		
LI01		38.0	44.3	6.3	41.8	2.0
LI02		39.8	48.1	8.3	44.8	2.7
LI03		39.8	43.8	4.0	42.4	1.1
LI04		38.3	41.7	3.5	40.4	1.1
AR01		33.7	48.3	14.6	42.4	2.3

NMC: Nickel Manganese Cobalt

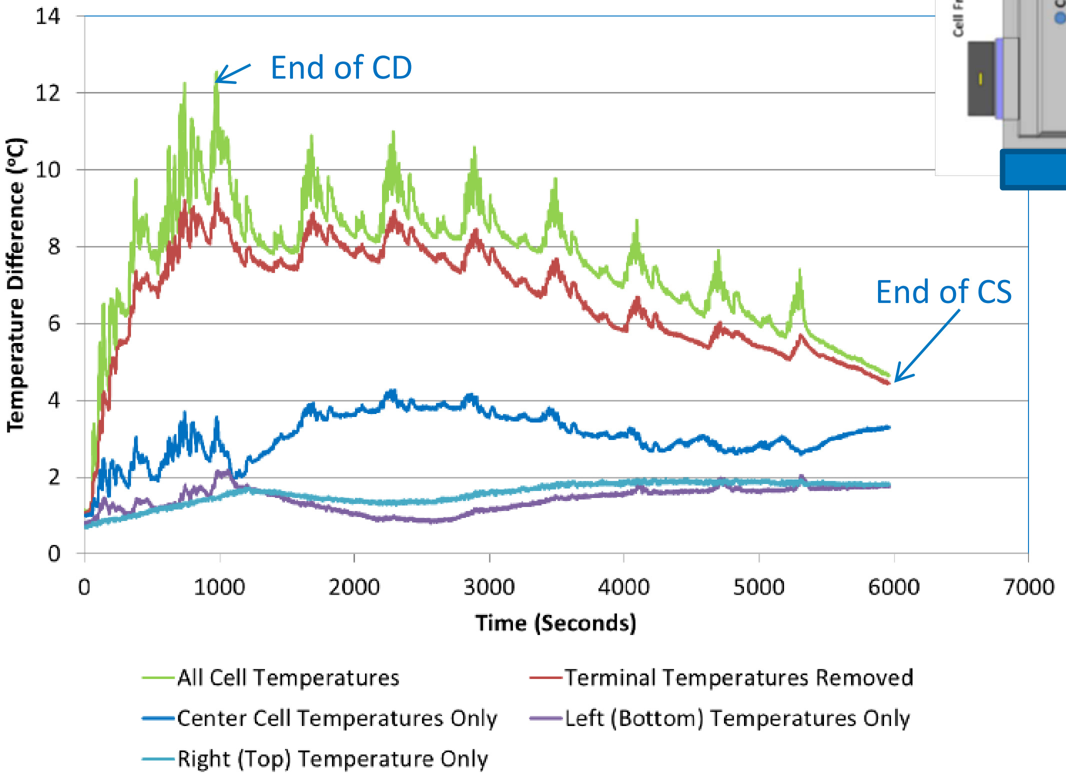
Pack-Level Thermal Implications

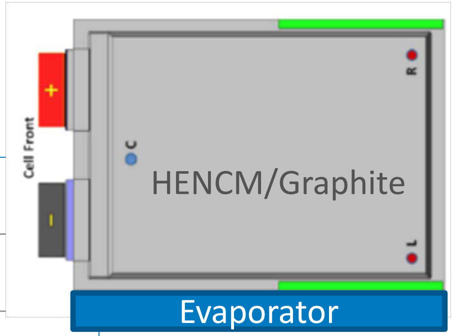
Current Thermal Management Strategies

Strategy	Air Cooling	Liquid Cooling	Active Cooling
Temperature Uniformity	+	+	+
Heat Transport	-	+	+
Thermal Control	-	+	+
Electrical Isolation	+	-	+
Compact Design	+	-	-
Maintenance	+	-	-
Cost	+	-	-
Weight	+	-	-
Ancillary Power	+	+	-
Noise	-	+	-

Present BEV cooling systems range from 1–5 kW. This may need to be increased substantially to meet XFC demands. In addition, new cooling strategies may need to be considered such as jet impingement, immersion, stationary “boost” cooling, etc.

Active Thermal Management System Performance

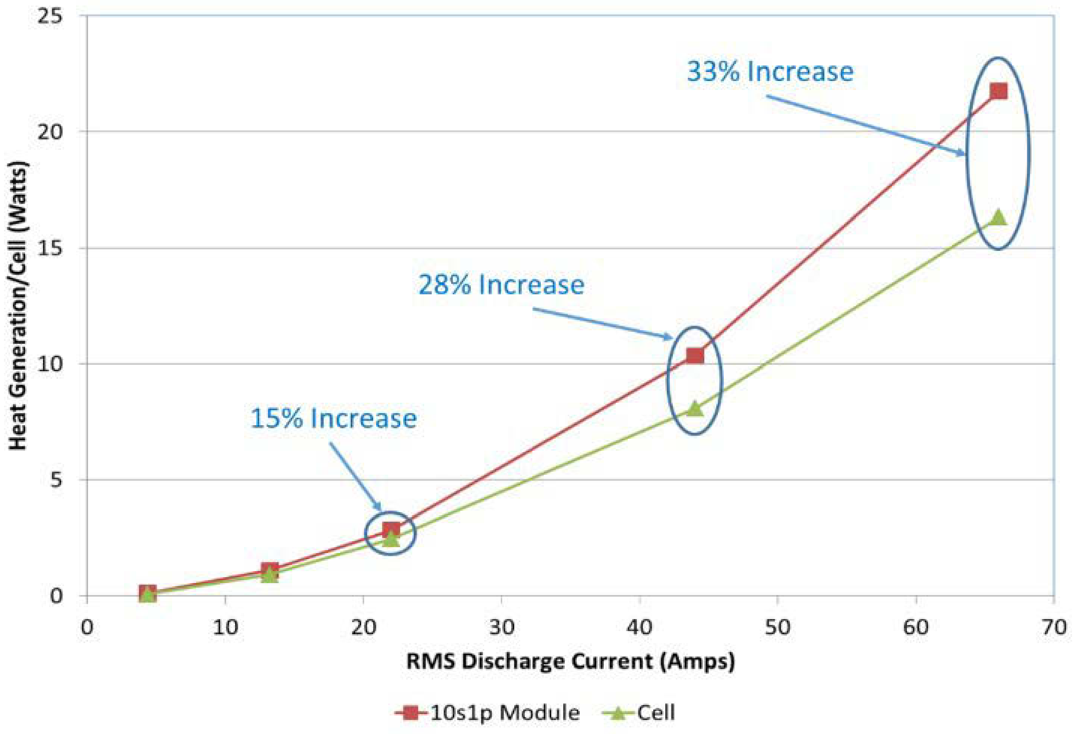




Approximately 100 cells in pack

CD = charge depleting
CS = charge sustaining
HENCM = high energy nickel manganese cobalt

Heating from Pack Interconnect Design



Under XFC the battery interconnect design will have added importance.

Summary and Conclusion

Summary

- Robust battery thermal management will be required to make XFC a reality—even with high-power cells, an oversized battery thermal management system will be needed.
- The size of the battery thermal management system will have to increase from today's BEV average size of 1 – 5 kW to around 15 – 25 kW.
- The heat efficiency of high energy density cells will need to improve by 10% – 20% at high rates of charge.
- New thermal management strategies like jet impingement or immersion of the battery in a dielectric fluid may need to be investigated to keep the battery below the operational maximum temperature limit.
- The cell-to-cell imbalance due to XFC will affect the longevity and cycle life cost of the cells. New passive and/or active battery management systems will need to be investigated to ensure that the batteries meet the original equipment manufacturer's (OEM's) warranty obligations.
- Cell design will have an impact on the temperature variation within the cell and the temperature imbalance within the pack.
- The mean average temperature of the battery directly affects the cycle life of the battery. High XFC utilization by the driver will have a strong influence on this metric.
- Additional cooling at the XFC station may be required to ensure a complete charge of the battery pack.

Collaborators

- **Department of Energy (DOE)**
  - Dave Howell, Samm Gillard

- **U.S. DOE National Laboratories**
  - Argonne National Laboratory[1], Idaho National Laboratory[2], National Renewable Energy Laboratory[3]

- **Industry Stakeholders**
  - Automotive OEMs: BMW, Daimler, FCA, Ford, GM, Nissan, Porsche
  - EVSE Manufacturers & Network Operators: ABB, AeroVironment, ChargePoint, Efacec USA, EVGO, GreenLots, Recargo/PlugShare
  - Battery Manufacturers: Farasis, JCI
  - Utility Suppliers: Black & Veatch, BTC Power, EPRI, PG&E, Rocky Mountain Power, SMUD, SCE

- **Contributing Team**
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Thank You

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