



An Update on the Battery Projects at NREL

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Acknowledgements

The Team

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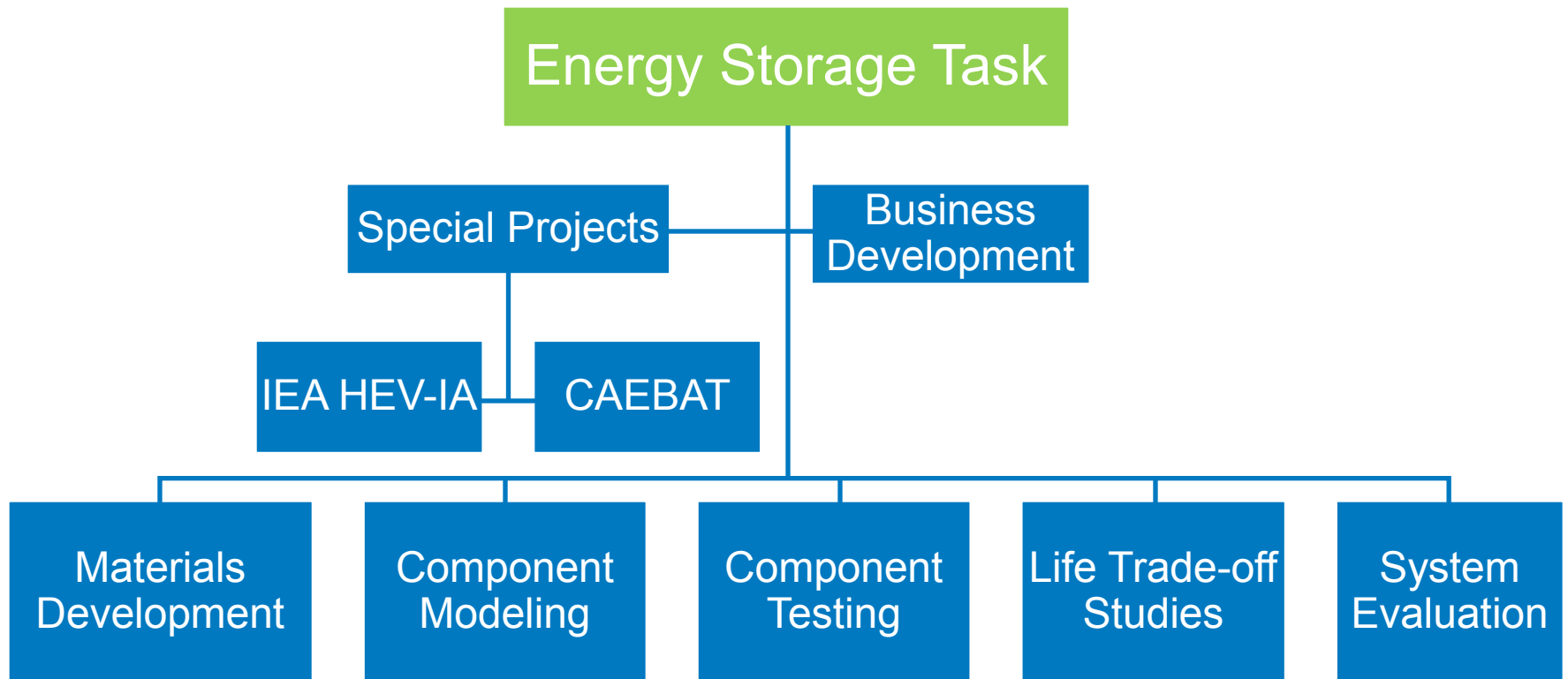
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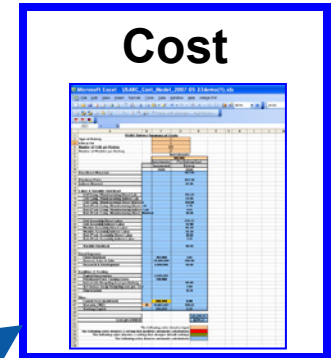
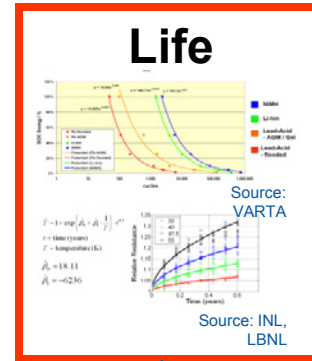
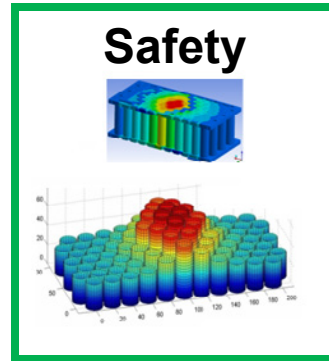
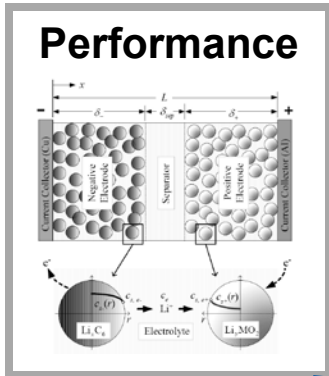
Tien Duong
Brian Cunningham

NREL Energy Storage Project Structure

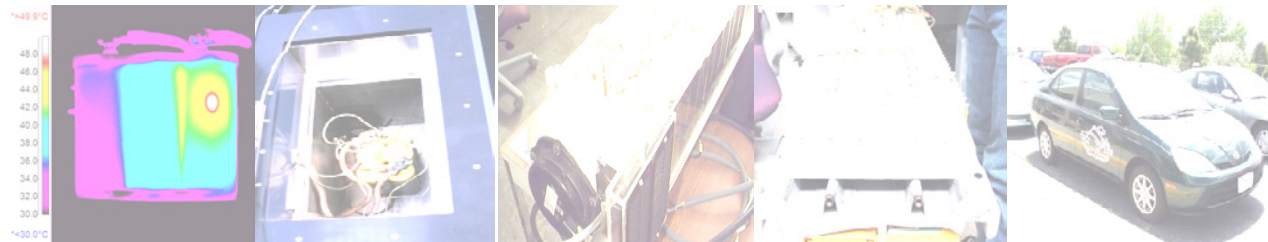


NREL Approach to Vehicle Battery Optimization

Robust design of batteries to meet the industry's requirements at minimum cost



Focused on Leveraging Expertise in Battery Thermal Management



Lab Upgrades

New Calorimeter for Large, Liquid-Cooled HEV & PHEV Modules



Photo: Matt Keyser

Completed System with Heating/Cooling Unit



Photo: Matt Keyser

Test Chamber in Isothermal Bath

Controlled Environment Chambers and Pack Testers



Photo: Dirk Long

New Environmental Chambers

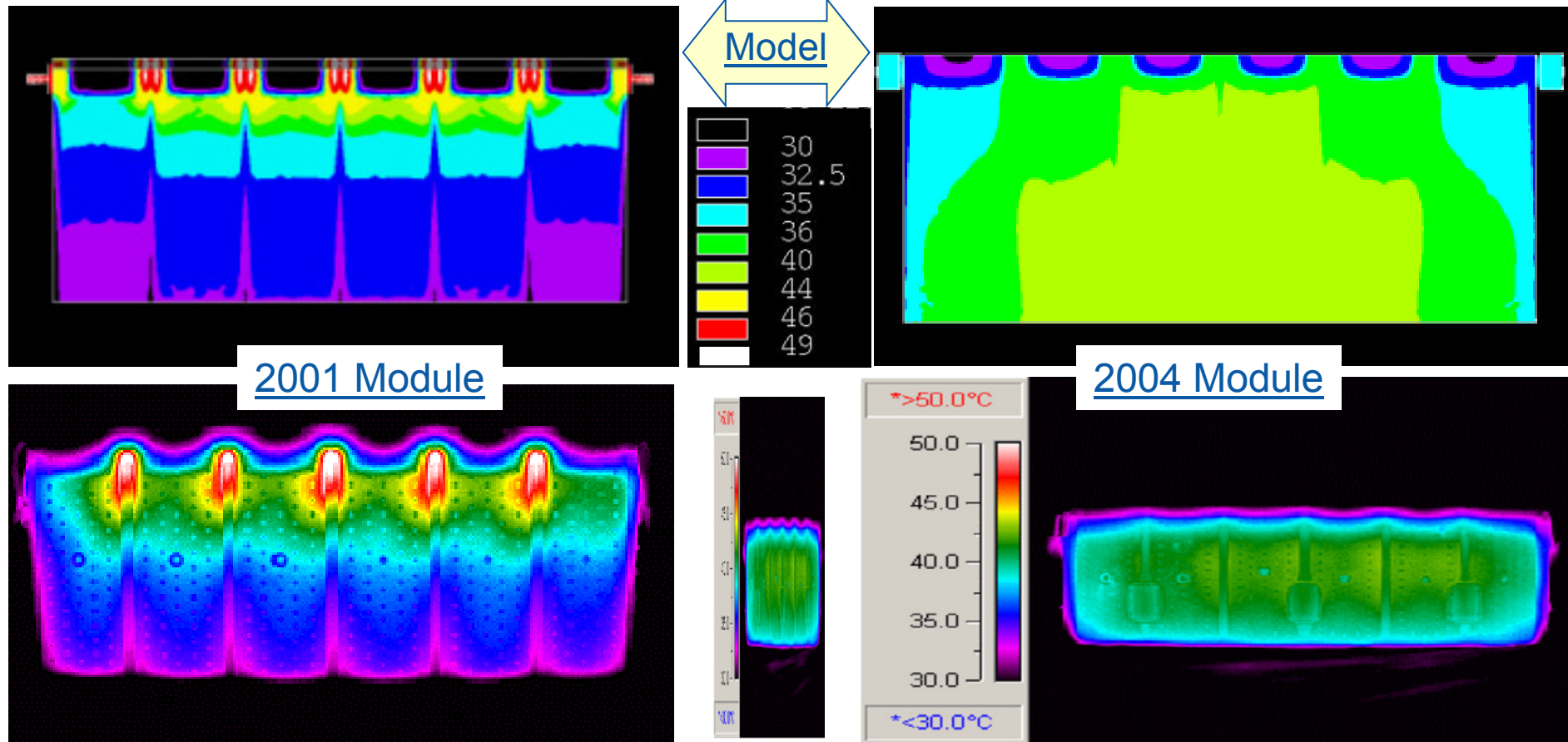


Photo: Dirk Long

Battery Pack Testers

The E-T Model – A Tool To Design Batteries with Better Thermal Performance

Response at the end of 100 A constant current discharge (3 min)

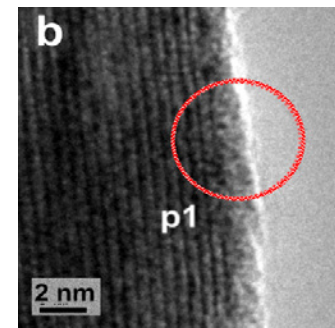
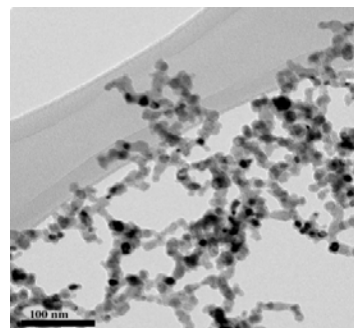
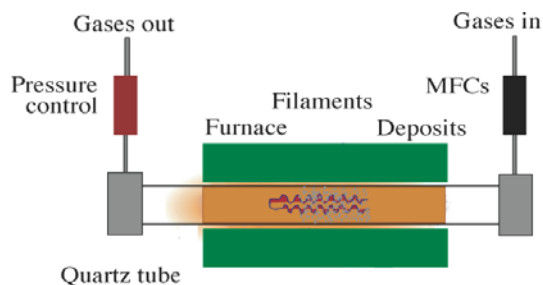


The model predicted lower and more uniform temperature distribution in 2004 module.

Materials Work

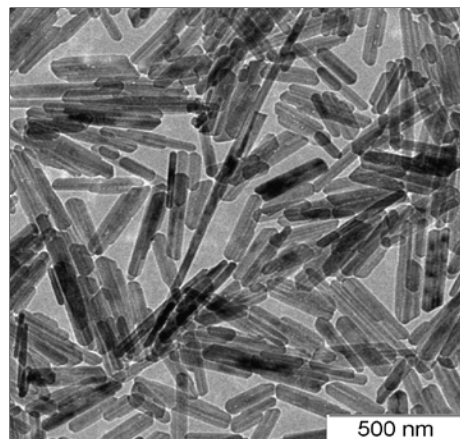
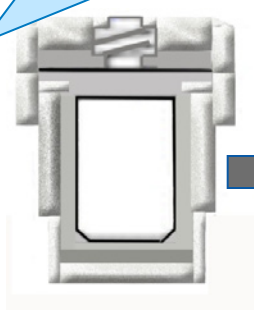
NREL Demonstrated Two Methods to Improve Rate

MoO₃ nanoparticles produced with economical hot-wire chemical vapor deposition (HWCVD). Atomic layer deposition (ALD) coatings enable durable high-rate capability cycling.

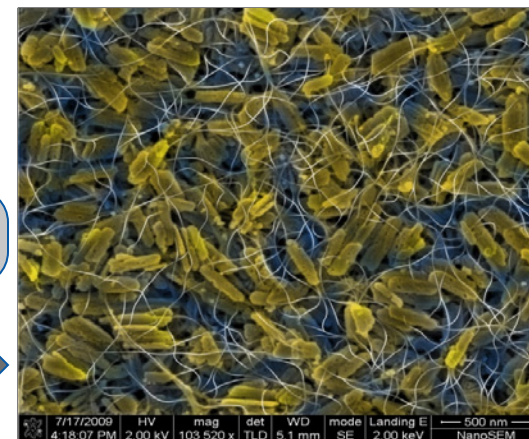


Iron oxide made with inexpensive hydrothermal process. 5 wt.% single wall carbon nanotubes (SWNTs) enable binder-free electrode with durable high-rate capability cycling.

Iron Precursor
Buffer Solution
Solvent



Annealing
w/ SWNT

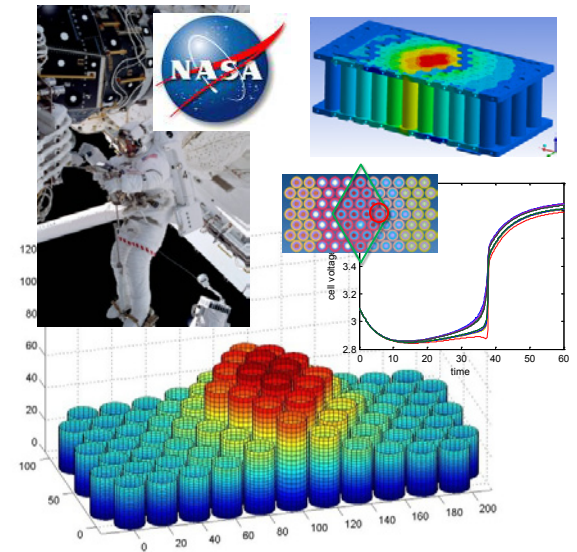
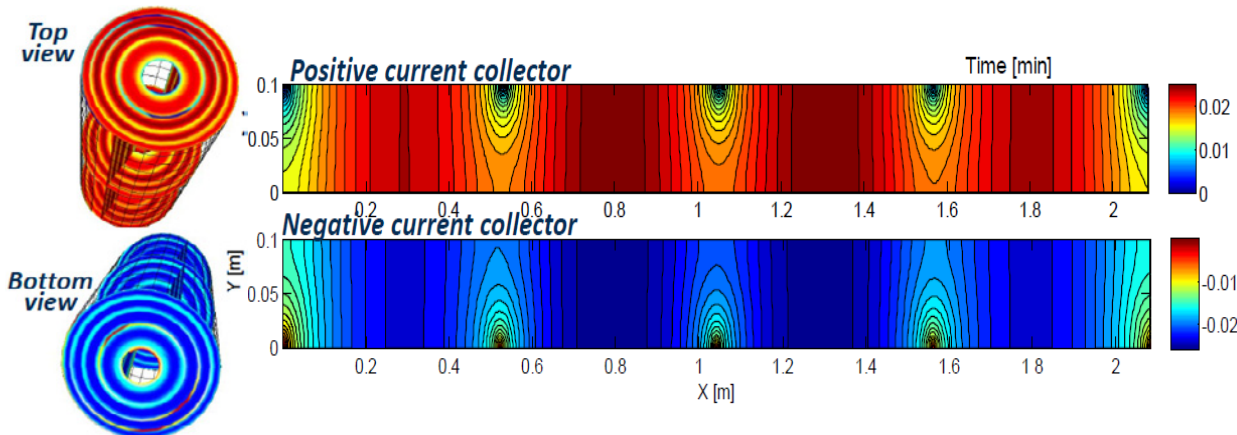
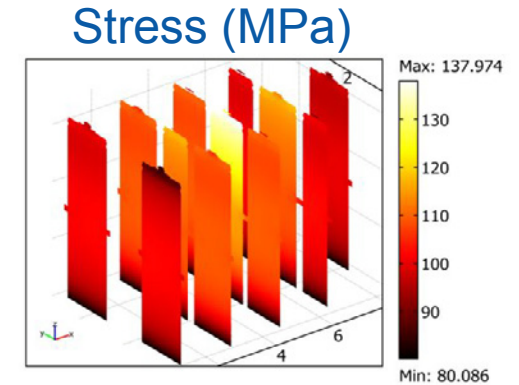
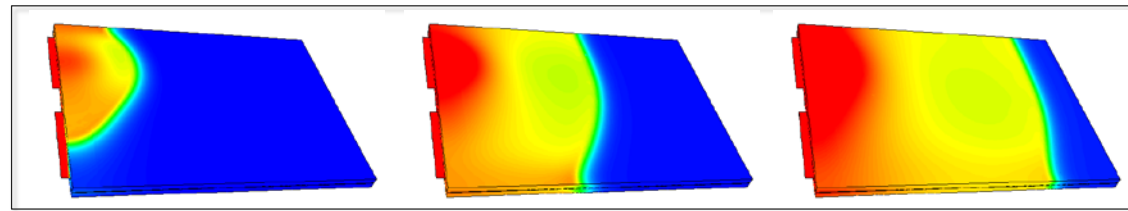
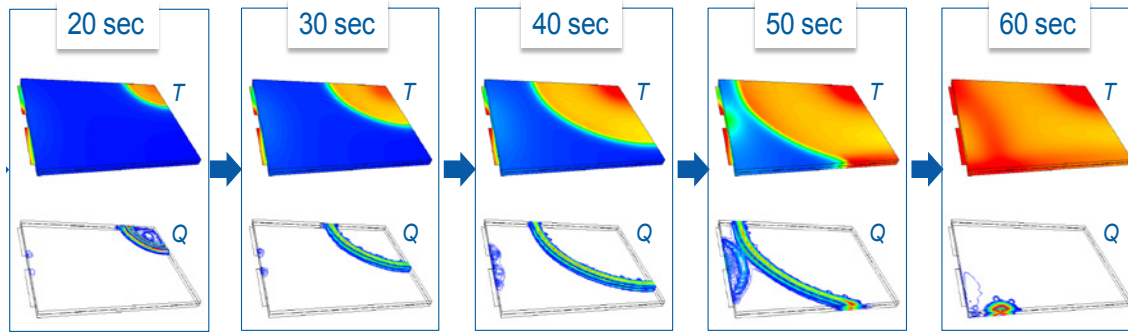


TEM of as-synthesized product

Fe₃O₄/SWNT electrode

L.A. Riley, A.S. Cavenagh, S.M. George, Y. S. Jung, Y. Yan, S-H. Lee, and A.C. Dillon - *ChemPhysChem* (available online)
C. Ban, Z. Wu, D. T. Gillaspie, L. Chen, Y. Yan, J. L. Blackburn, and A.C. Dillon - *Advanced Materials* (available online)

NREL's Safety Models



NREL Life Model

NCA datasets fit with empirical, yet physically justifiable formulas

*K. Smith, T. Markel, A. Pesaran. "PHEV Battery Trade-off Study and Standby Thermal Control," 26th International Battery Seminar & Exhibit, Fort Lauderdale, FL, March 2009.

Calendar fade

- SEI growth (partially suppressed by cycling)
- Loss of cyclable lithium
- $a_1(\Delta DOD, T, V)$

Cycling fade

- Active material structure degradation and mechanical fracture
- $a_2(\Delta DOD, T, V)$

Resistance Growth

$$R = a_1 t^{1/2} + a_2 N$$

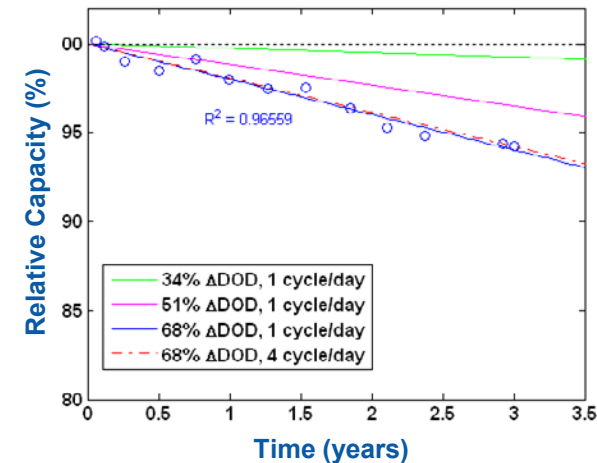
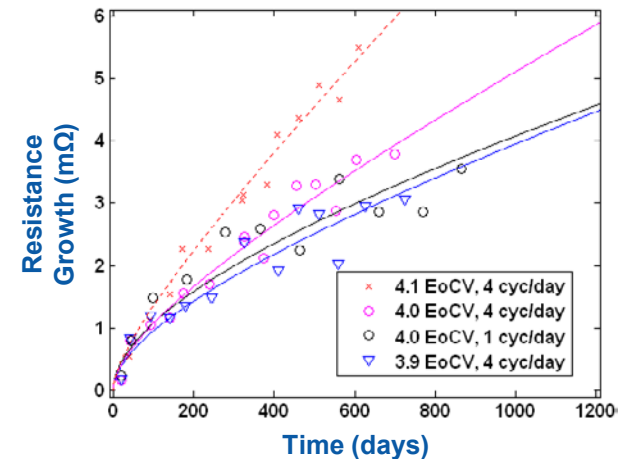
Relative Capacity

$$Q = \min(Q_{Li}, Q_{active})$$

$$Q_{Li} = b_0 + b_1 t^{1/2}$$

$$Q_{active} = c_0 + c_1 N$$

Li-ion NCA chemistry



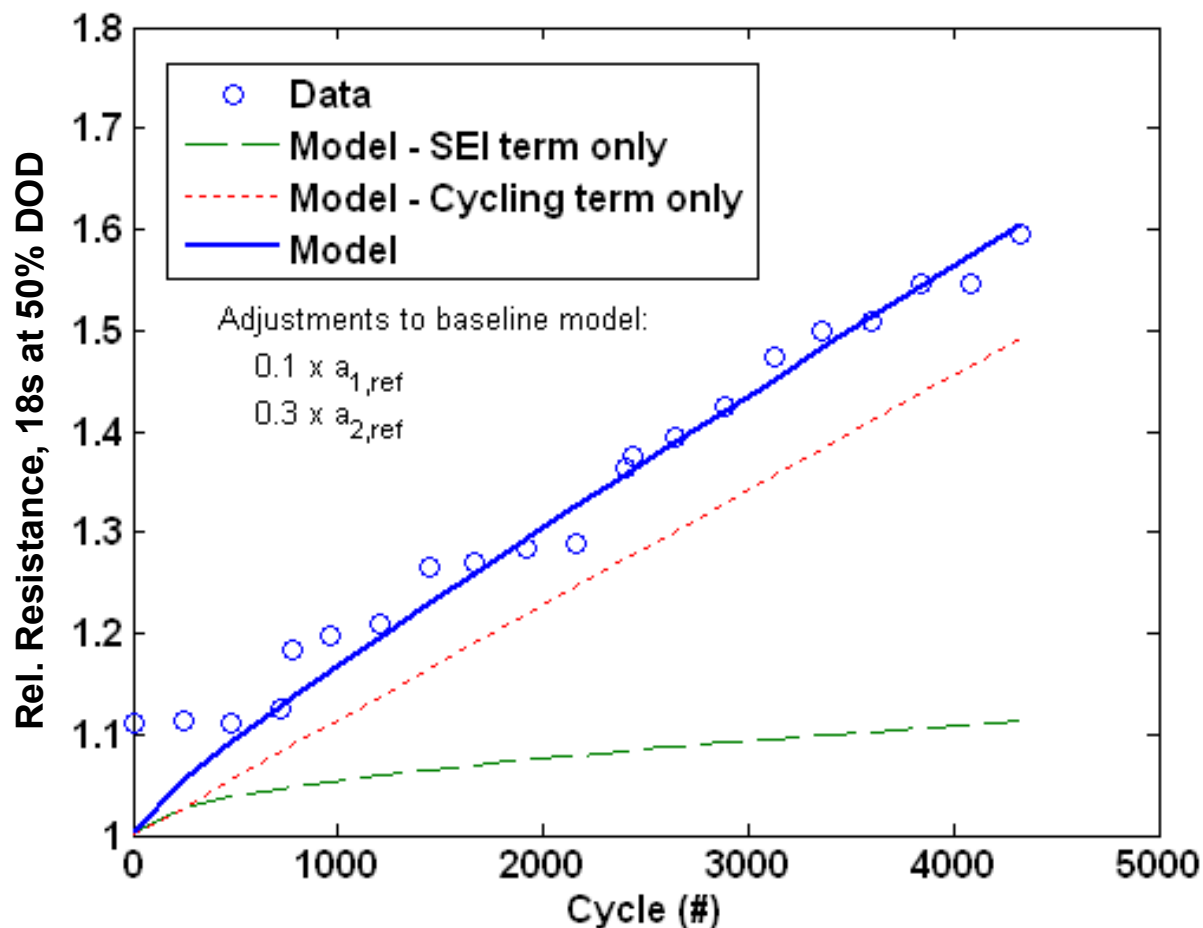
- Data shown above: J.C. Hall, IECEC, 2006.
- Not shown: Model also fit to DOE/TLVT, Southern CA Edison & NASA data

Predictive model that considers effects of real-world storage and cycling scenarios

Model Comparison: PHEV Accelerated Cycling

Data: Gaillac/SCE (2009)

- 3.75 years CD/CS cycle testing, ~4 cycles/day at $\Delta\text{DOD} = 0.75$, $T = 25\text{ C}$

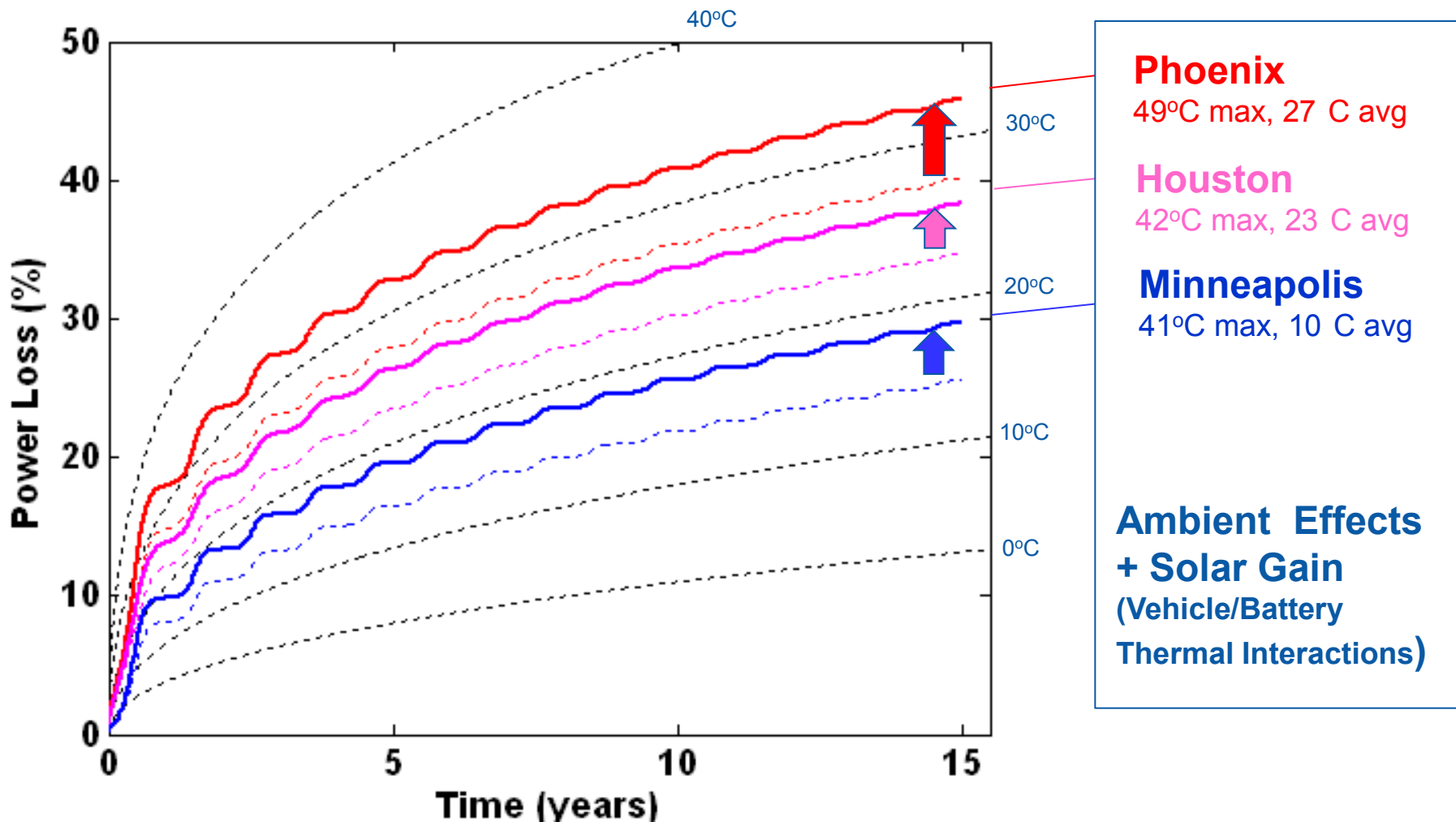


Resistance Growth:

- Linear trend of data indicates cycling dominates resistance growth rather than SEI growth with square-root-of-time
- Baseline life model requires some adjustment:
 - SEI-resistance-growth rate constant, $a_{1,\text{ref}}$, is reduced as required to match Belt/INL's Saft HP12LC HEV data
 - Cycling-resistance-growth rate constant, $a_{2,\text{ref}}$, is also reduced

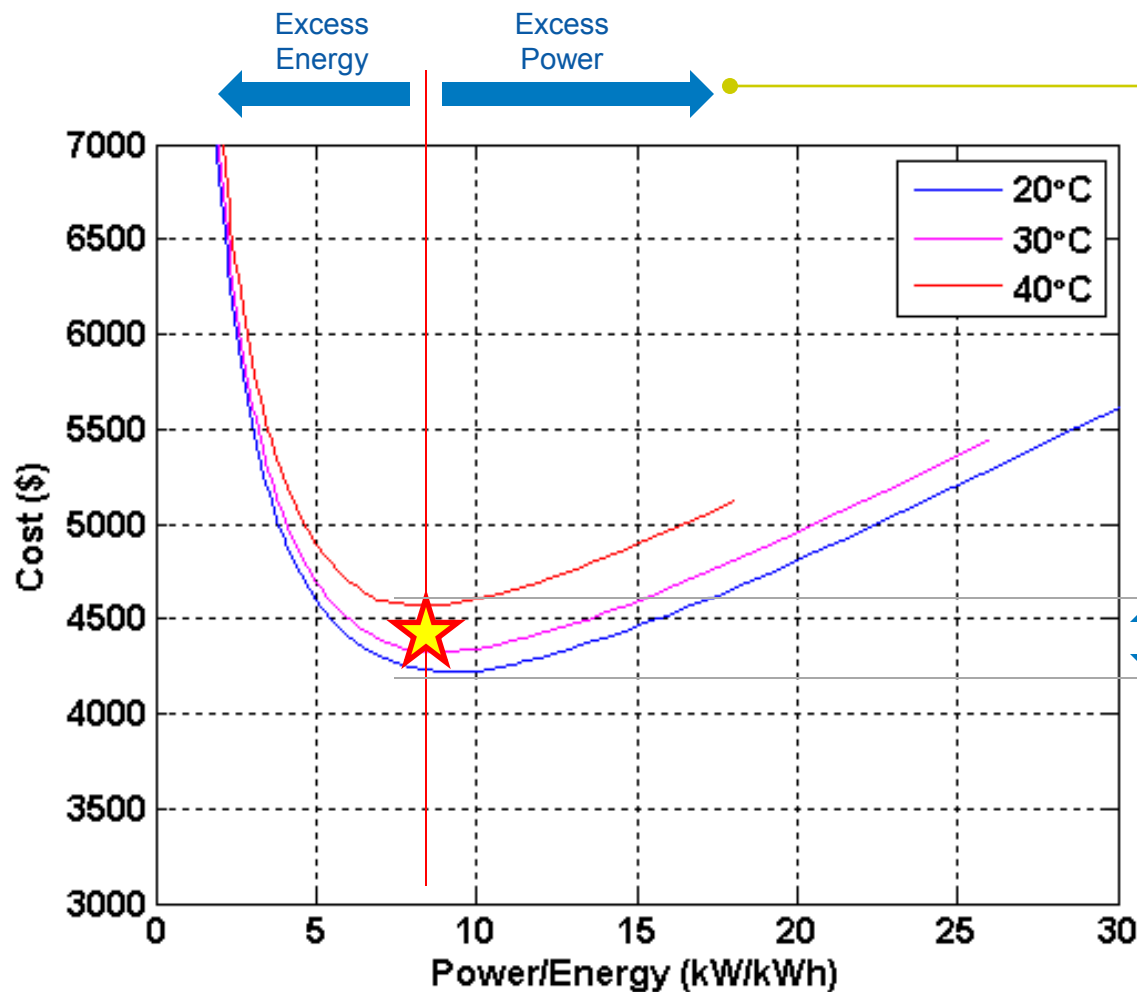
Impact of Temperature on Battery in a Parked Car (Battery T = Ambient T + Solar Gain)

- The same as previous slide (PHEV10, NCA chemistry, and TYM weather)
- Developed a vehicle-battery-ambient model to predict the battery temperature
- Results show significant fade due to the ambient temperature and solar gain



Cost Versus Power/Energy Ratio of Cell Design

Example: PHEV20 battery sized for 10 years life with 1 cycle/day



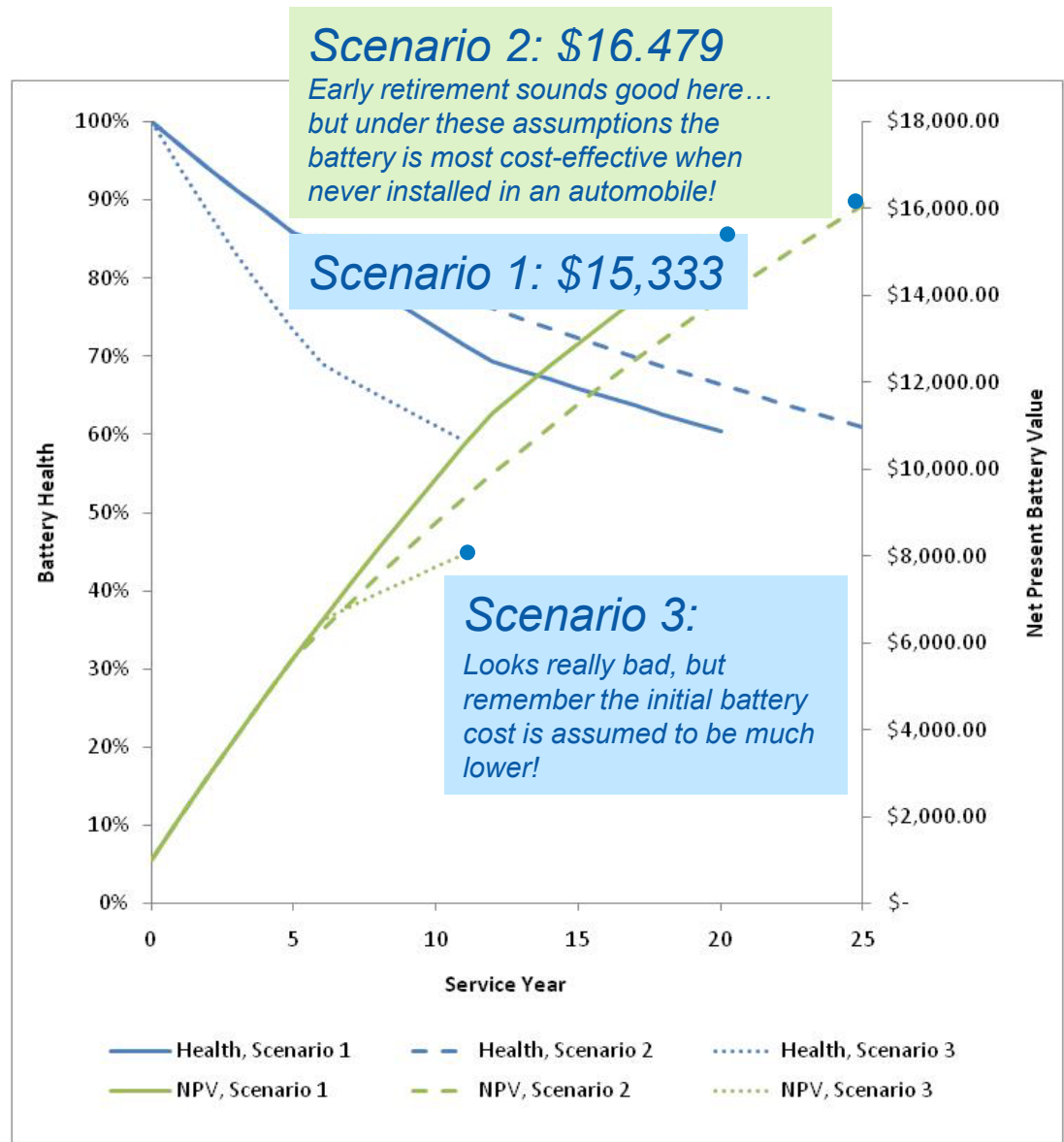
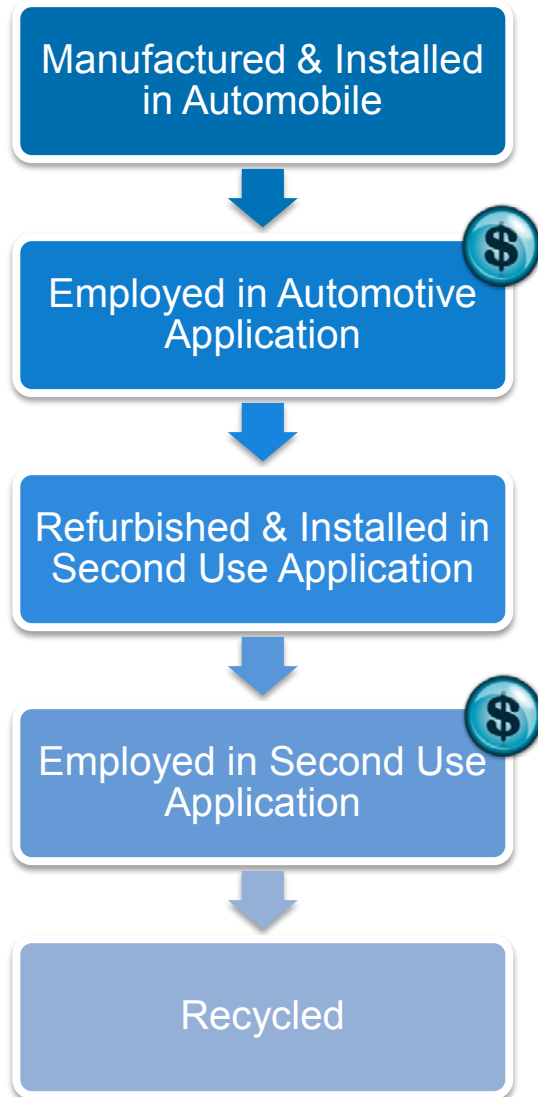
– Battery designer must select from available cell designs (e.g., P/E = 5, 10, 15 kW/kWh)

- Excess Energy = unused active material (very expensive)
- Excess Power
 - Allows deeper Δ DOD (most efficient use of active materials)
 - Reduces heat load

– Pack cost rises \$180 for each 10 C additional temperature exposure

- Thermal management
- Ambient temperature

Battery Second-Use Strategies



Strong Partnership with Universities and Industry

DOE-sponsored projects



Industry-sponsored projects



Summary

- *NREL collaborates with industry, universities, and other national labs as part of the DOE integrated Energy Storage Program to develop advanced batteries for vehicle applications.*
- Our efforts are focused in the following areas:
 1. Thermal characterization and analysis
 2. Evaluation of thermal abuse tolerance via modeling and experimental analysis
 3. Implications on battery life and cost
- Our activities support DOE goals, FreedomCAR targets, the USABC Tech Team, and battery developers.
- We develop tools to support the industry both through one-on-one collaborations and by dissemination of information in the form of presentations in conferences and journal publications.

www.nrel.gov/vehiclesandfuels/energystorage/publications.html