An Update on the Battery Projects at NREL

Shriram Santhanagopalan
Ahmad Pesaran

Funding provided by Energy Storage R&D, Vehicle Technologies, U.S. Department of Energy (David Howell)

Battery Power 2010
October 19-20, Dallas, Texas

NREL/PR-5400-49796

Acknowledgements

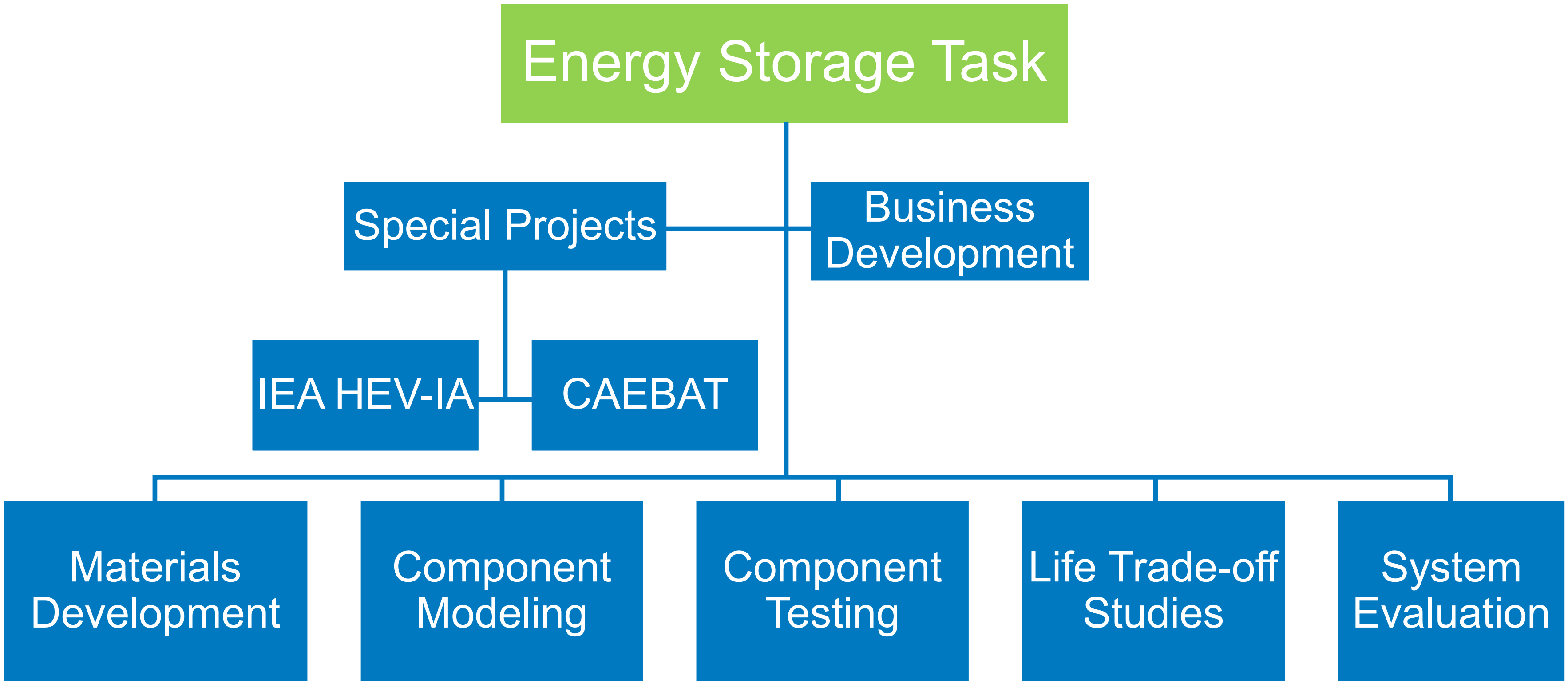
The Team

Terry Penney
Ahmad Pesaran
Matt Keyser
Gi-Heon Kim
Kandler Smith
Jeremy Neubauer
Jeff Gonder
Aaron Brooker
Larry Chaney
Anne Dillon
Chunmei Ban
Kyu Jin Lee
Dirk Long
Yoon Seok Jung
John Ireland
Michael O'Keefe
Tony Markel
Robert Tenant

Funding from The Department of Energy

Dave Howell
Steve Gougen
Tien Duong
Brian Cunningham

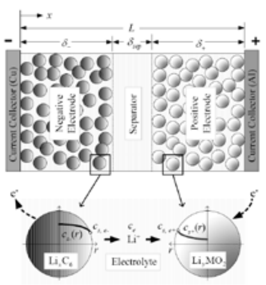
NREL Energy Storage Project Structure



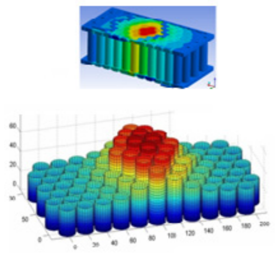
NREL Approach to Vehicle Battery Optimization

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

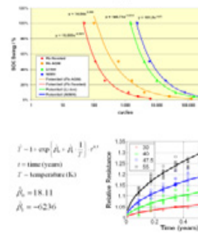
Performance



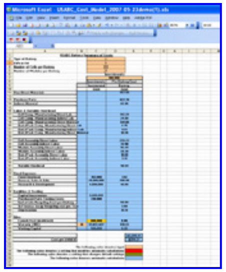
Safety



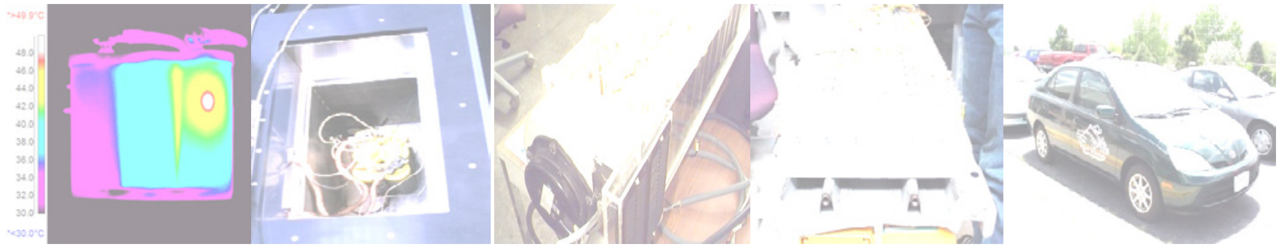
Life



Cost



Focused on Leveraging Expertise in Battery Thermal Management



Lab Upgrades

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

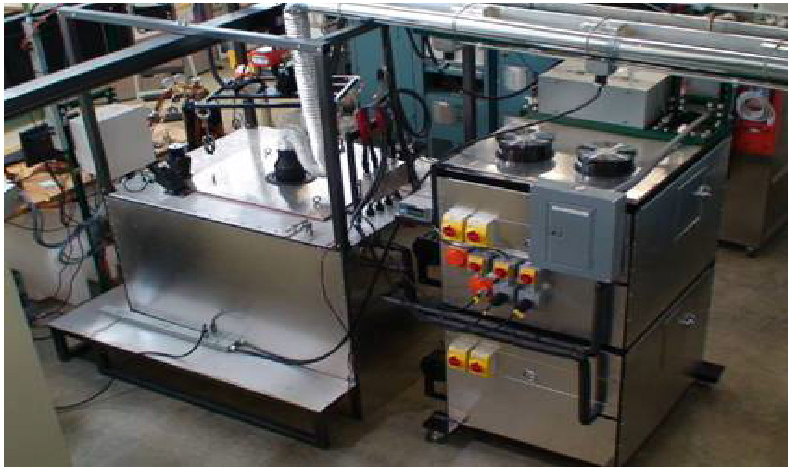


Photo: Matt Keyser

Completed System with Heating/Cooling Unit

Photo: Matt Keyser

Test Chamber in Isothermal Bath

Controlled Environment Chambers and Pack Testers

Photo: Dirk Long

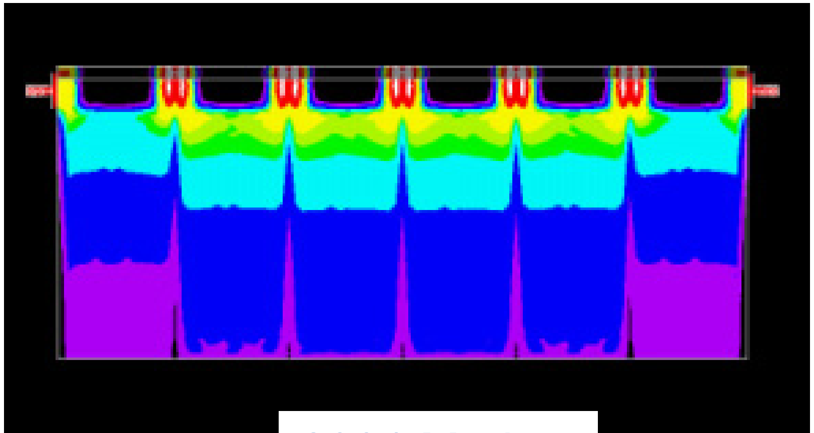
New Environmental Chambers

Photo: Dirk Long

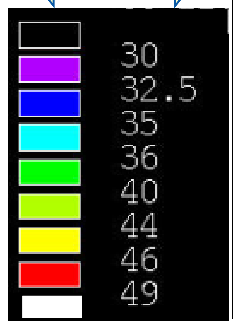
Battery Pack Testers

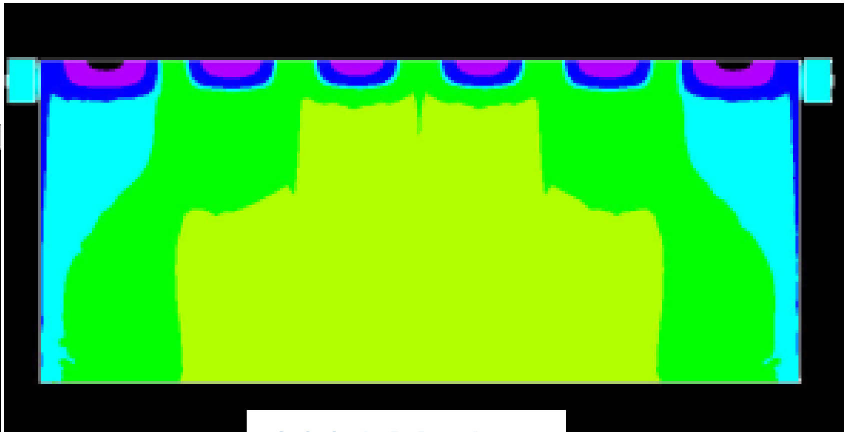
The E-T Model – A Tool To Design Batteries with Better Thermal Performance

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



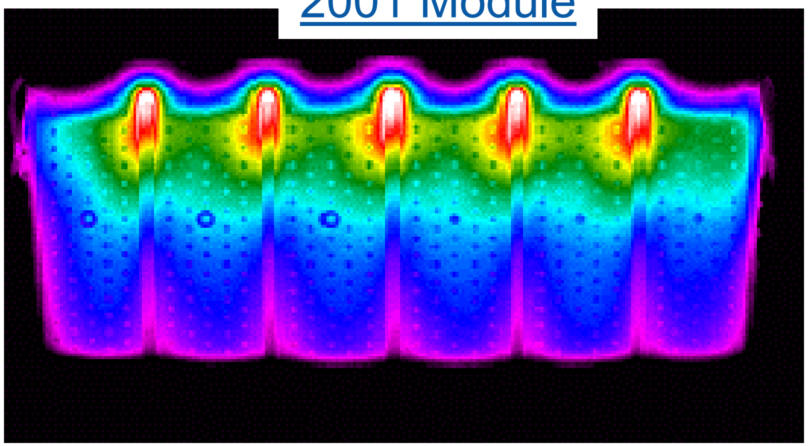
Model

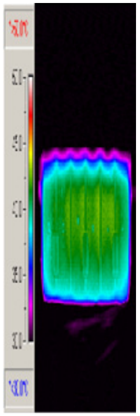


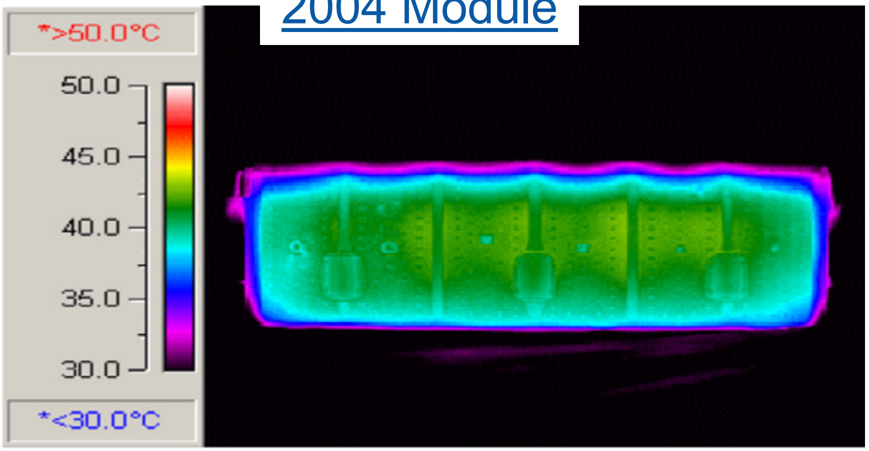


2001 Module

2004 Module





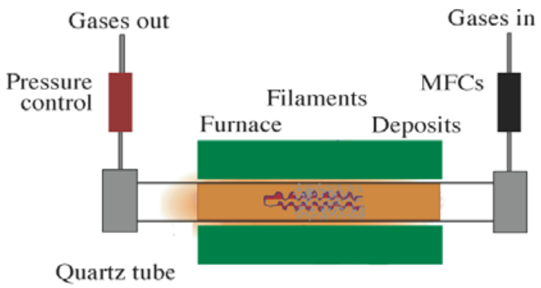


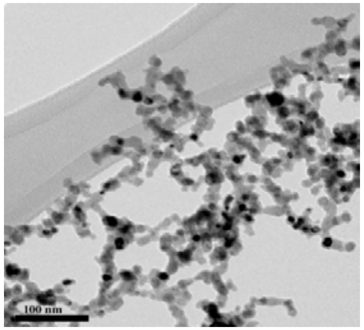
The model predicted lower and more uniform temperature distribution in 2004 module.

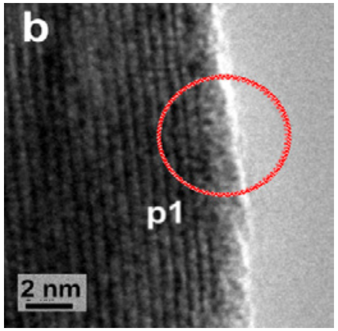
Materials Work

NREL Demonstrated Two Methods to Improve Rate

MoO_3 nanoparticles produced with economical hot-wire chemical vapor deposition (HWCVD). Atomic layer deposition (ALD) coatings enable durable high-rate capability cycling.

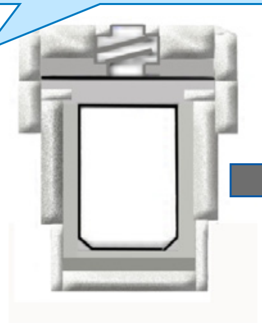


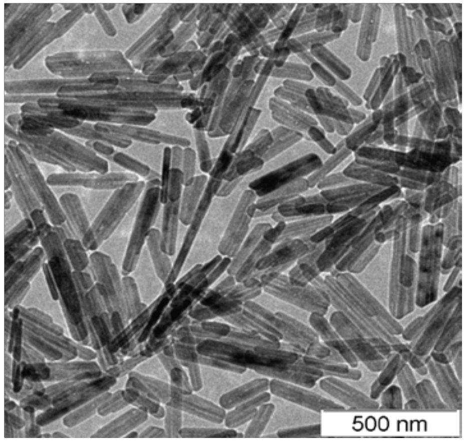




Iron oxide made with inexpensive hydrothermal process. 5 wt.% single wall carbon nanotubes (SWNTs) enable binder-free electrode with durable high-rate capability cycling.

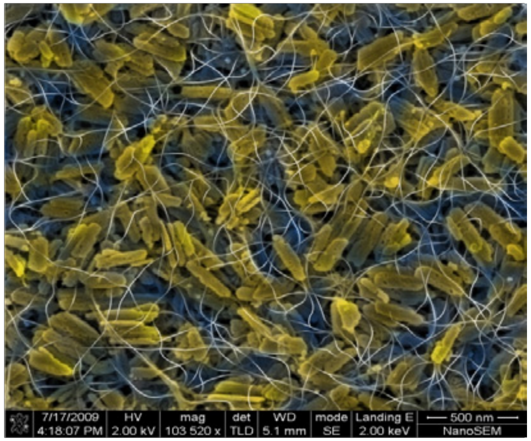
Iron Precursor
Buffer Solution
Solvent





TEM of as-synthesized product

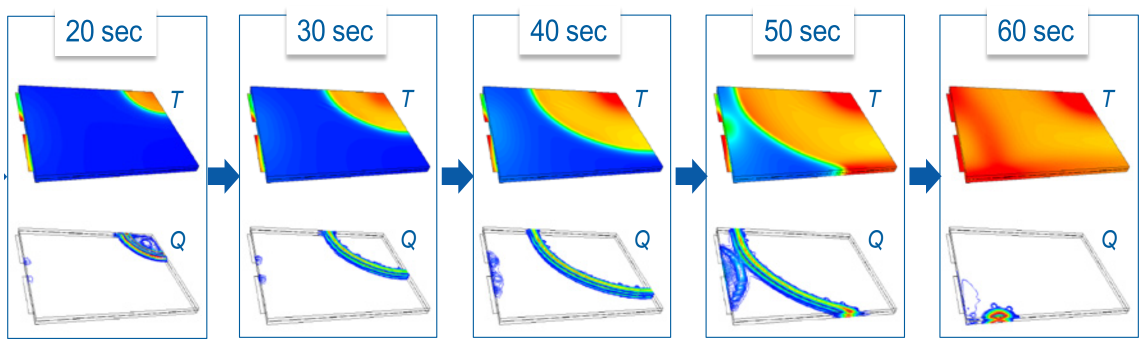
Annealing w/ SWNT



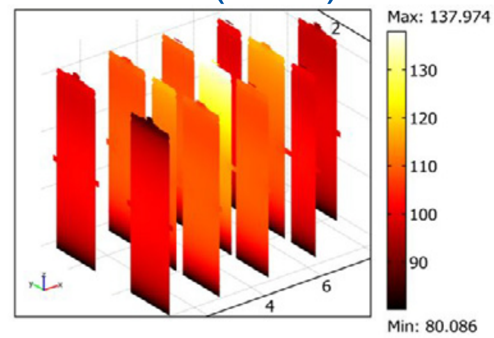
Fe_3O_4/ SWNT electrode

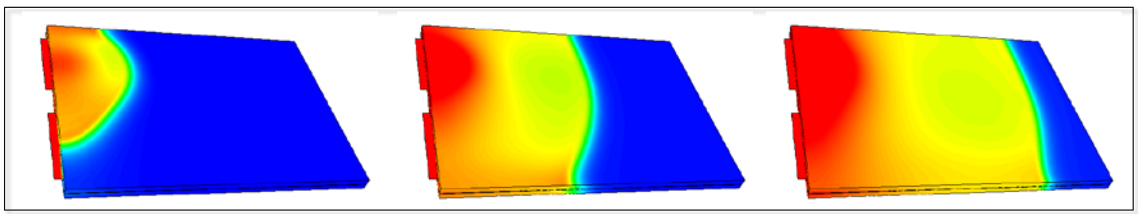
L.A. Riley, A.S. Cavenagh, S.M. George, Y. S. Jung, Y. Yan, S-H. Lee, and A.C. Dillon - *ChemPhysChem* (available online)
C. Ban, Z. Wu, D. T. Gillaspie, L. Chen, Y. Yan, J. L. Blackburn, and A.C. Dillon - *Advanced Materials* (available online)

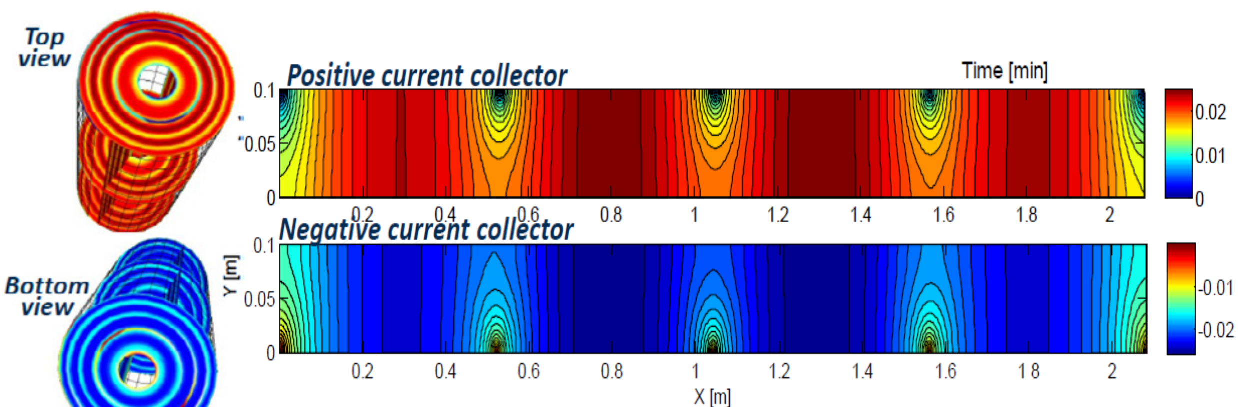
NREL’s Safety Models

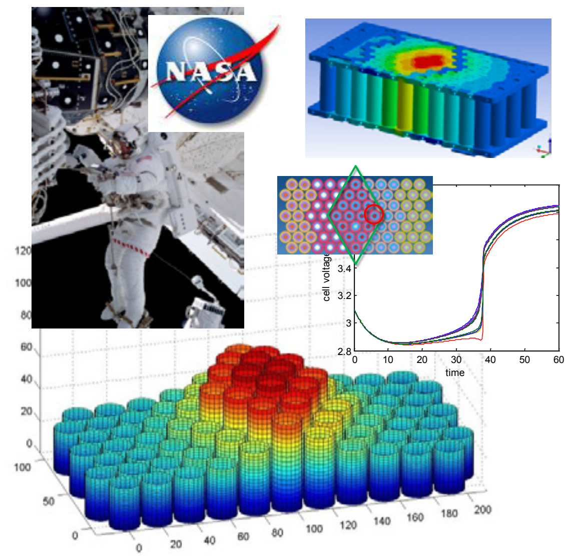


Stress (MPa)









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
- a1(ΔDOD,T,V)

Cycling fade
- Active material structure degradation and mechanical fracture
- a_2(ΔDOD,T,V)

Resistance Growth

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

Relative Capacity

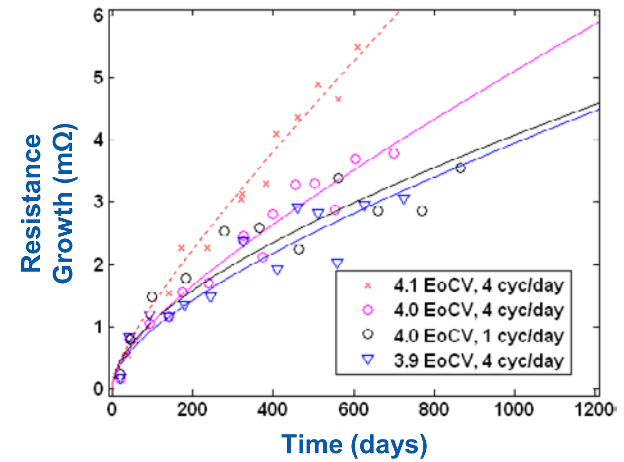
$$Q = \min(Q_{Li}, Q_{active})$$

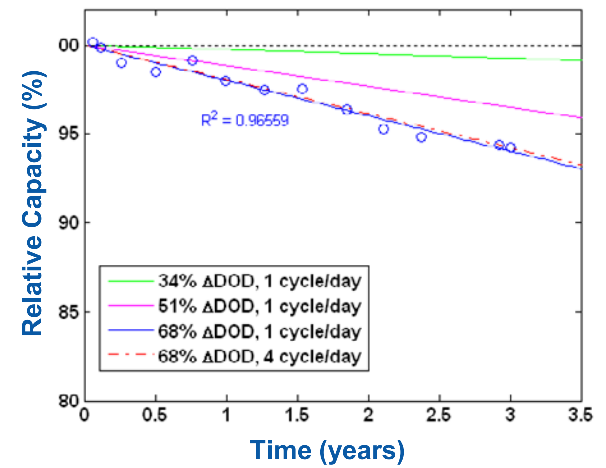
$$Q_{Li} = b_0 + b_1 t^{1/2}$$

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

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

Li-ion NCA chemistry



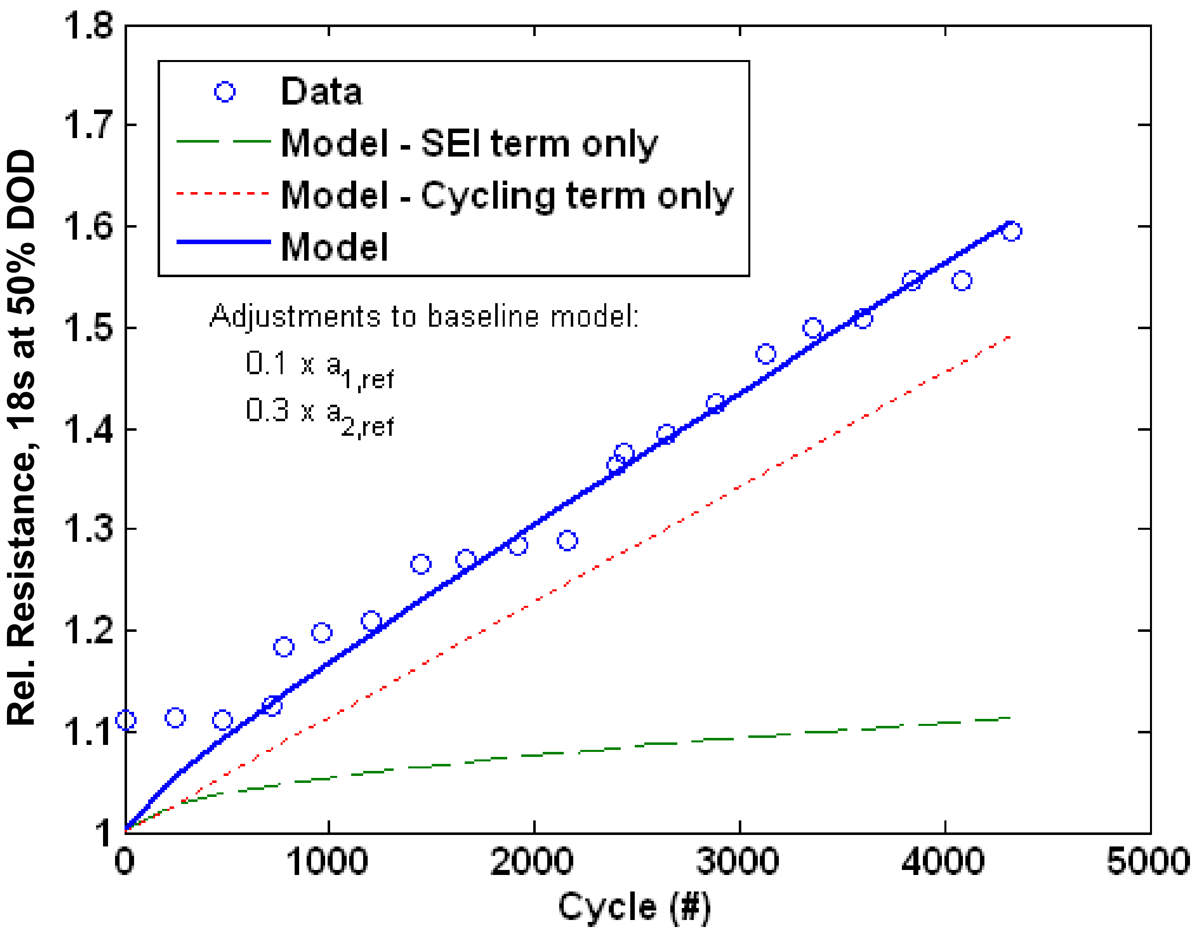


- Data shown above: J.C. Hall, IECEC, 2006.
- Not shown: Model also fit to DOE/TLVT, Southern CA Edison & NASA data

Model Comparison: PHEV Accelerated Cycling

Data: Gaillac/SCE (2009)

– 3.75 years CD/CS cycle testing, ~4 cycles/day at ΔDOD = 0.75, T = 25 C



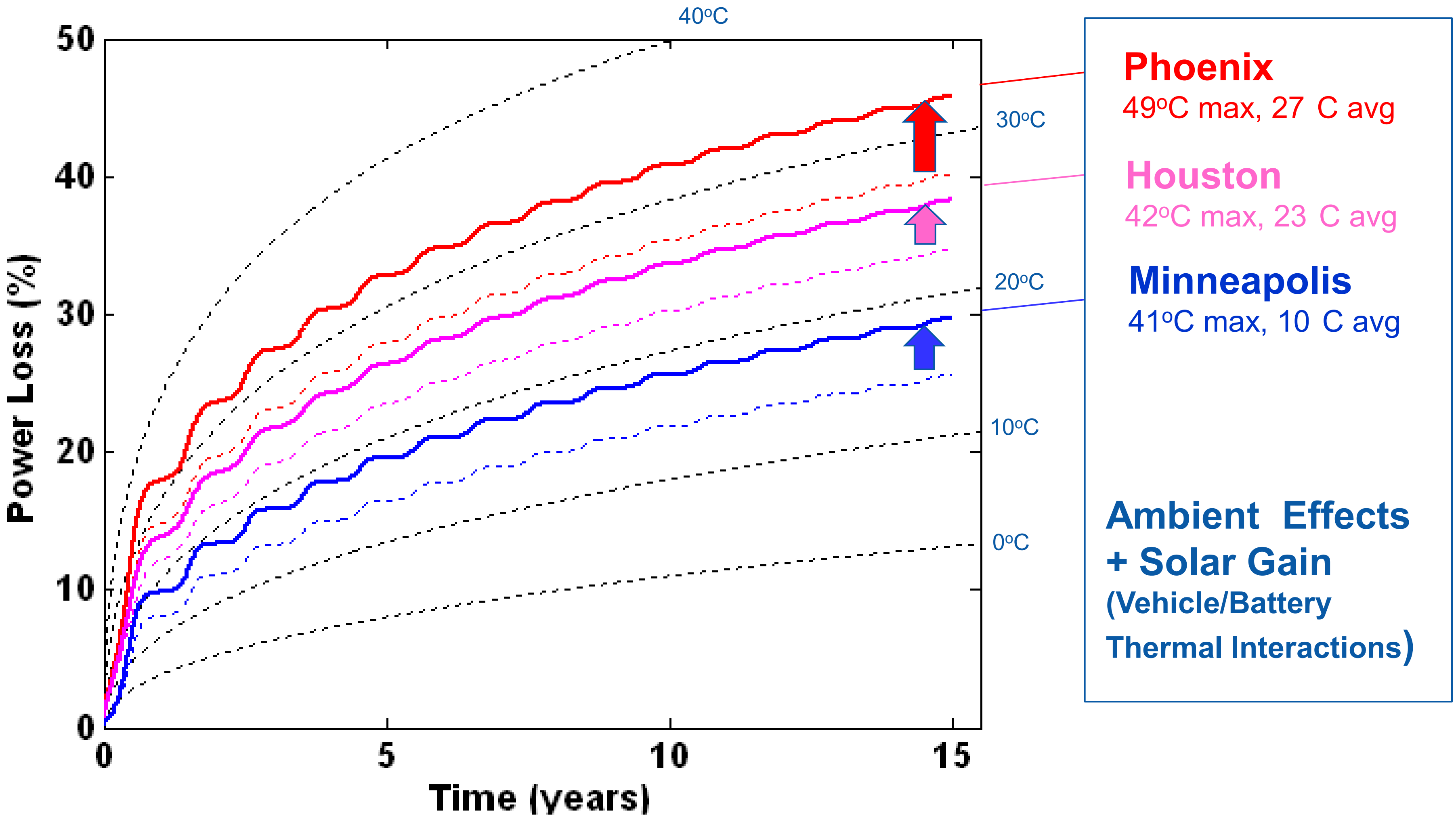
Resistance Growth:

- 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, $a_{1,ref}$, is reduced as required to match Belt/INL's Saft HP12LC HEV data
  - Cycling-resistance-growth rate constant, $a_{2,ref}$, is also reduced

Impact of Temperature on Battery in a Parked Car

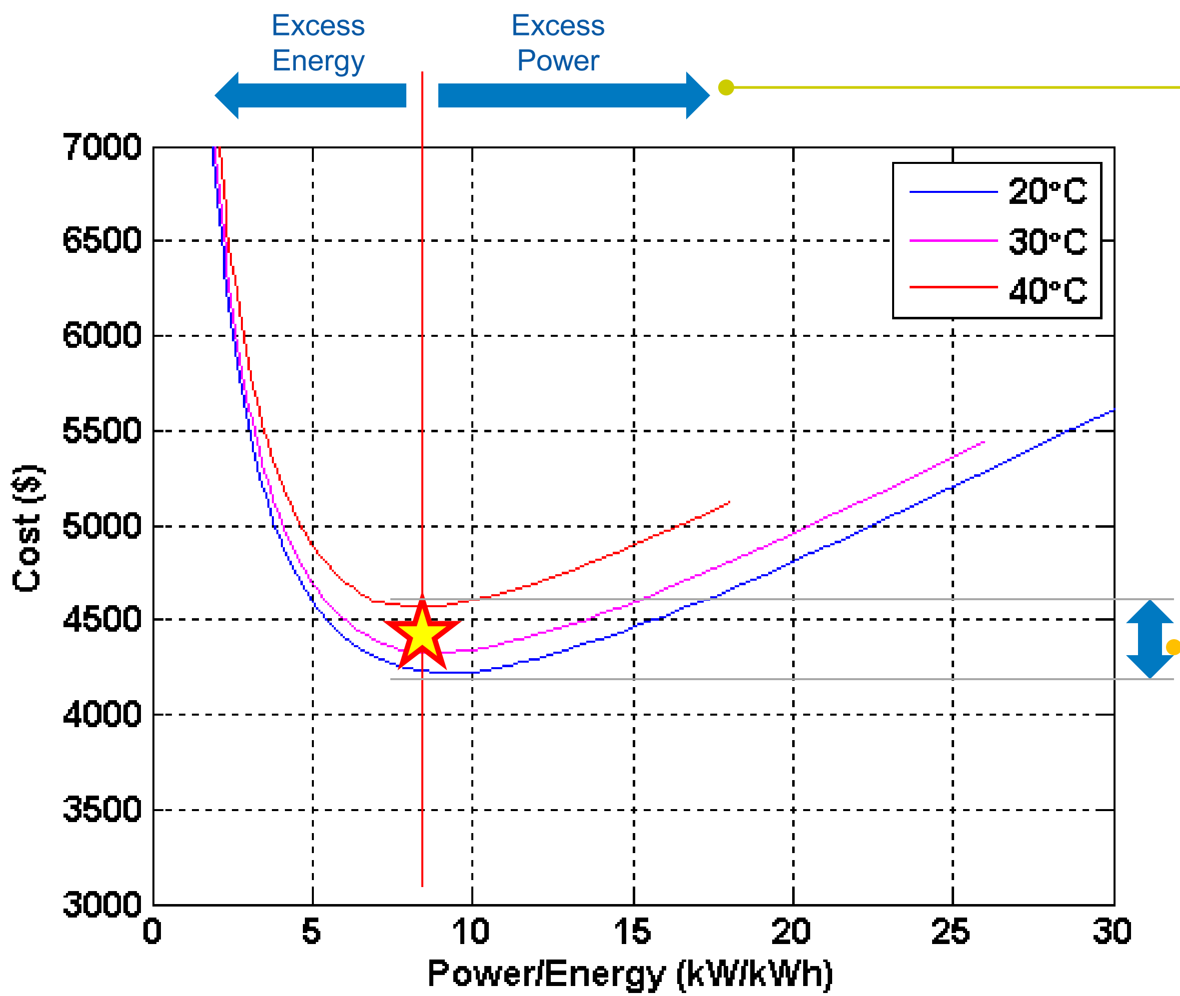
(Battery T = Ambient T + Solar Gain)

- *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

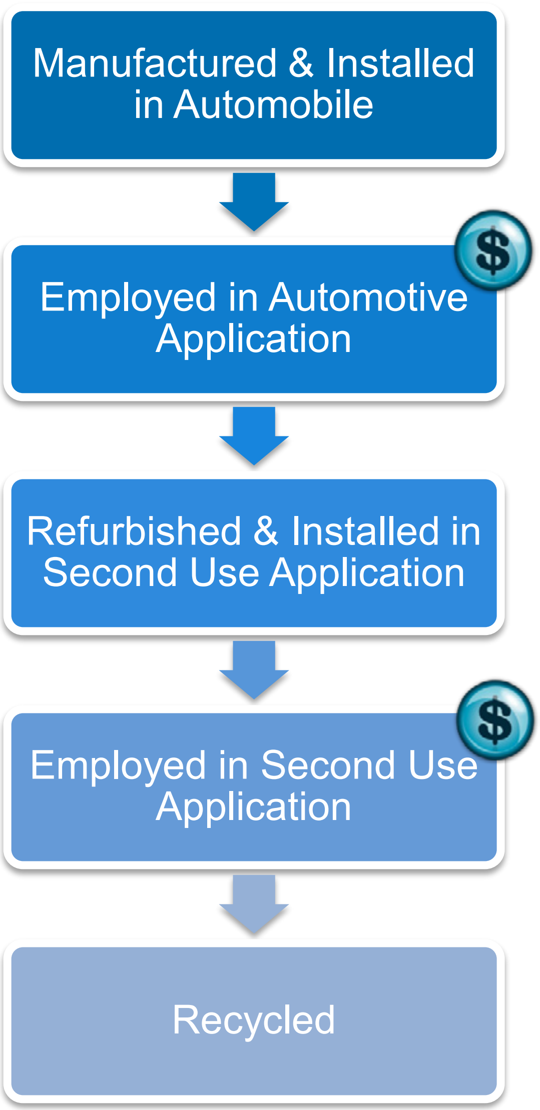
Example: PHEV20 battery sized for 10 years life with 1 cycle/day

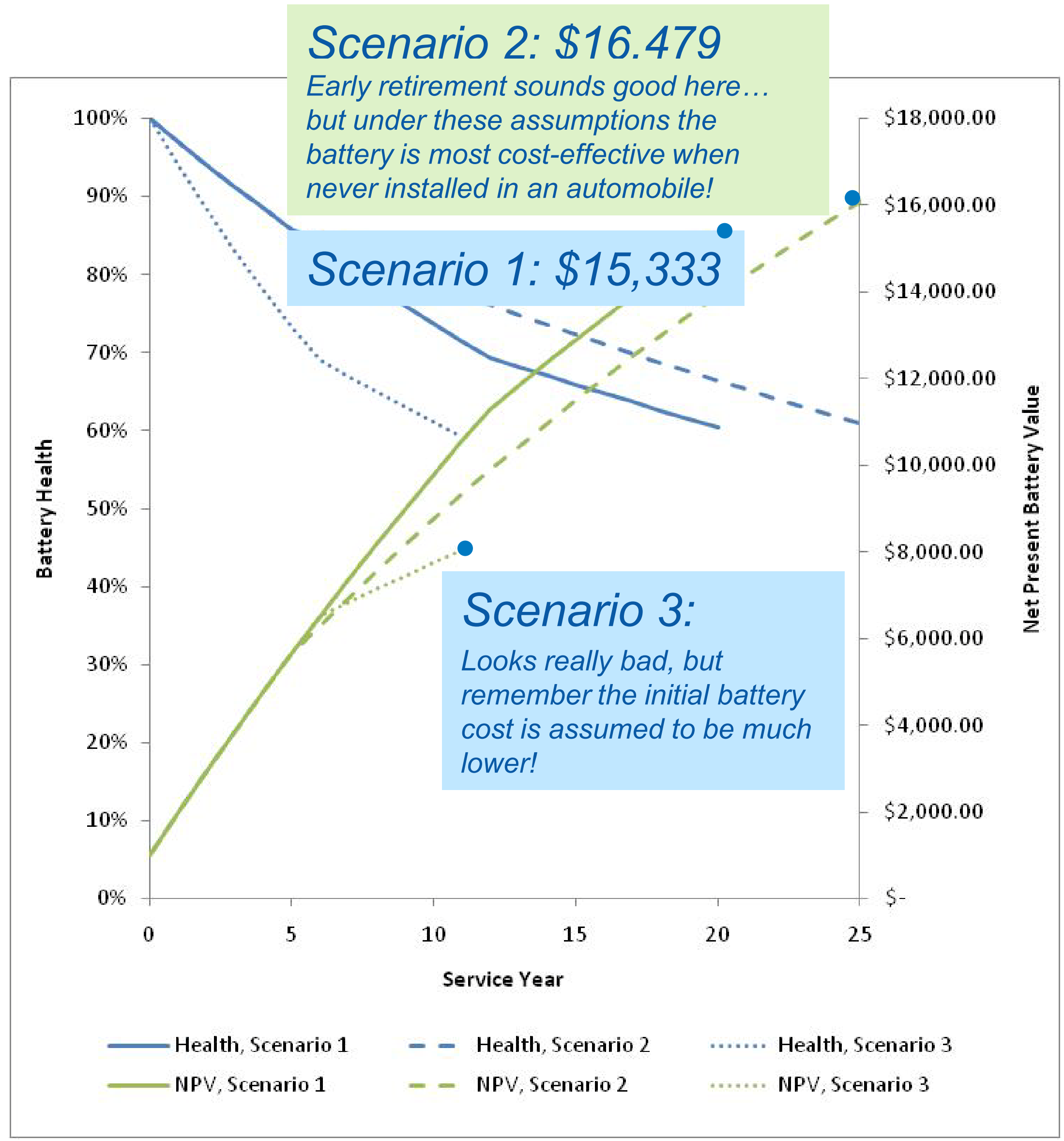


- Battery designer must select from available cell designs (e.g., P/E = 5, 10, 15 kW/kWh)
  - Excess Energy = unused active material (very expensive)
  - Excess Power
    - Allows deeper ΔDOD (most efficient use of active materials)
    - Reduces heat load

- 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

OPTIMA BATTERIES
PNGV
GM
SAFT
Department of Energy, United States of America
FreedomCAR & Fuel Partnership
Ford
USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM
GNB TECHNOLOGIES
AeroVironment
Texas Instruments
CHRYSLER
A123 SYSTEMS
JOHNSON CONTROLS
cpi
PolyStor
BYU
BRIGHAM YOUNG UNIVERSITY
Maxwell TECHNOLOGIES
ECD OVONICS
EnerDel
COBASYS
LG Chem
BD Battery Design
University of Toledo

Industry-sponsored projects

The Advanced Lead-Acid Battery Consortium
ALABC
BOLDER Technologies
Ford
RAYOVAC
BAE SYSTEMS
NASA
KATECH
Trojan BATTERY COMPANY
OPTIMA BATTERIES
Compact Power
Kokam Engineering Co., LTD.

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