Overview of NREL HEV Energy Storage Projects

Battery Thermal Management
Battery Modeling and Validation
Ultracapacitor Modeling and Hybridization

National Renewable Energy Laboratory
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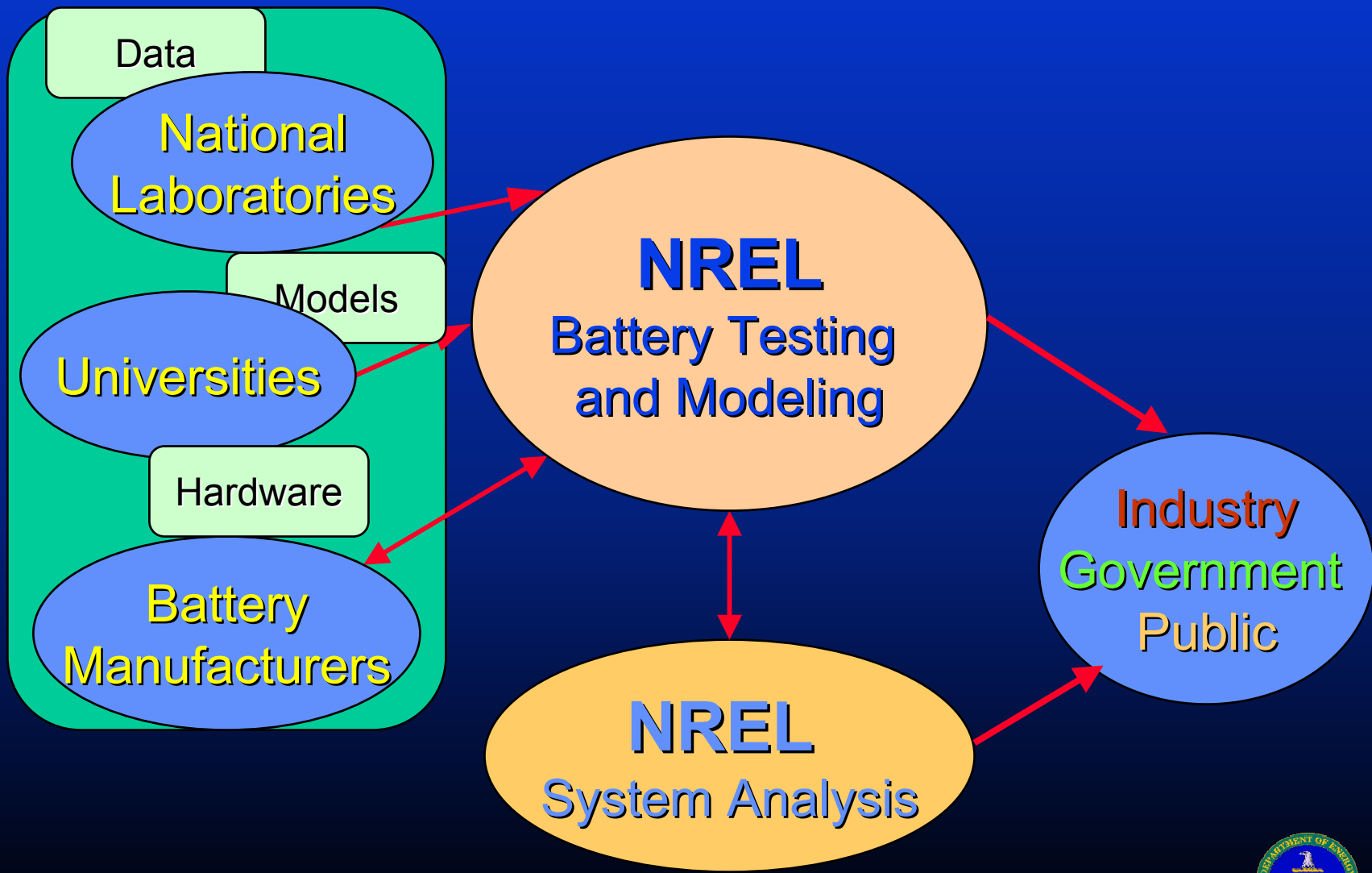
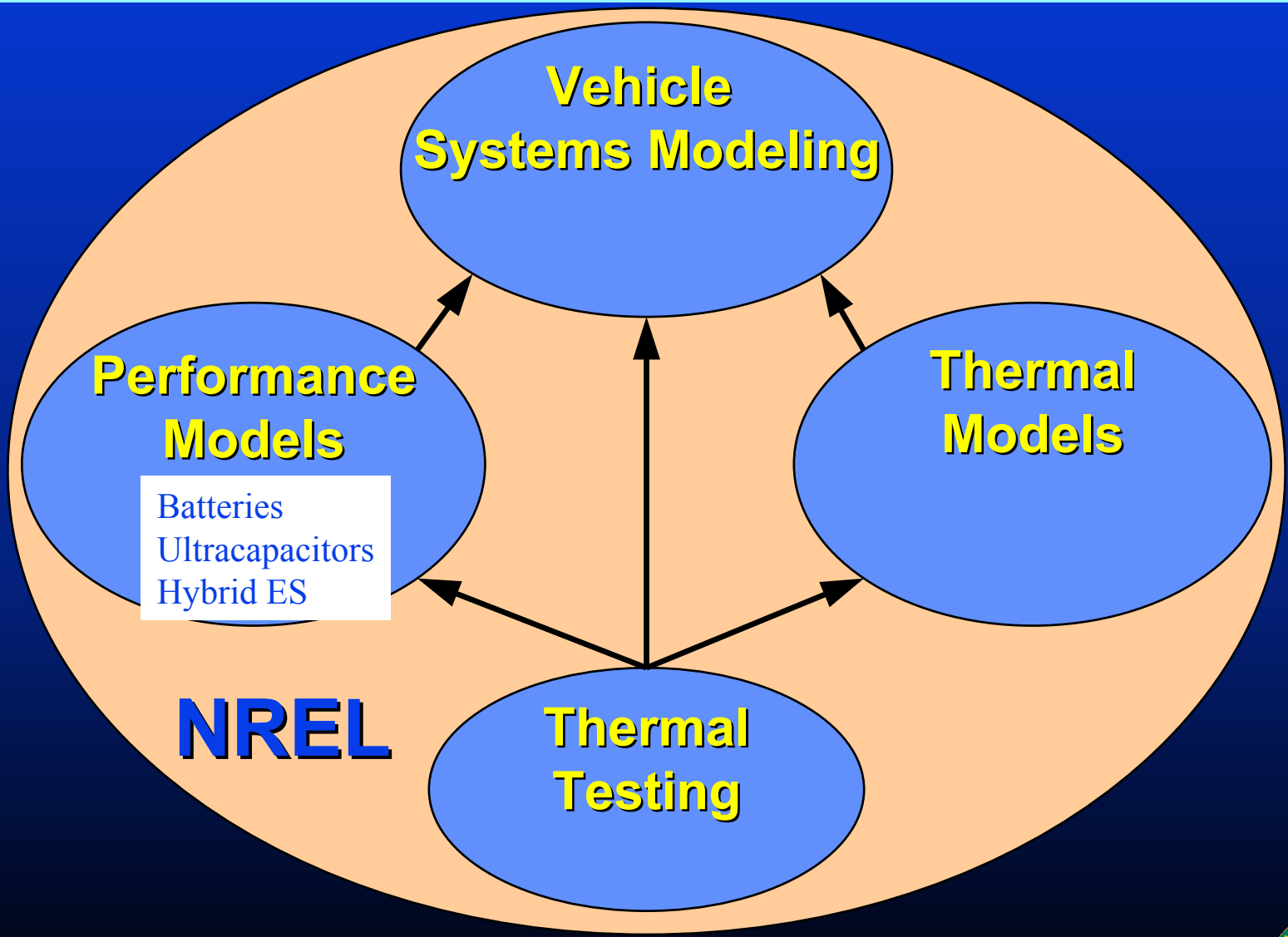
Integrated Battery Modeling and Testing Activities with others organizations

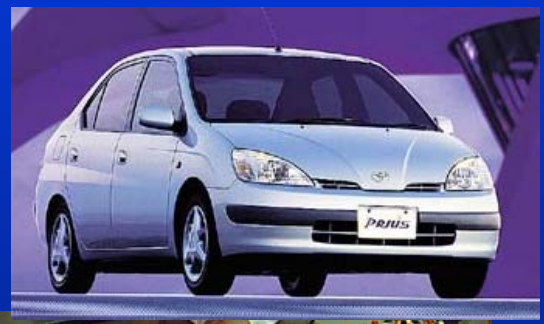


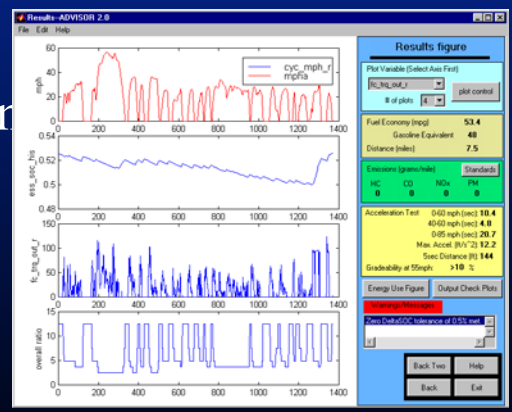
Integrated Battery Modeling and Testing Activities at NREL



Battery Thermal Management: a Core Capability of the NREL's HEV Program

- Needs
  - Battery temperature affects vehicle performance
  - Battery thermal management is needed for achieving performance, life, safety
- Mission
  - supporting the DOE/OTT programs and **industrial** partners with thermal characterization, analysis, and performance modeling of batteries for improving performance, life, safety
- Focus
  - Thermal characterization and evaluation and cells, modules, and packs
  - Developing validated battery performance and thermal models for ADVISOR vehicle simulator





Collaborating with Industry

- DOE-sponsored projects in support program battery and auto manufacturers

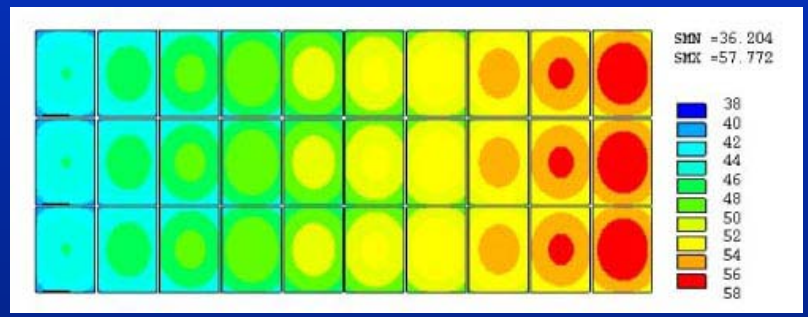
PNGV
PolyStor
GM
OPTIMA BATTERIES
AeroVironment
DEPARTMENT OF ENERGY UNITED STATES OF AMERICA
Ford
JOHNSON CONTROLS
GNB TECHNOLOGIES
TEXAS INSTRUMENTS
DAIMLERCHRYSLER
Compact Power
University of Toledo
SAFT
Energy Conversion Devices, Inc.
Ovonic NiMH

- Industry-sponsored projects in support their internal R&D

The Advanced Lead-Acid Battery Consortium — ALABC
Optimum charging
BOLDER Technologies
Trojan BATTERY COMPANY
Ford
EV applications
RAYOVAC
Zinc-Air

Why Battery Pack Thermal Management?

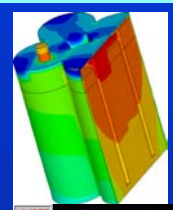
- Regulate pack to operate in the desired temperature range for optimum performance/life

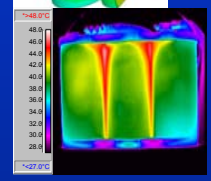
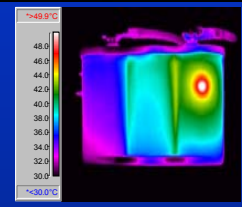


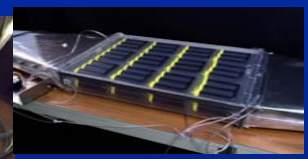
- Reduce uneven temperature distribution in a pack to avoid unbalanced modules/pack and thus, avoid reduced performance
- Improve fuel economy by 2% to 5% with properly designed BTM systems
- Protect battery pack from damage and premature end-of-life and thus saving cost to consumer and energy for manufacturing

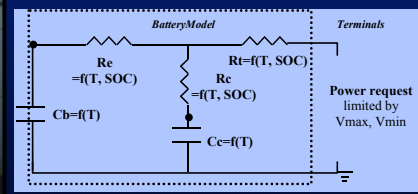
NREL's Battery Thermal Management Capabilities/Expertise

- Thermal analysis (CAD) for proper design, evaluation, and packaging of battery modules/packs
- Thermal imaging for evaluation and diagnostics of battery modules
- Fluid and heat transfer experiments for uniform temperature distribution and low parasitic power designs in battery packs
- Calorimeter/cyclers for measuring module heat generation and heat capacity
- Battery/Capacitor model development and validation for vehicle simulations
- Benchmarking prototype and production battery packs at lab and on dynamometer







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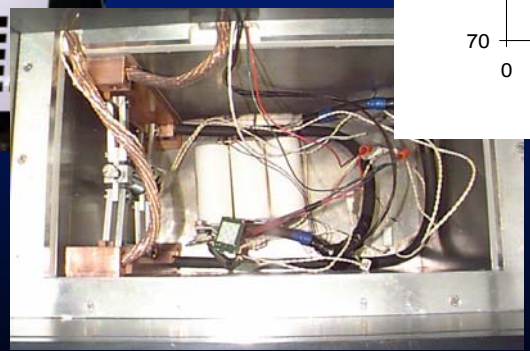
Battery Thermal Management Test Facility

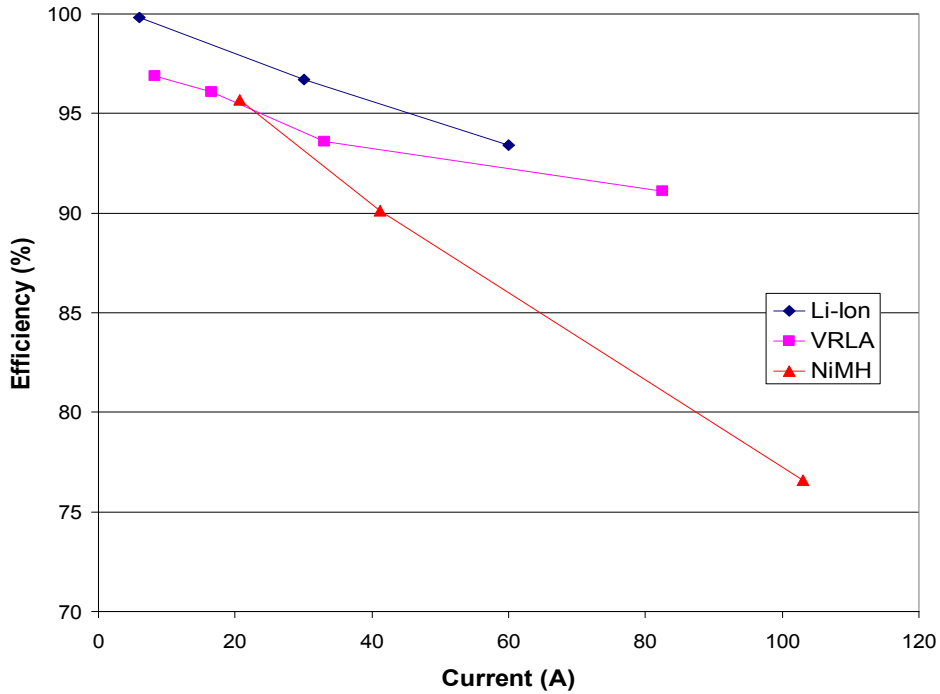
- Large size calorimeter
- ABC-150 bi-directional power unit (120 kW, 440V, 500A)
- Bitrode battery cyclers (12kW-72V, 500A)
- Several environmental chambers and isothermal baths
- Infrared camera

Battery Calorimeter: for Thermal Characterization

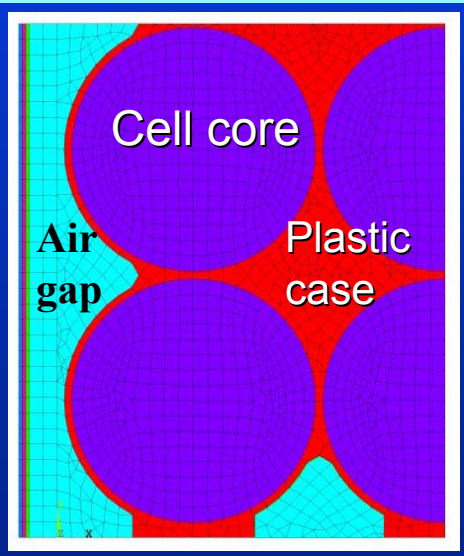
- We use a large conduction calorimeter to measure **heat generation** at various rates, Temp, and SOC and **heat capacity**



Calorimeter Cavity



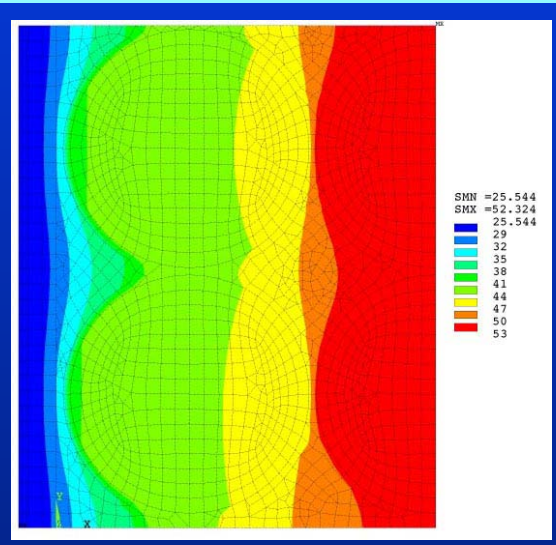
Thermal analysis could improve module thermal performance

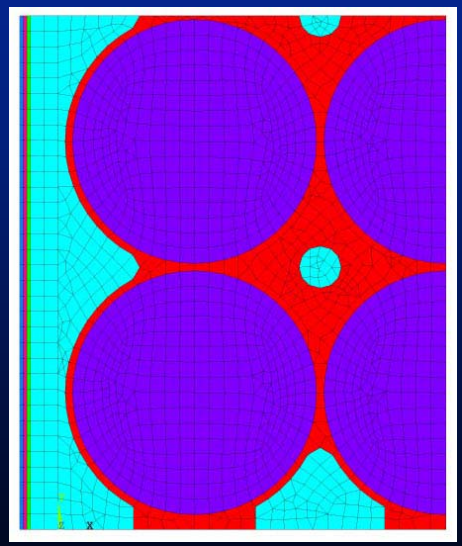


No Holes

Tmax = 53ºC

Delta Tcore = 13ºC

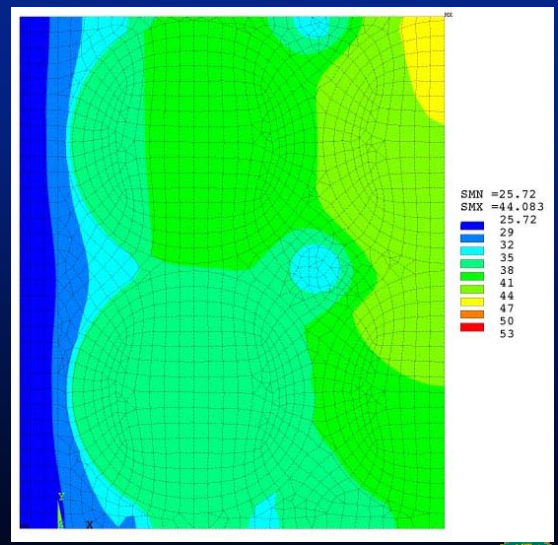




With Holes

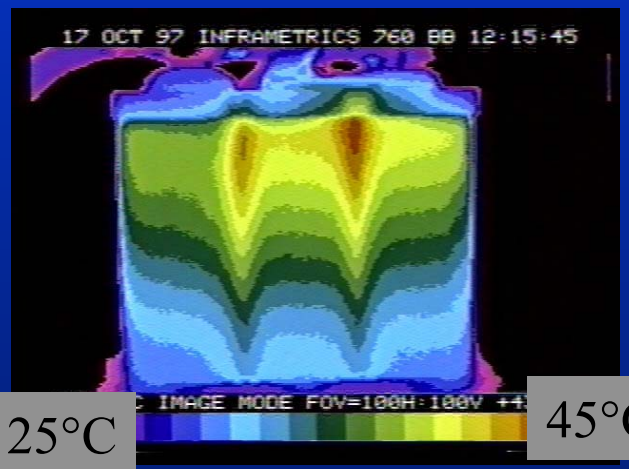
Tmax = 44ºC

Delta Tcore = 9ºC



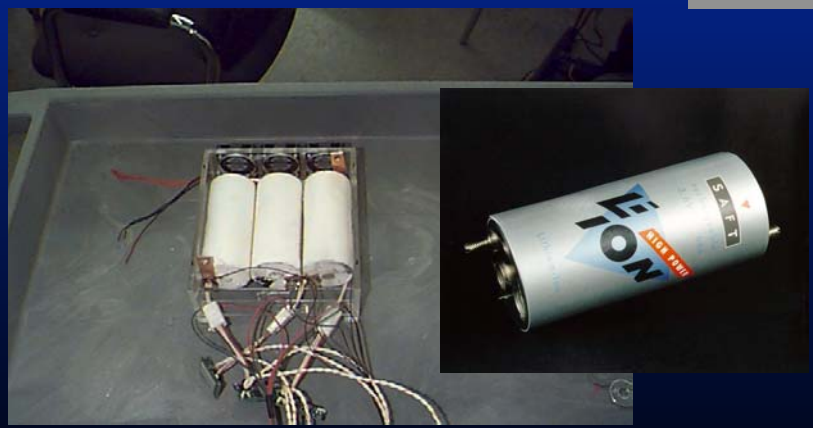
Thermal Imaging: Temperature Distribution is Dictated by Module/Cell Design

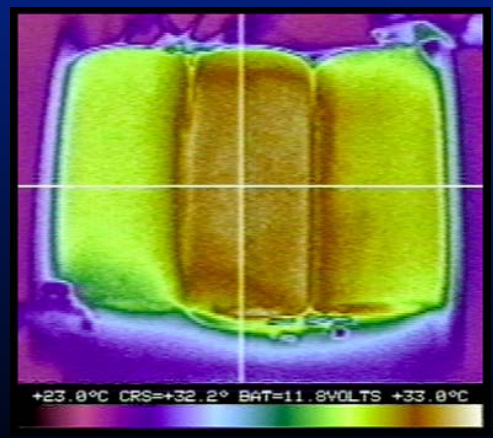
Influencing Factors: aspect ratio, # of cells, geometry, thermal conductivity, location of terminals, current density



25°C 45°C

15°C Difference

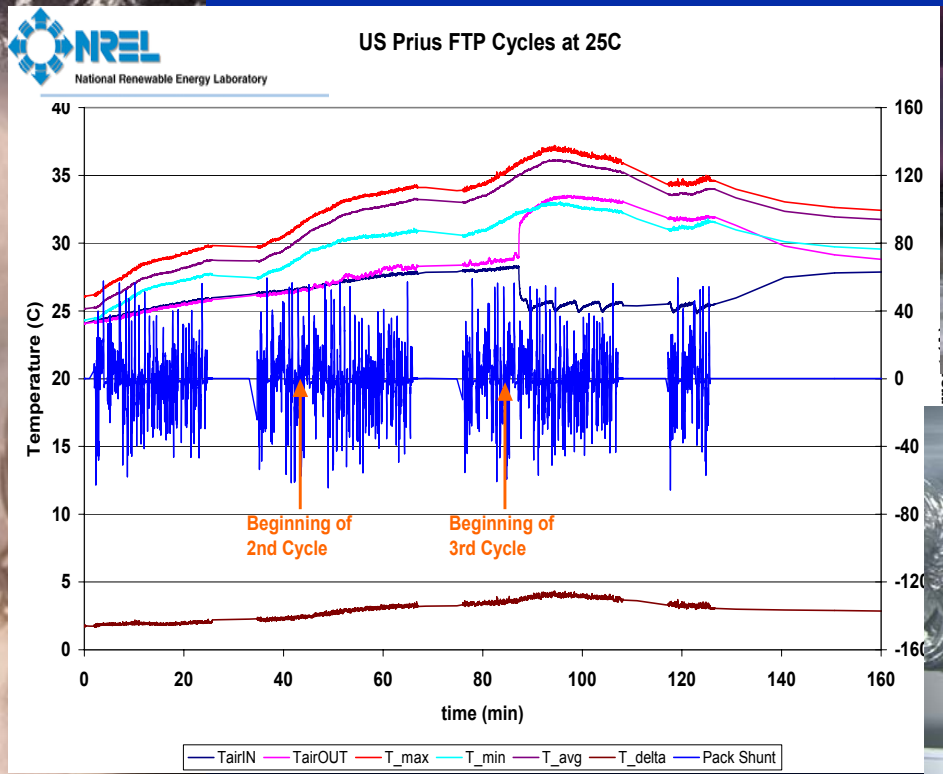


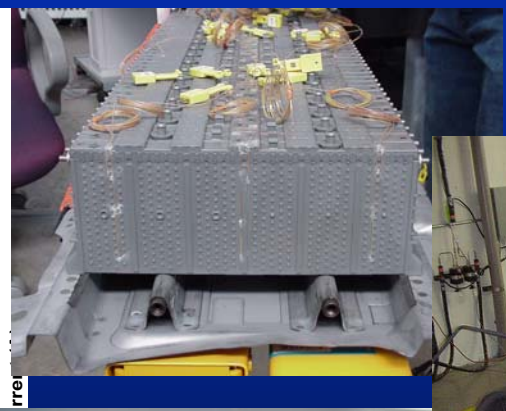


Only 2°C Difference

Benchmarking: Battery Thermal Management Systems in HEVs

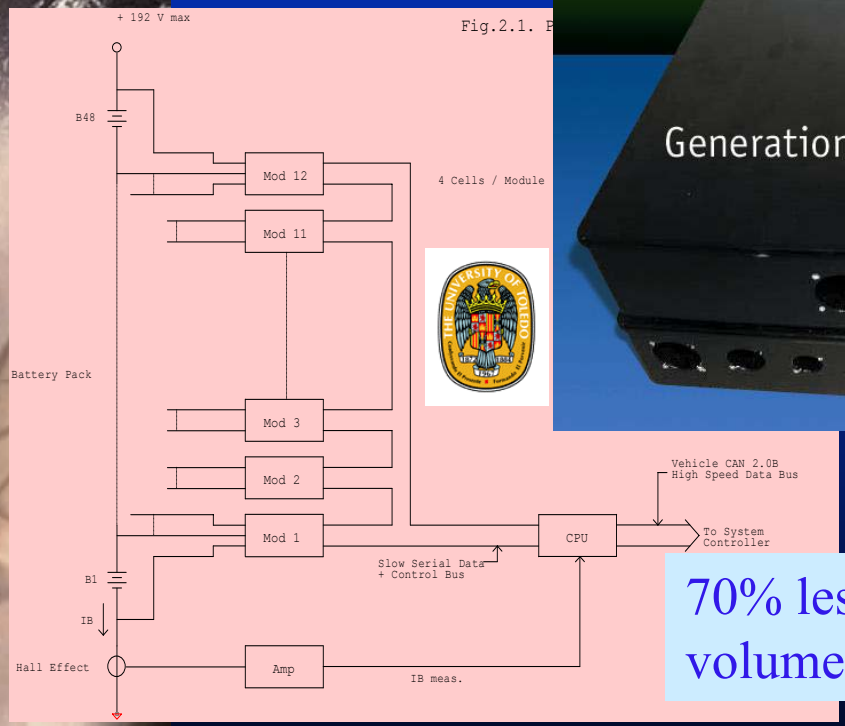
- Tested the Prius pack (out-of-the-vehicle and on dynamometer) under various driving cycles and temperatures.
- Prius battery thermal management works well under most conditions, but its temperature distribution could be improved.

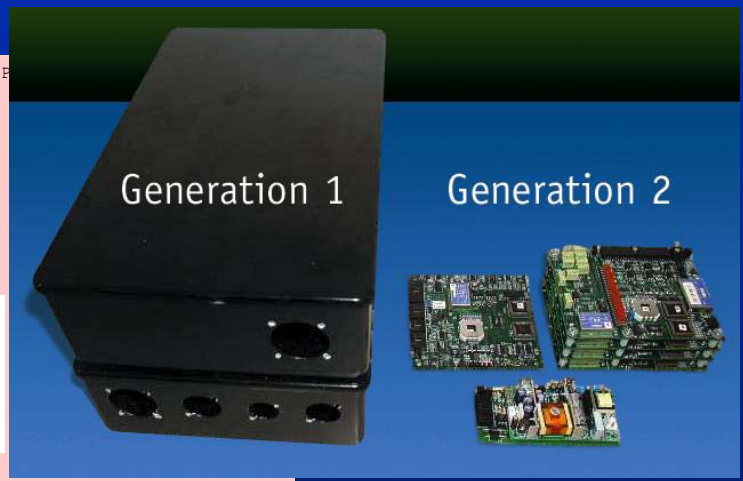




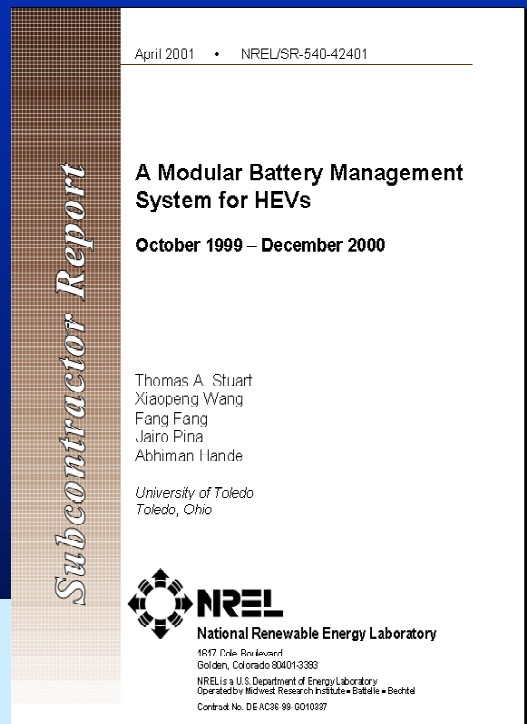
Supported Developing an Improved Battery Management System

- Working with DaimlerChrysler and Texas Instruments, University of Toledo developed a prototype that is much smaller in weight and volume and with better performance and functionality than previous generation.





70% less mass and 80% less volume than first generation



DAIMLERCHRYSLER

TEXAS INSTRUMENTS

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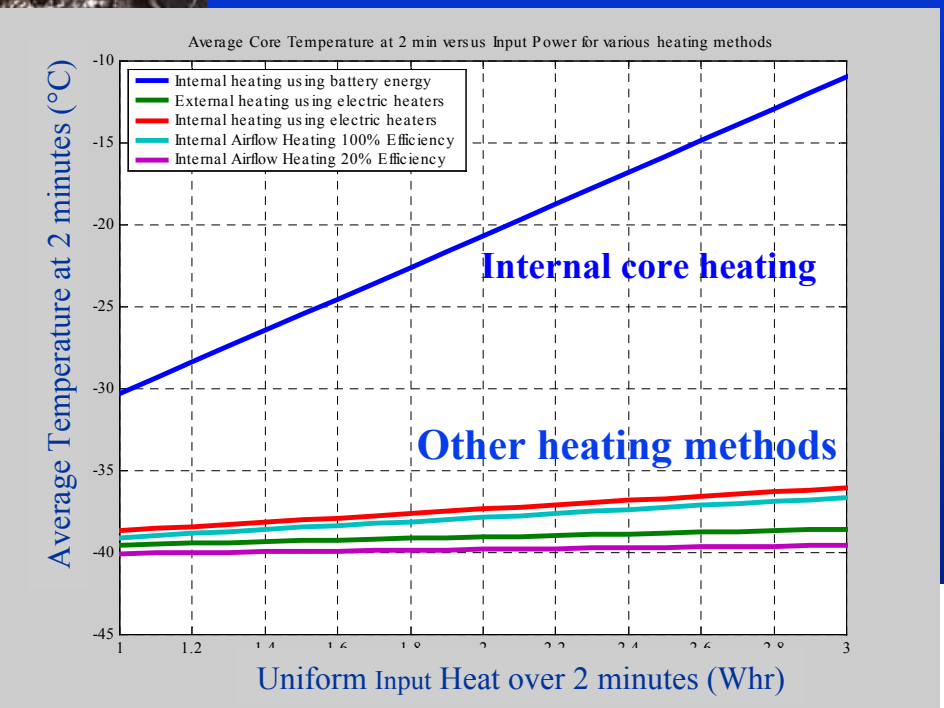
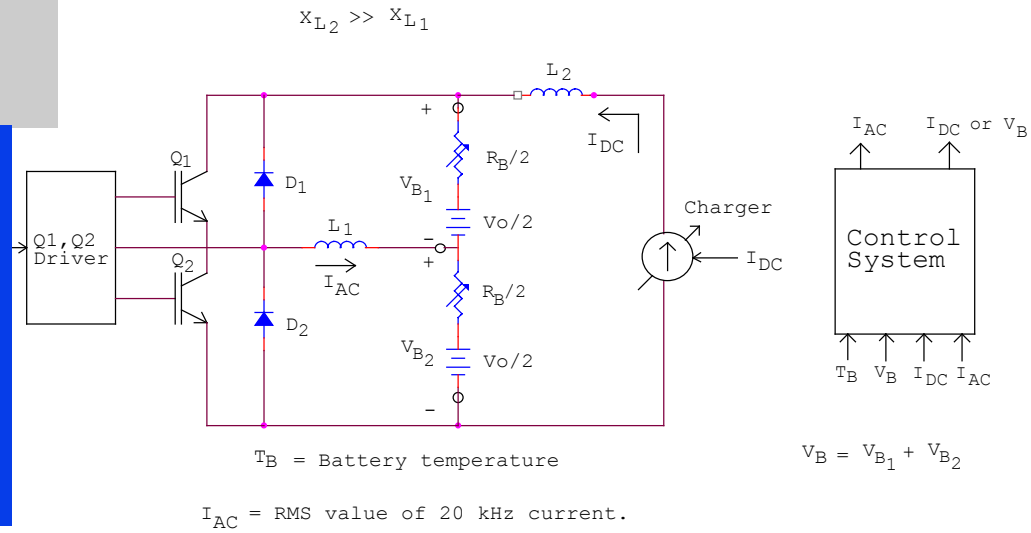
Evaluating High Frequency AC Heating of Batteries at very Cold Temperatures

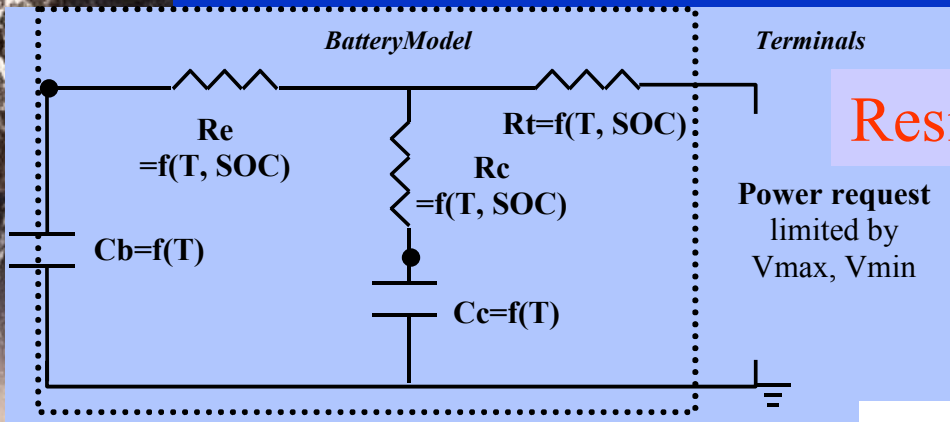


- Analysis has shown that core heating batteries is the most efficient and effective method.
- Core heating can be achieved by applying high frequency AC power through battery terminals
- Because of high battery resistance at low temperature battery heat up

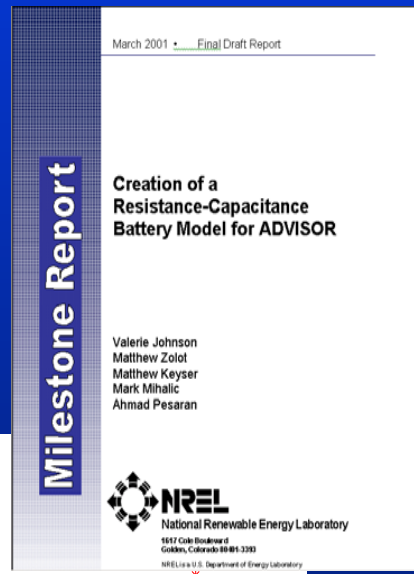
- We are working with University of Toledo to evaluate various AC heating techniques.
- Initial results show that a non-operation lead acid battery at -40°C can be warm up quickly to deliver satisfactory power



Developing Improved Battery Models for ADVISOR/PSAT

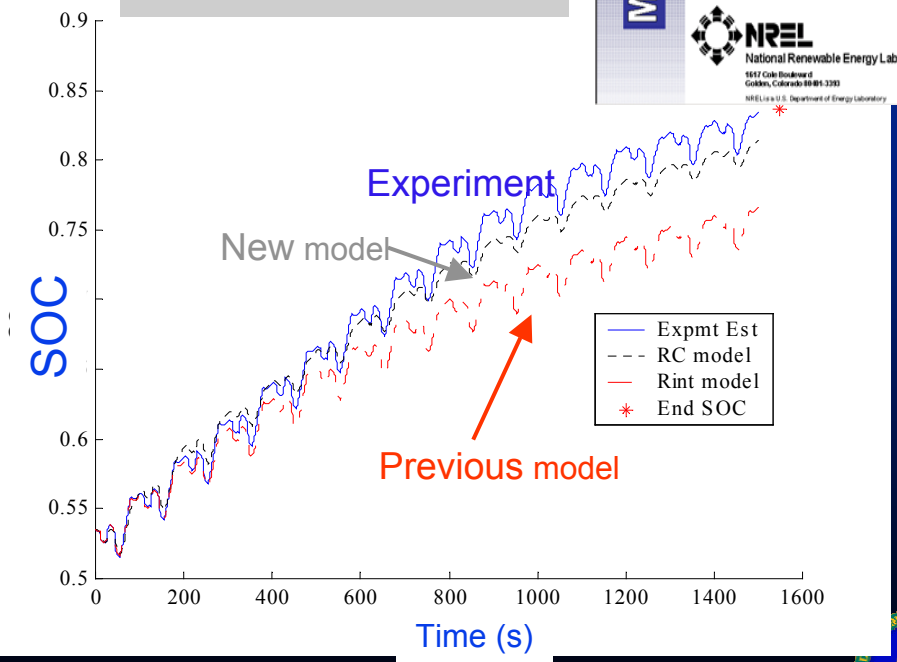


Resistive + Capacitive



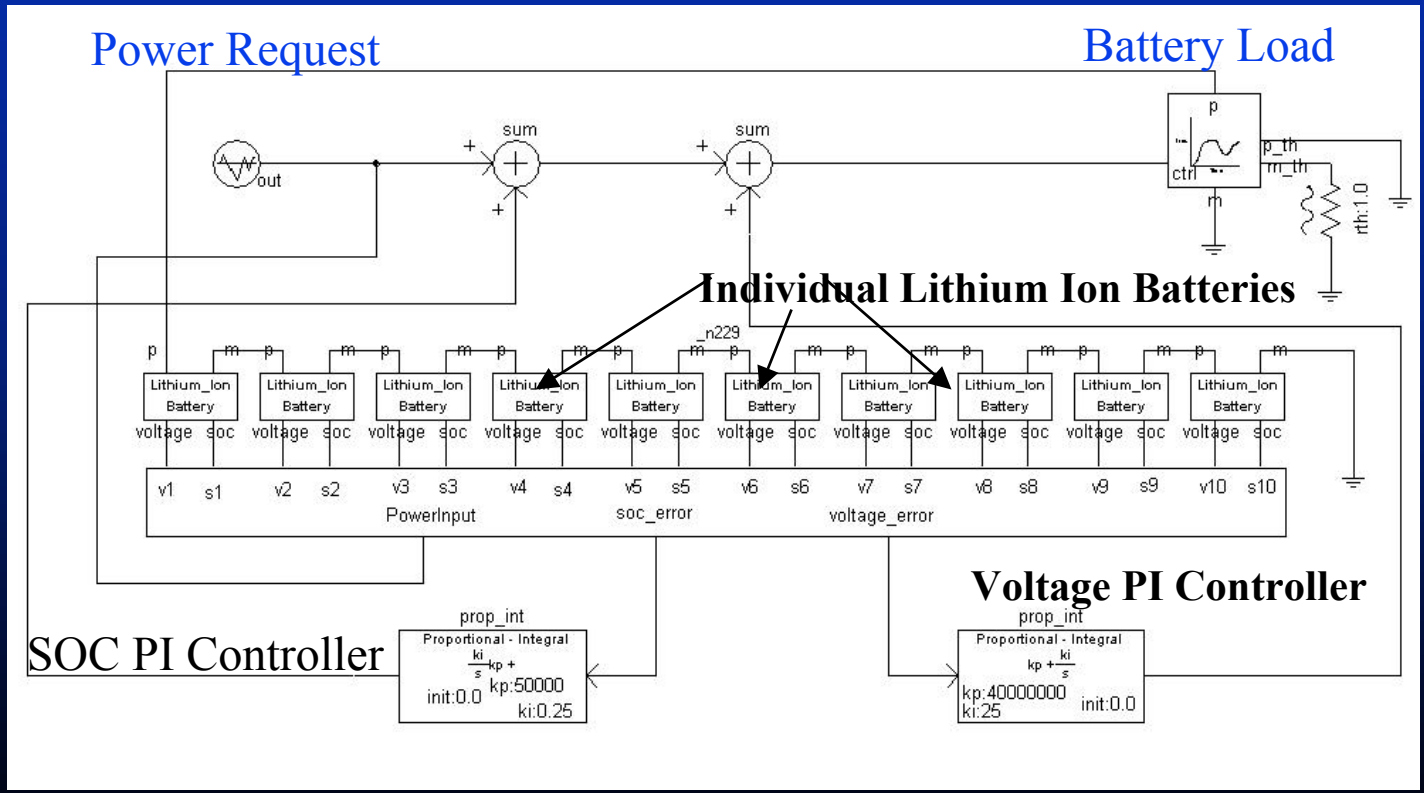
More accurate

New battery model was validated with Saft lithium ion and Panasonic NiMH test data



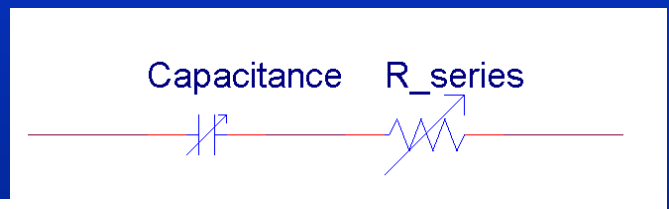
Developing a "Discretized" Battery Pack Model

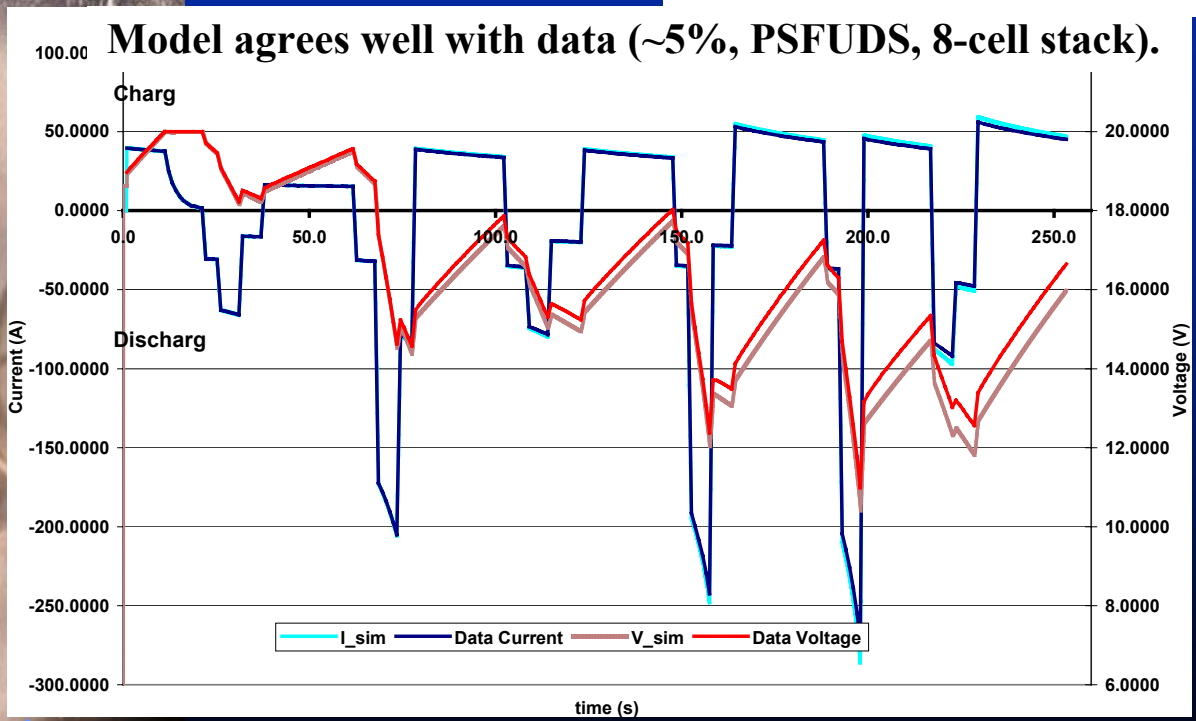
- Capturing individual behavior of each module in the pack rather than treating the pack as a single large module.
- Allows evaluating the impact of pack imbalances in temperature, SOC, resistance.
- Although in Saber, it is co-simulated with ADVISOR for vehicle simulations

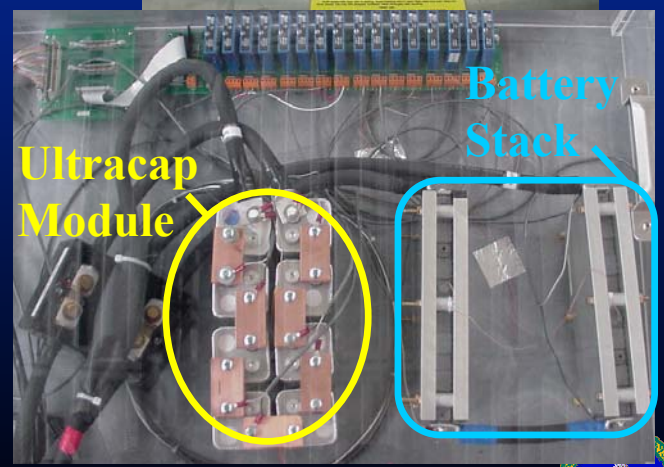


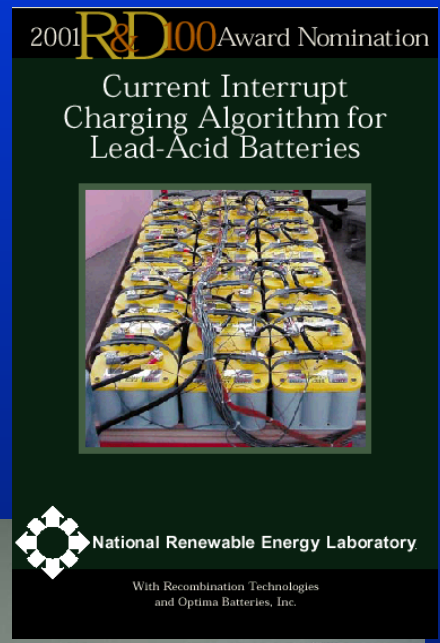
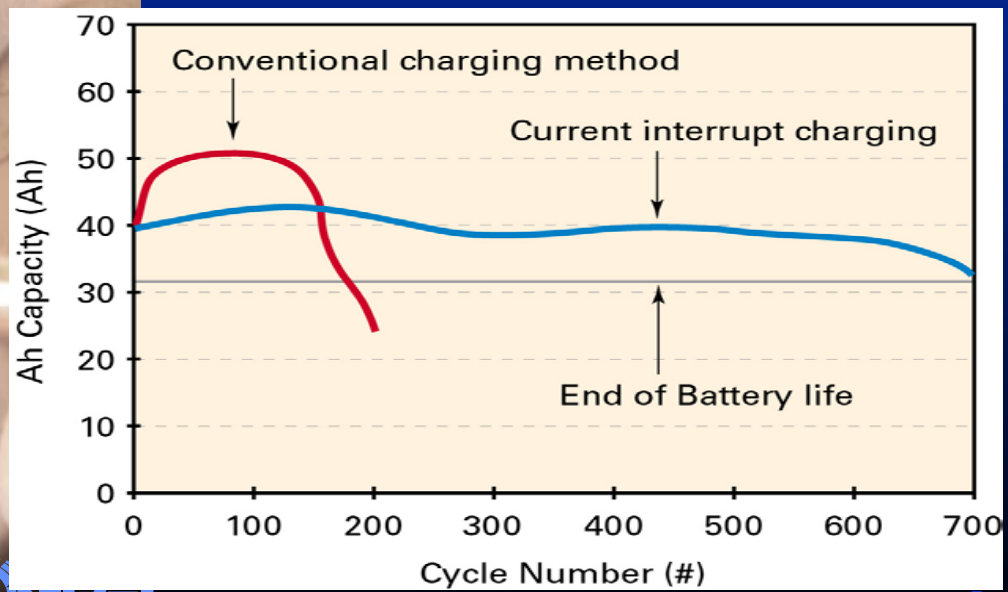
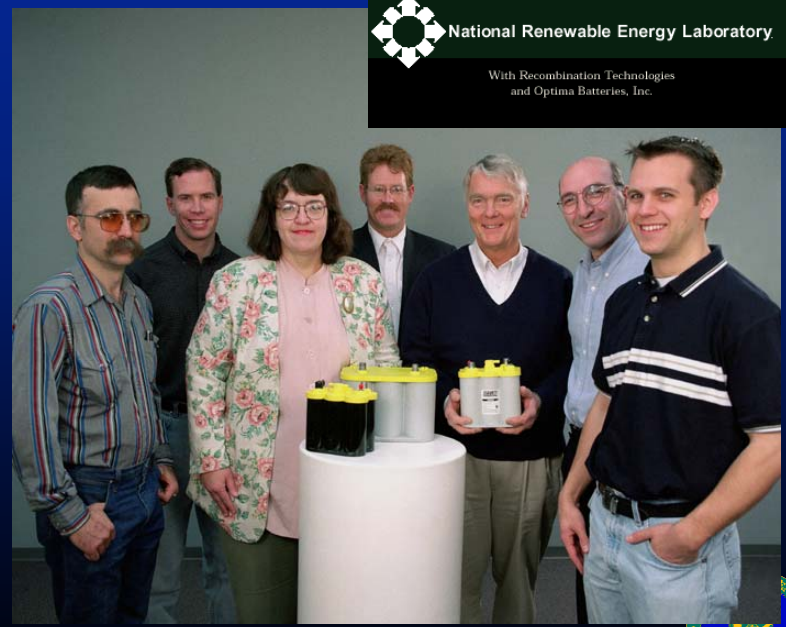
Developing Ultracapacitor Models for Vehicle Simulations and Energy Storage Hybridization

- Tested ultracapacitors and developed a validated Matlab/Simulink model
- Added the ultracapacitor model to ADVISOR for vehicle simulations
- Initiated investigating hybridization of energy storage (battery + ultracapacitor)







HEV Battery Team Won an R&D 100 Award for a Battery Charging Algorithm in 2001

- Collaborated with Recombination Technologies and Optima Batteries with funding from ALABC and DOE support
- Developed and demonstrated that current interrupt charging algorithm for valve regulated lead acid batteries improves life cycle by a factor of 3-4
- Making lead acid batteries competitive for EV applications