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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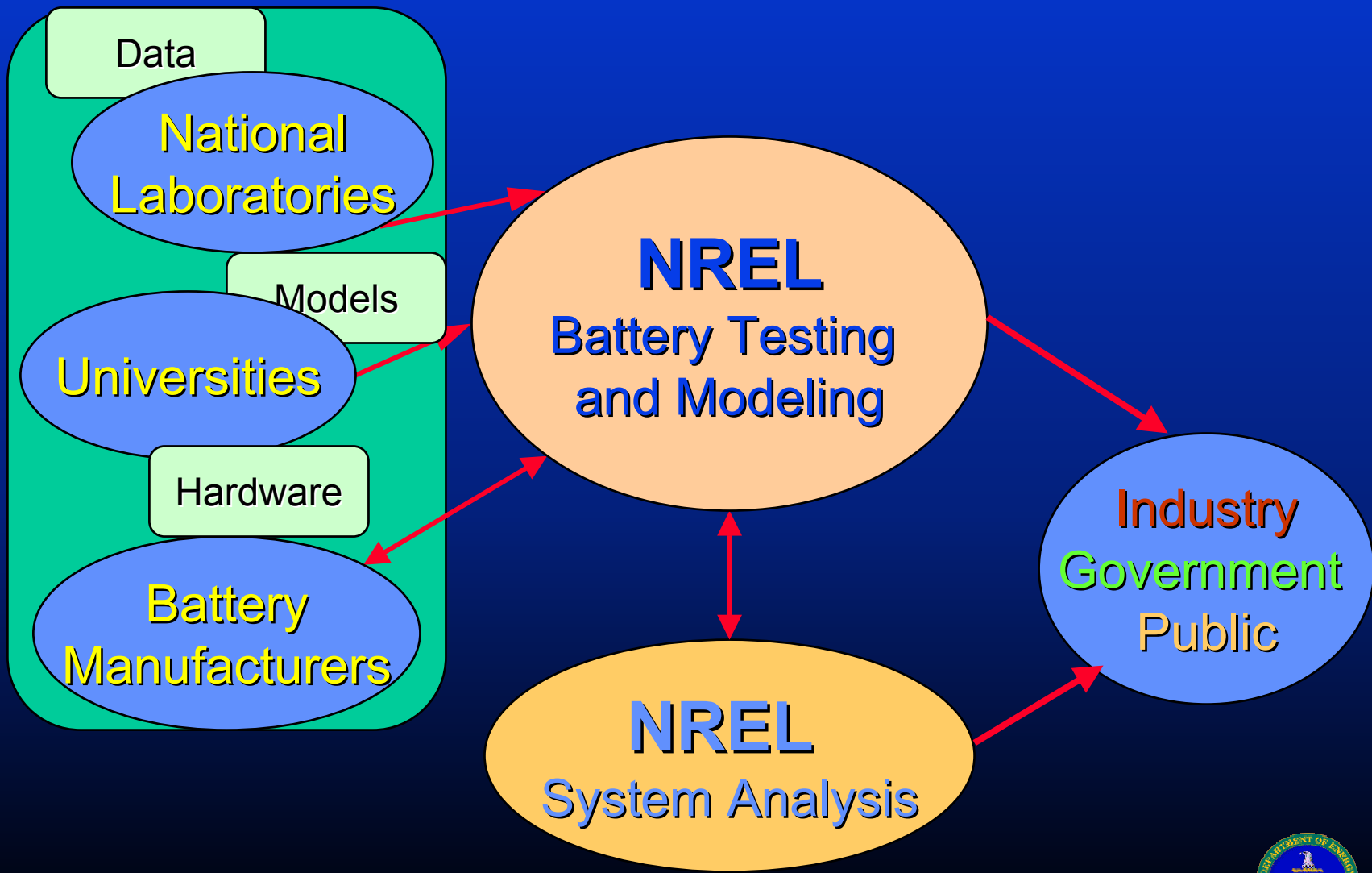
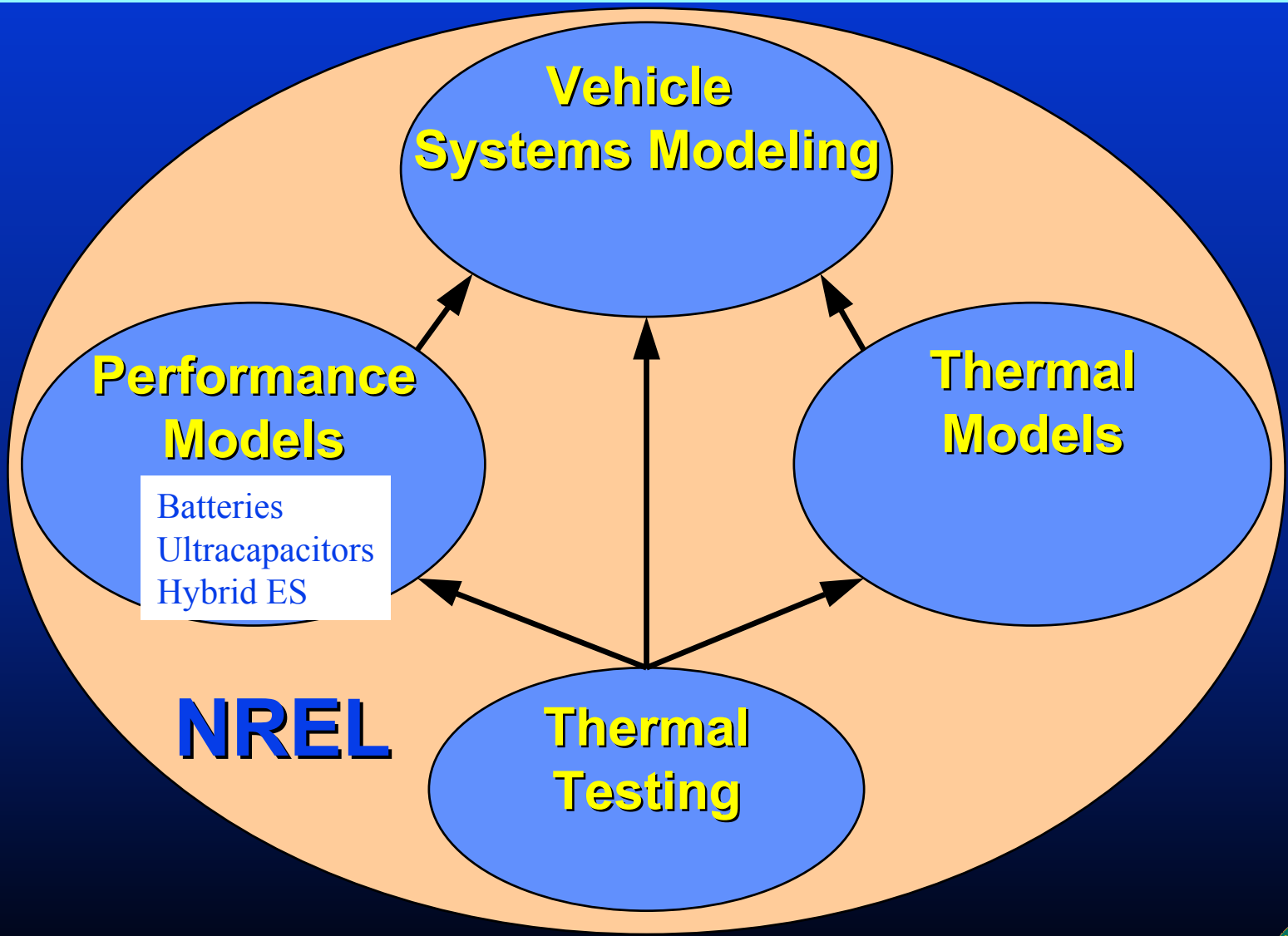
Integrated Battery Modeling and Testing Activities with others organizations

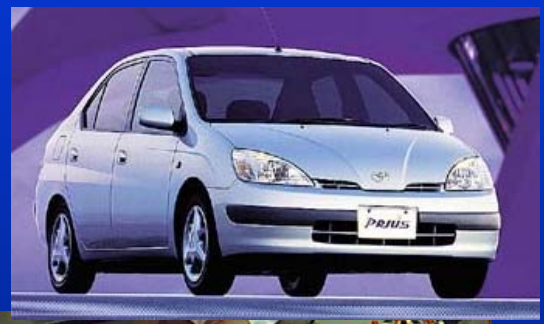


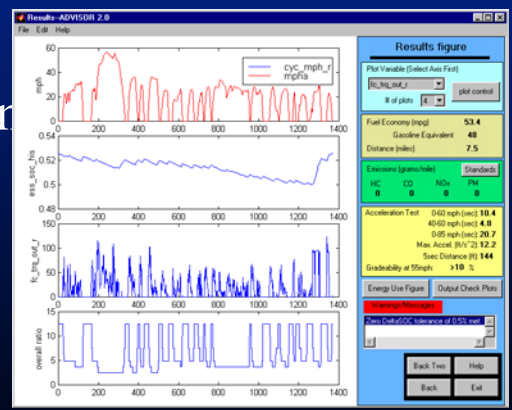
Integrated Battery Modeling and Testing Activities at NREL



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

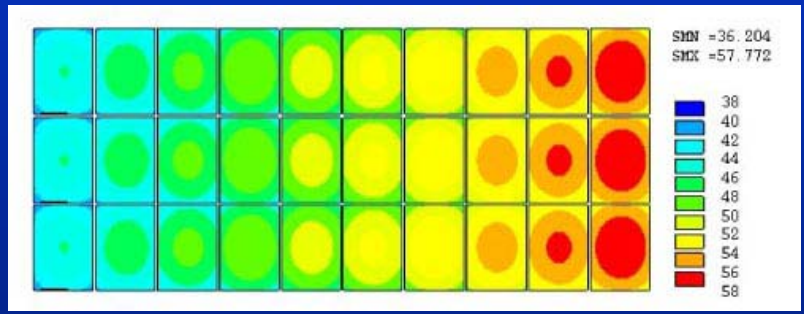
EV applications

RAYOVAC

Zinc-Air

Why Battery Pack Thermal Management?

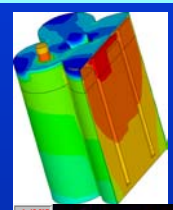
- Regulate pack to operate in the desired temperature range for optimum performance/life

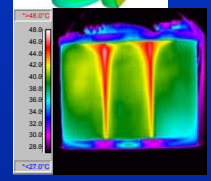
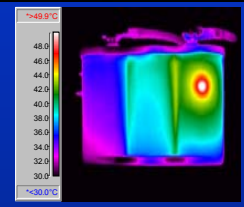


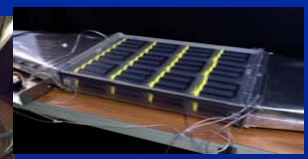
- Reduce uneven temperature distribution in a pack to avoid unbalanced modules/pack and thus, avoid reduced performance
- Improve fuel economy by 2% to 5% with properly designed BTM systems
- Protect battery pack from damage and premature end-of-life and thus saving cost to consumer and energy for manufacturing

NREL's Battery Thermal Management Capabilities/Expertise

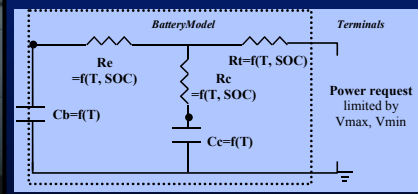
- Thermal analysis (CAD) for proper design, evaluation, and packaging of battery modules/packs
- Thermal imaging for evaluation and diagnostics of battery modules
- Fluid and heat transfer experiments for uniform temperature distribution and low parasitic power designs in battery packs
- Calorimeter/cyclers 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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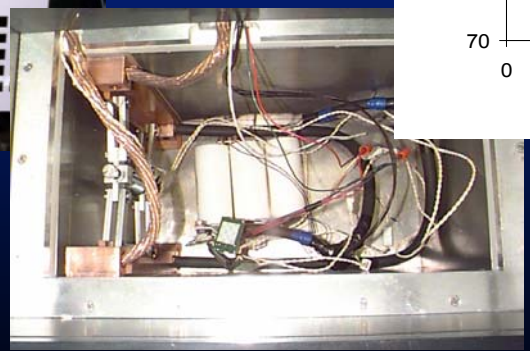
Battery Thermal Management Test Facility

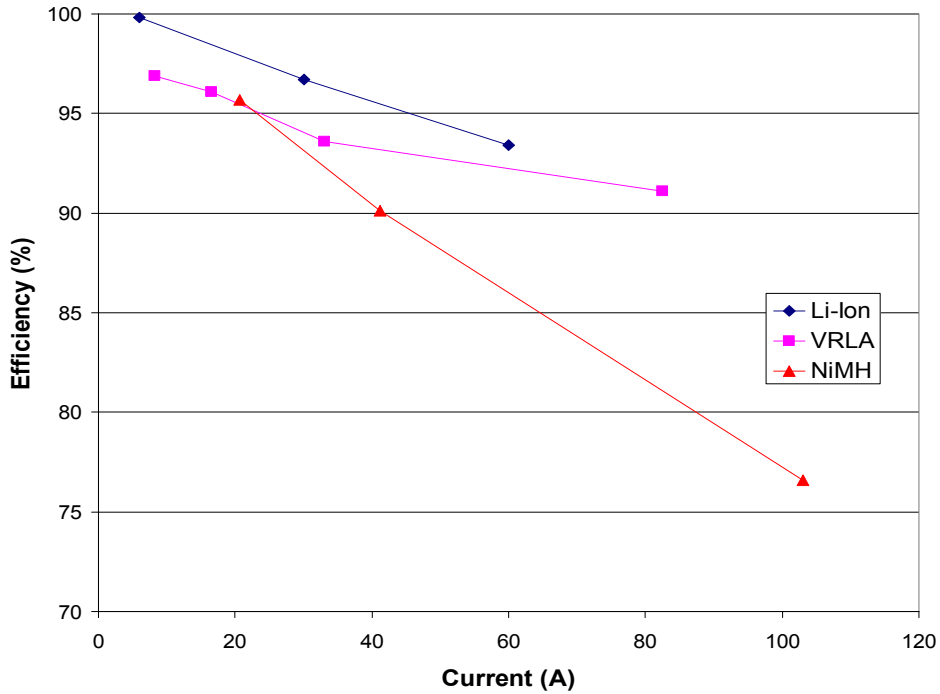
- Large size calorimeter
- ABC-150 bi-directional power unit (120 kW, 440V, 500A)
- Bitrode battery cyclers (12kW-72V, 500A)
- Several environmental chambers and isothermal baths
- Infrared camera

Battery Calorimeter: for Thermal Characterization

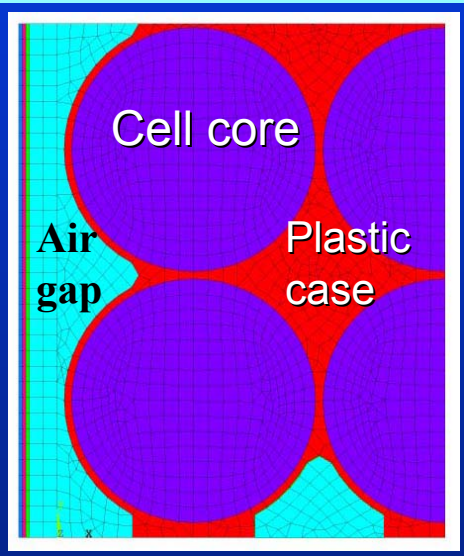
- We use a large conduction calorimeter to measure **heat generation** at various rates, Temp, and SOC and **heat capacity**



Calorimeter Cavity



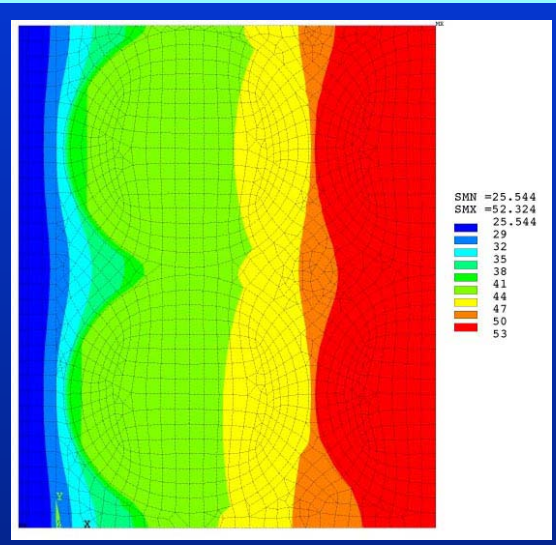
Thermal analysis could improve module thermal performance

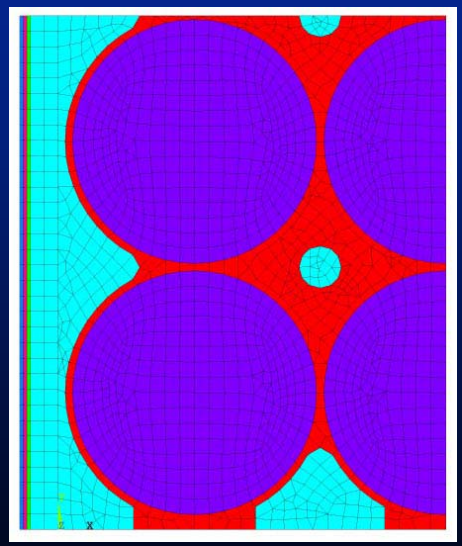


No Holes

Tmax = 53ºC

Delta Tcore = 13ºC

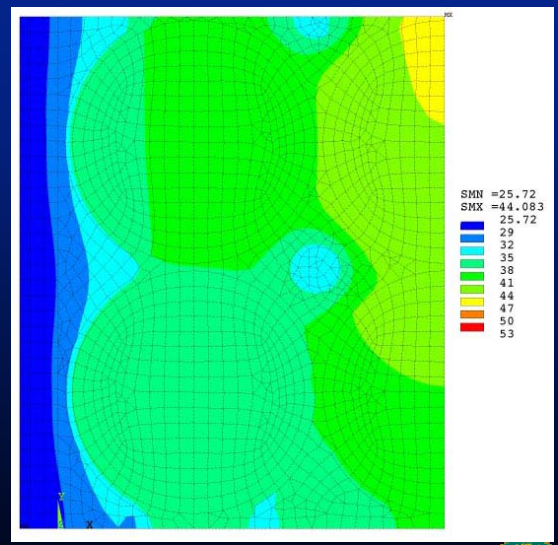




With Holes

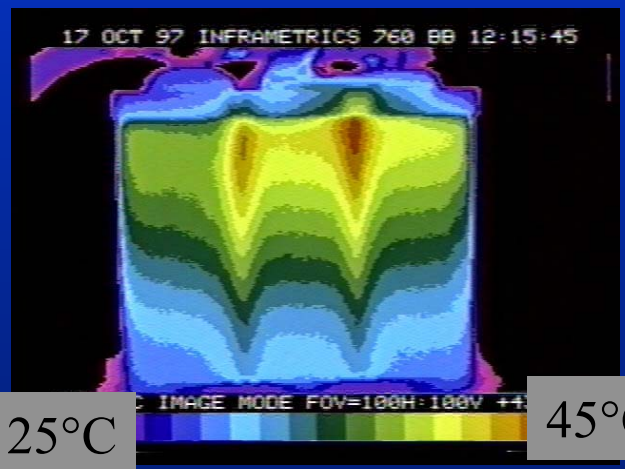
Tmax = 44ºC

Delta Tcore = 9ºC



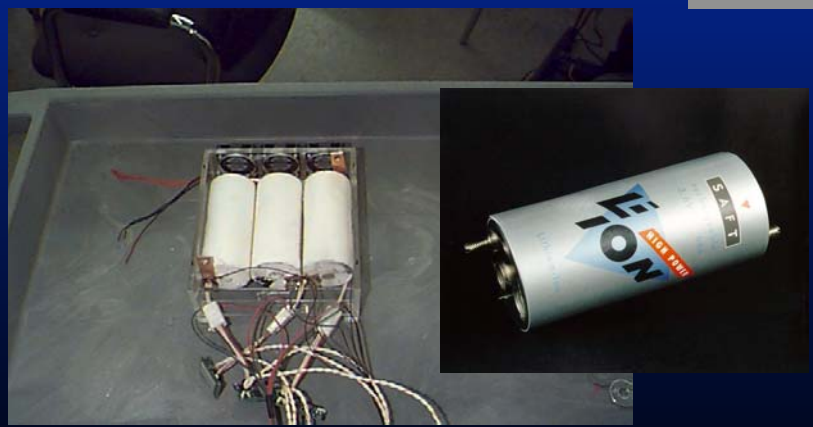
Thermal Imaging: Temperature Distribution is Dictated by Module/Cell Design

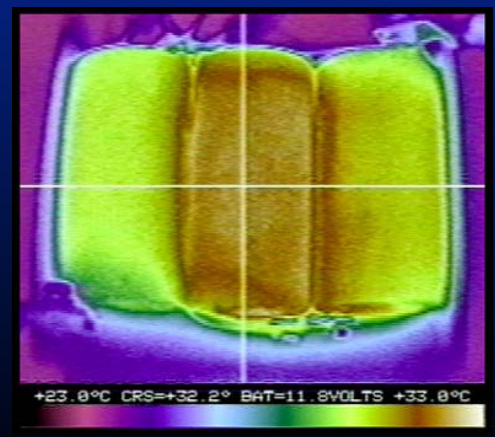
Influencing Factors: aspect ratio, # of cells, geometry, thermal conductivity, location of terminals, current density



25°C 45°C

15°C Difference

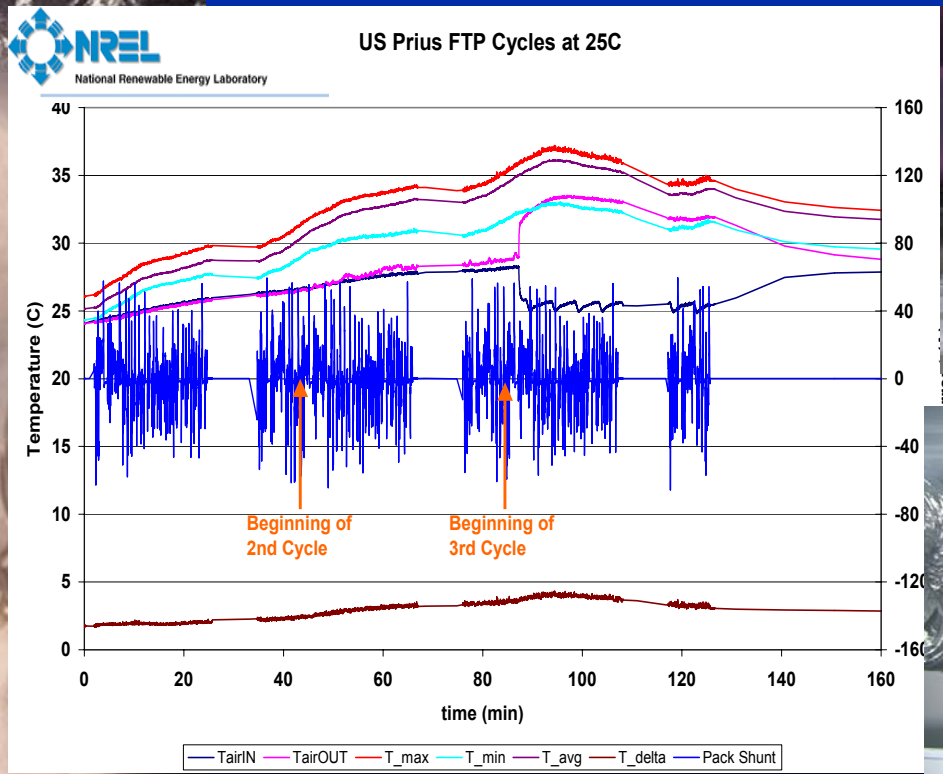




Only 2°C Difference

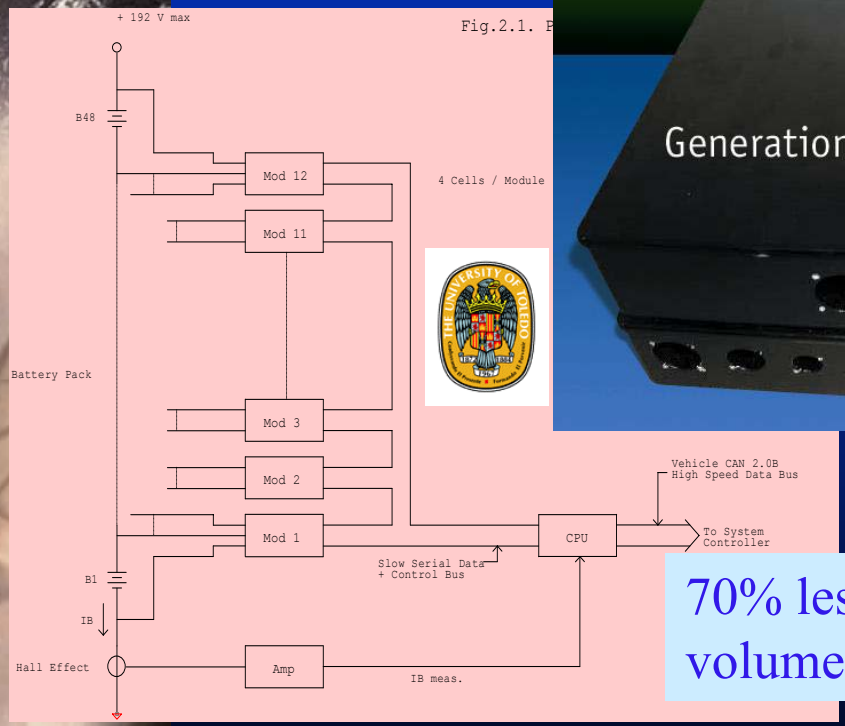
Benchmarking: Battery Thermal Management Systems in HEVs

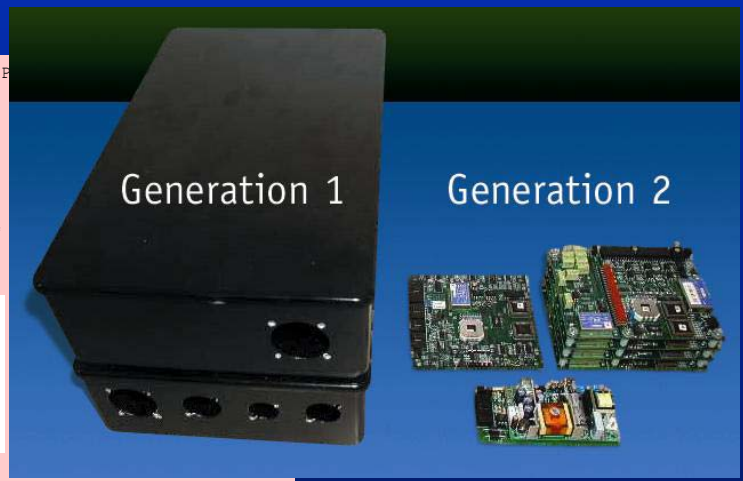
- Tested the Prius pack (out-of-the-vehicle and on dynamometer) under various driving cycles and temperatures.
- Prius battery thermal management works well under most conditions, but its temperature distribution could be improved.



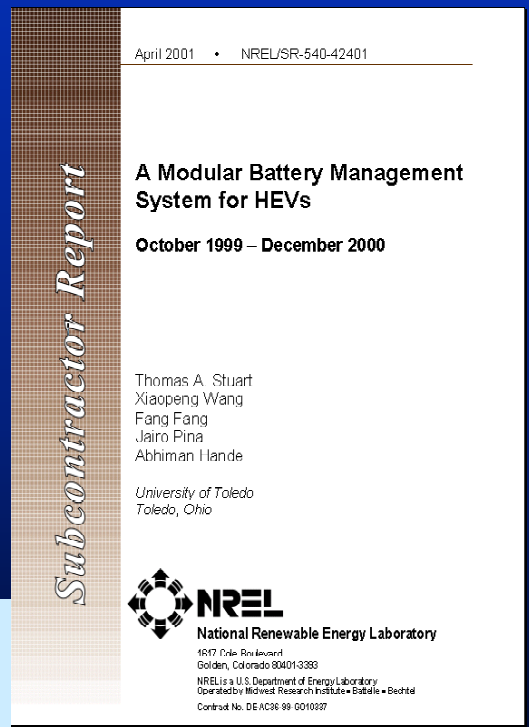
Supported Developing an Improved Battery Management System

- 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



TEXAS INSTRUMENTS

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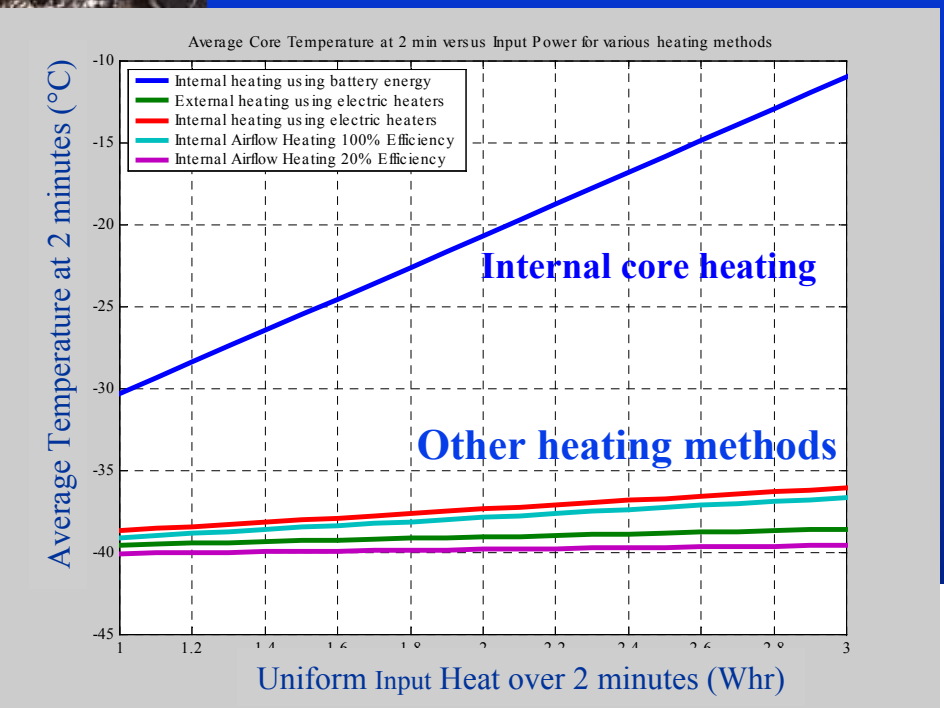
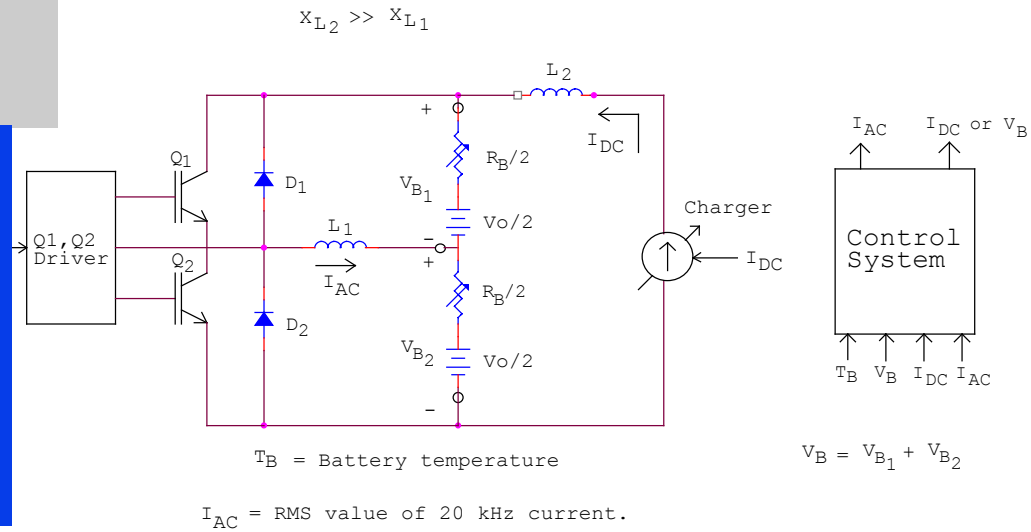
Evaluating High Frequency AC Heating of Batteries at very Cold Temperatures

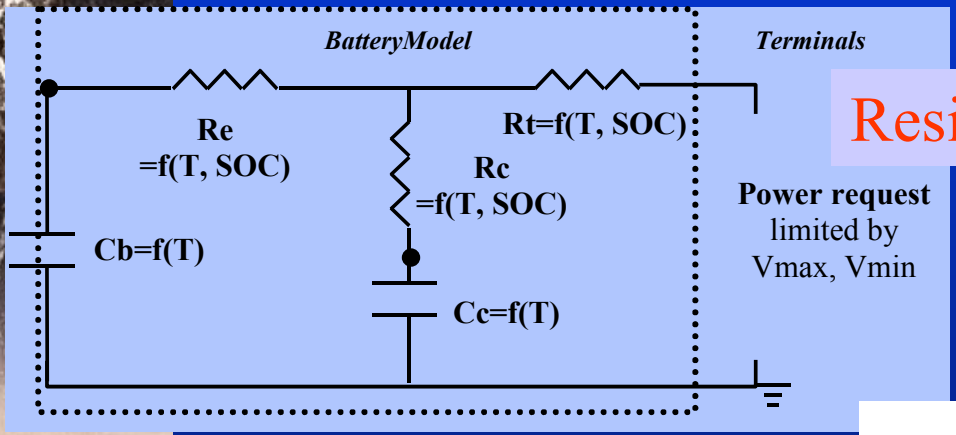


- Analysis has shown that core heating batteries is the most efficient and effective method.
- Core heating can be achieved by applying high frequency AC power through battery terminals
- Because of high battery resistance at low temperature battery heat up

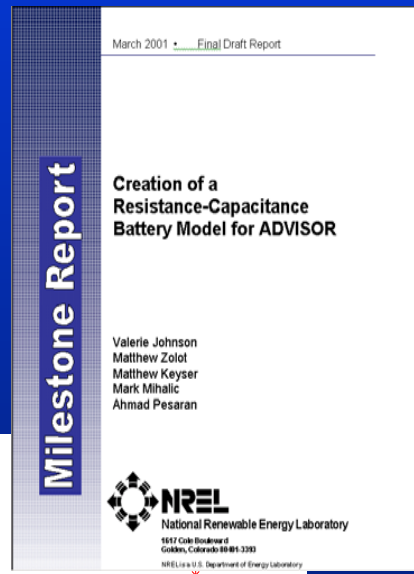
- We are working with University of Toledo to evaluate various AC heating techniques.
- Initial results show that a non-operation lead acid battery at -40°C can be warm up quickly to deliver satisfactory power



Developing Improved Battery Models for ADVISOR/PSAT

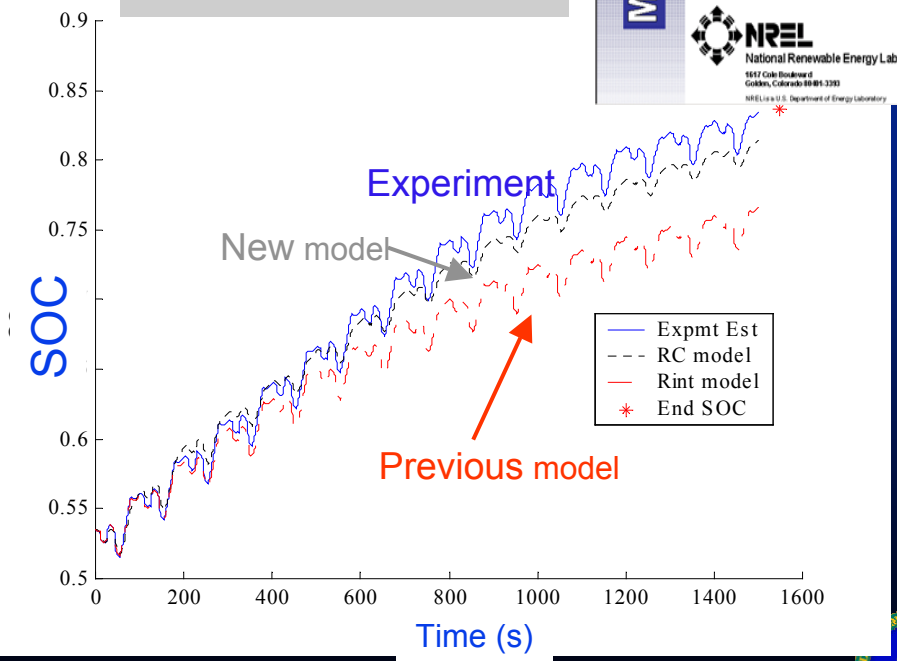


Resistive + Capacitive



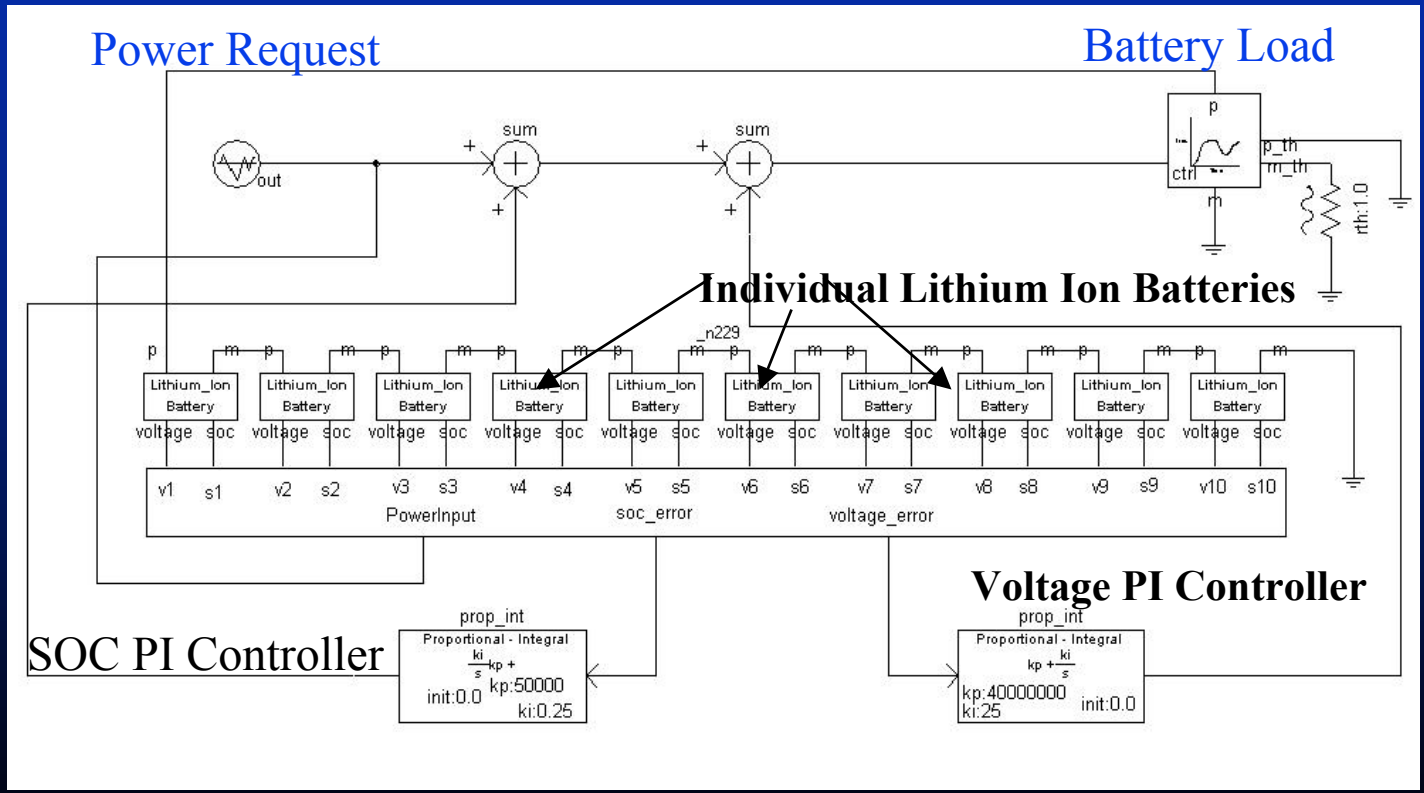
More accurate

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



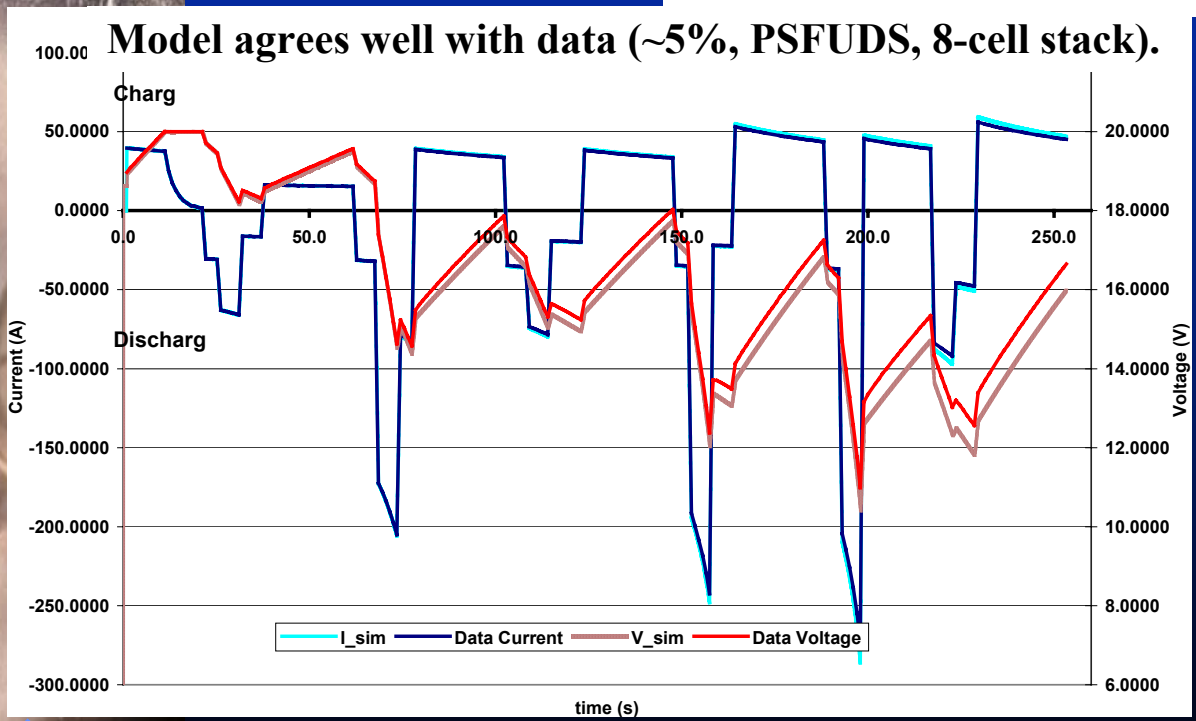
Developing a "Discretized" Battery Pack Model

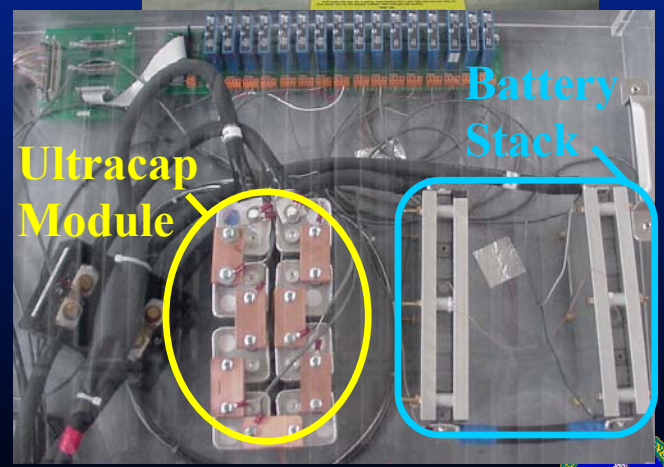
- Capturing individual behavior of each module in the pack rather than treating the pack as a single large module.
- Allows evaluating the impact of pack imbalances in temperature, SOC, resistance.
- Although in Saber, it is co-simulated with ADVISOR for vehicle simulations



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