Overview and Progress of the Battery Testing, Design, and Analysis Activity

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Energy Storage R&D
Hybrid and Electric Systems Team
Vehicle Technologies Office

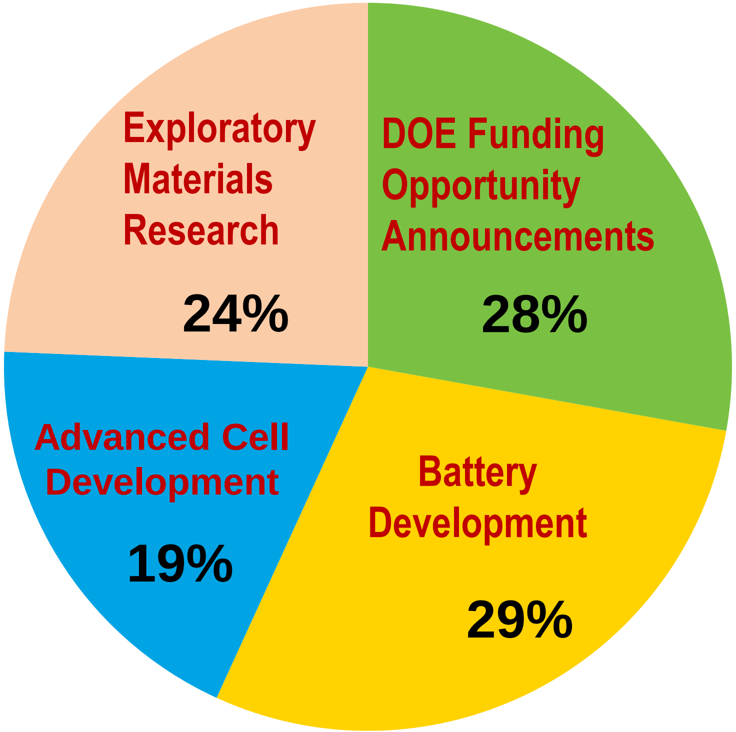
Tuesday, June 17, 2014

Project ID: ES116

Battery R&D Budget

Yearly Battery/Energy Storage R&D Funding ($,M)	
FY 2013	$88
FY 2014	$85
FY 2015 (request)	$100
inclusive of SBIR/STTR.	

FY 2014 Major R&D Activities



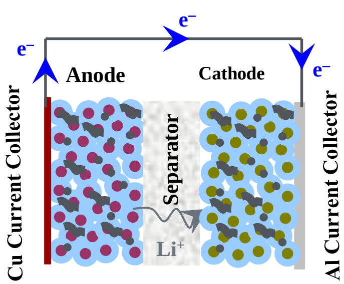
Energy Storage R&D

CHARTER: Develop battery technology that will enable large market penetration of electric drive vehicles

- By *2014,* develop a PHEV battery that can deliver a 40-mile all-electric range and costs $3,400
- By *2022,* develop an EV battery that can store 40 kWh of electricity and costs $5,000

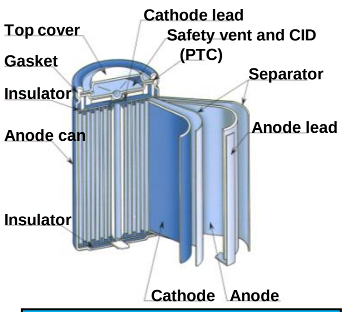
Energy Storage R&D

Exploratory Technology Research



New Materials R&D, Diagnostics, Modeling

Applied Battery Research for Transportation

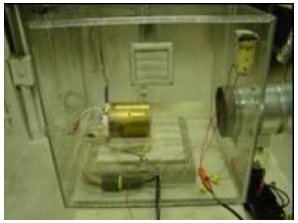


Next Generation Cell R&D

Battery Development

Battery Development & Cost Reduction

Battery Testing, Design & Analysis



Standardized Testing Life/Cost Projections Design Tools

Testing (~60% of TDA funding)

Performance | **Thermal** | **Abuse**

Core Testing Facilities for Deliverables

INL

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

Argonne
NATIONAL LABORATORY

Developmental Test Methods and Tools

Performance:

- Technology Life Verification Testing
- Smart Battery Status Monitor
- Developmental and Applied Diagnostics

Abuse:

- Development of Techniques to Study Internal Shorts
- Internal Short Circuit Emulation
- Aged Cell Testing

Battery Testing Throughput

Performance

Idaho National Laboratory

Over 25 programs tested
- **> 450 cells**
- **> 30 modules**
- **5 packs**

Argonne National Laboratory

Over 10 programs tested
- **> 150 cells**
- **1 pack**

Abuse

Sandia National Laboratories

Over 10 programs tested
- **> 200 cells**
- **> 40 modules**

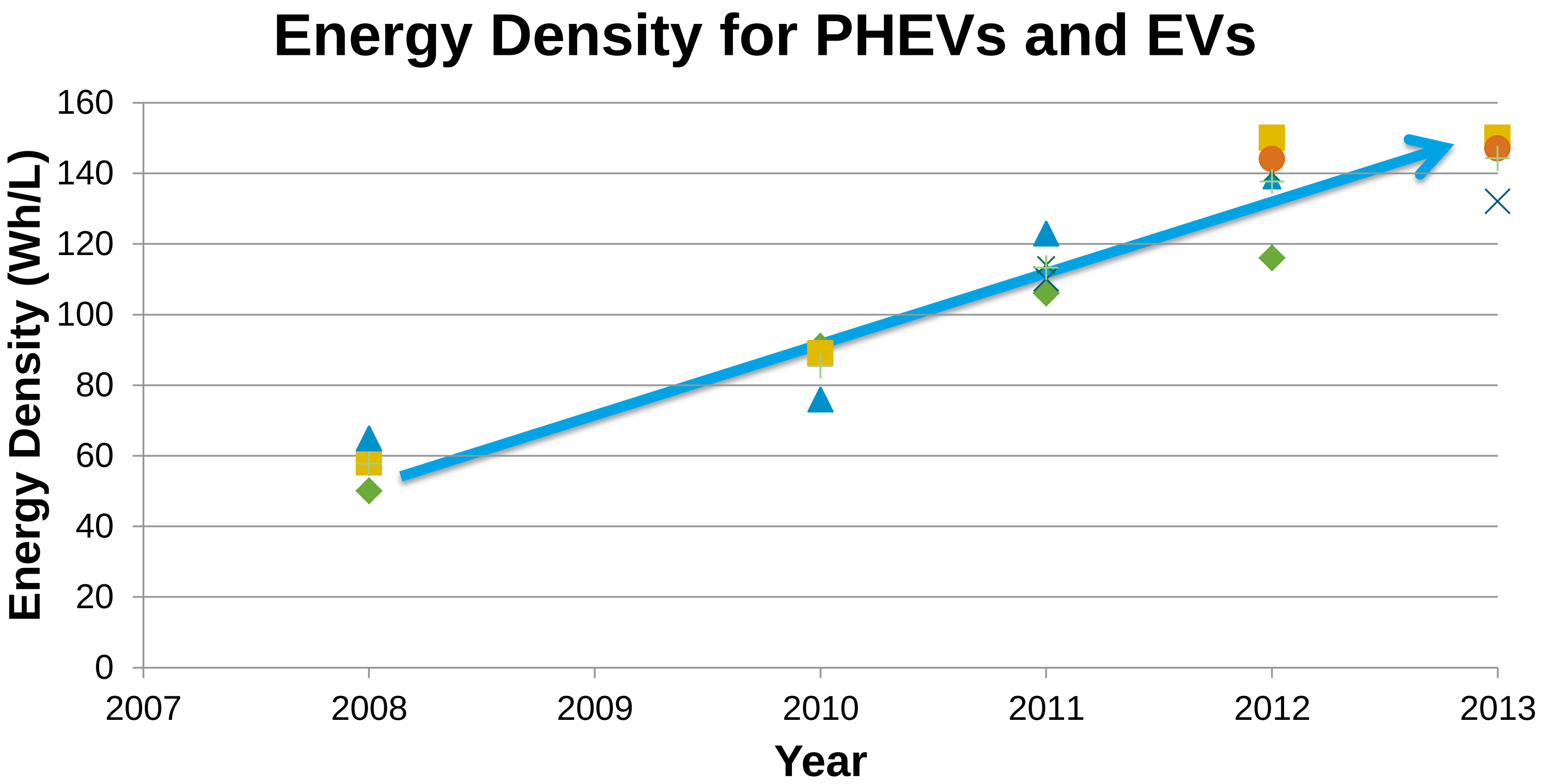
Thermal

NREL National Renewable Energy Laboratory

Over 10 programs tested
- **> 35 cells**
- **2 modules**
- **1 pack**

Battery Programs Tested

Johnson Controls
SK energy
DOW KOKAM
COBASYS
SAMSUNG
3M
ActaCell
TIAX
SAKTI3
LISHEN
A123 SYSTEMS
cpi compact power, inc.
LG Chem
envia SYSTEMS
AXION POWER INTERNATIONAL INC.
QUALLION
K2 Energy
Maxwell TECHNOLOGIES
Leyden energy
saft
Hydro Québec
ENTEK INTERNATIONAL
MILTEC
amprius
APPLIED MATERIALS
nanosys
SEEO
FARASIS
EXIDE BATTERIES
OneD material
EAST PENN manufacturing co., inc.



As DOE expanded its focus from HEVs to PHEVs in 2008, energy density of system deliverables at end-of-life has increased from about 60 Wh/L to about 150 Wh/L. DOE's goal for 2022 is 400 Wh/L.

Battery Testing Trends

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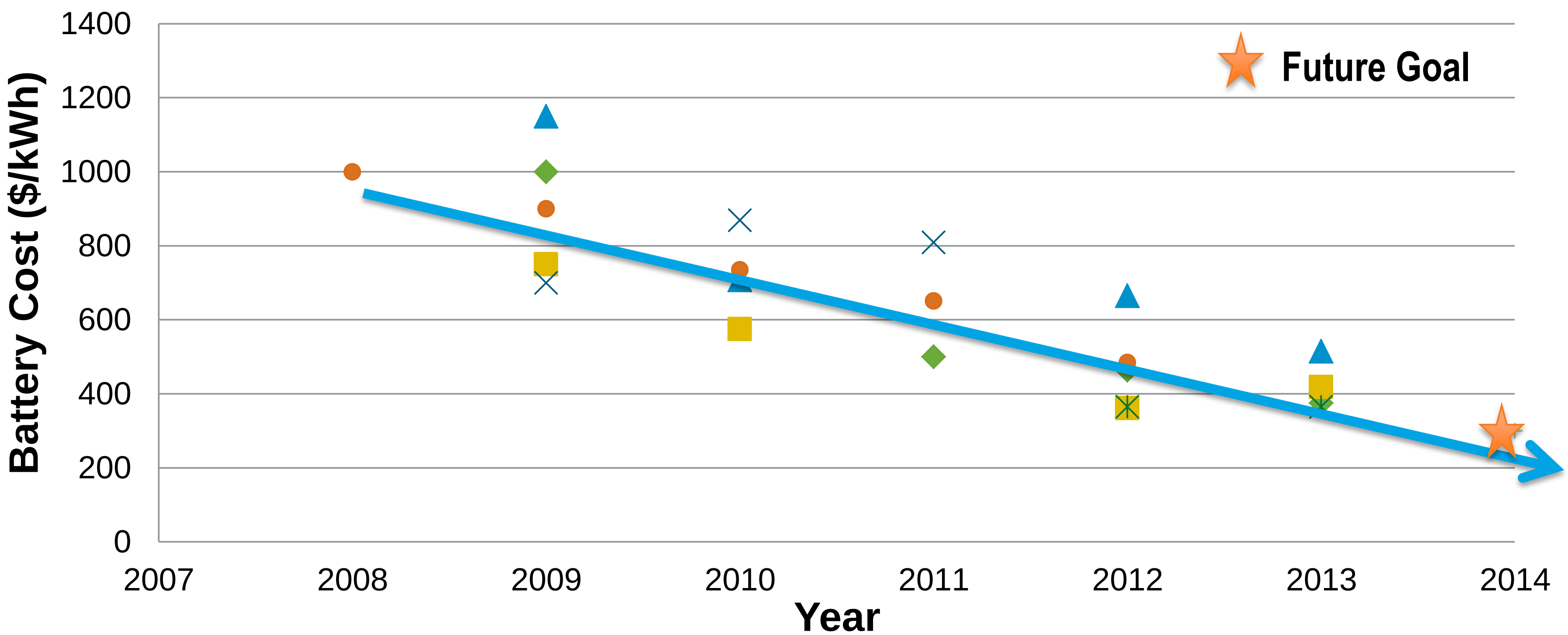
Battery Cost Data for PHEVs and EVs



As DOE expanded its focus from HEVs to PHEVs in 2008, the cost of useable energy at the system level of program deliverables has decreased from about $1000/kWh to just under $400/kWh. DOE's goal in 2022 is $125/kWh.

Battery Performance Testing

- **Battery Testing Protocols and Targets**
  - **Develop battery performance and cycle life test protocols based on different EDV architectures**
  - **Assist in development of battery system targets**

New EV Goals published and revised manual in progress

- **Current Test Procedures (posted at http://www.uscar.org)**
  - **Battery Test Manual for Plug-in HEV (PHEV)**
  - **Power Assist Battery Test Manual (HEV)**
  - **Electric Vehicle Battery Test Procedures Manual (EV)**
  - **Test Manual for Low-Energy Storage System (LEESS) for HEVs**
  - **Battery Test Manual for 12-Volt Start Stop System**
  - **48 Volt Battery Test Manual**
  - **Ultracapacitor Test Manual**
  - **Battery Technology Life Verification Test Manual**
  - **Energy Storage Abuse Test Manual for HEV Applications**
  - **Abuse Test Procedures Manual (EVs)**

Many have been globally adopted: the abuse test manuals are the basis for SAE standards.

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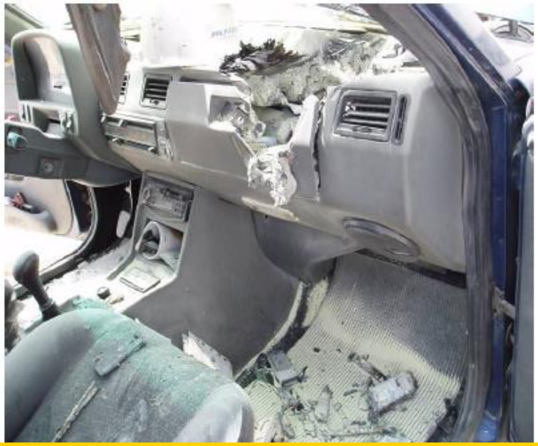
Safety & Abuse Testing of Batteries is of Central Importance

- **Safety, along with cost and life, is a key barrier to introduction of advanced, high energy rechargeable batteries into vehicles**
  - **The safety of large cells and large capacity batteries, such as used for vehicle traction, is more difficult to manage than small cells and batteries**
  - **Vehicle environment is challenging (temperature, vibration, etc.)**
- **Safety is a systems issue, with many inputs and factors**
  - **"Safe" cells and batteries can be unsafe in applications because of poor engineering implementation or incomplete understanding of system interactions**
- **Standardized tests are crucial to obtain a fair comparison of different technologies and to gauge improvements**
  - **Outcome of safety and abuse tolerance tests strongly influenced by experimental conditions.**
  - **Standardized tests can remove most of the variability**



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Safety/Abuse Testing (Cont'd)

- **Li-ion Safety Issues**
  - **High energy density**
  - **Reactive materials**
  - **Flammable electrolytes**
- **Abusive Conditions**
  - **Mechanical (crush, penetration, shock)**
  - **Electrical (short circuit, overcharge, over discharge)**
  - **Thermal (over temperature from external or internal sources)**
- **Abuse Testing Methodology**
  - **SAE Abuse Test Manual J2464**
- **Typical Tests**
  - **1 & 10 mohm short circuit**
  - **1C & 32A Overcharge/Overdischarge**
  - **Thermal Ramp @ 100% SOC & 90%SOC**
  - **Mechanical crush on both the positive and negative sides @ 100% SOC**
  - **Nail penetration @ 100% SOC**

Unacceptable

Preferable

Thermal Testing

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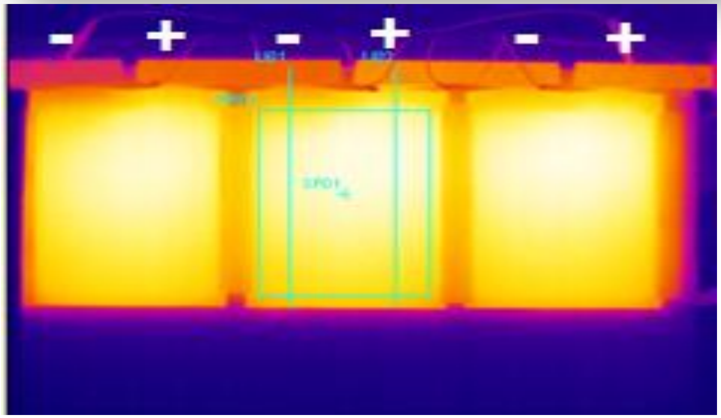
Objectives/Results

- Thermally characterize cell and battery hardware and provide technical assistance and modeling support to DOE/USABC battery developers for improved designs

- Enhance and validate physics-based models to support the design of long-life, low-cost energy storage systems

- Quantify the impact of temperature and duty-cycle on energy storage system life and cost



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Battery Testing Highlights

- Collaboration with Industry
  - NREL received an R&D100 award for their large volume battery calorimeter design which was licensed by Netzsch
  - This partnership resulted in the development of the IBC-284 isothermal battery calorimeter

- Patents
  - "Method of Detecting System Function by Measuring Frequency Response," U.S. Patent 8,352,204 B2, Jan. 8 2013. John L. Morrison, William H. Morrison, Jon P. Christophersen, C.G. Motloch
  - "Apparatuses and Methods for Testing Electrochemical Cells by Measuring Frequency Response," Attorney Docket 2939-P11886US (BA-706), June 2013. Jon P. Christophersen, John L. Morrison, William H. Morrison, Patrick A. Bald
- Publications/Presentations
  - "Universal Auto-Calibration For A Rapid Battery Impedance Spectrum Measurement Device", 2014 IEEE Aerospace Conference, Big Sky MT, March 2014, J. L. Morrison, J. P. Christophersen, and W. H. Morrison
  - "Evaluation of Mechanical Abuse Techniques in Lithium Ion Batteries", J. Power Sources, 247 (2014) 189-196. J. Lamb, C.J. Orendorff
  - "Battery Testing for EV Applications: A Comparison between US- and China-Based Protocols", AABC, 2014 Atlanta GA. J. P. Christophersen, T. Bennett, D. Robertson, and I. Bloom

Design and Analysis (~40%)

Design and Analysis

Computer Aided Engineering for Batteries (CAEBAT)

CAEBAT Overall Program

- Component Level Models
- Cell Level Models
- Battery Pack Level Models

Open Architecture Software

Battery Secondary Use Study

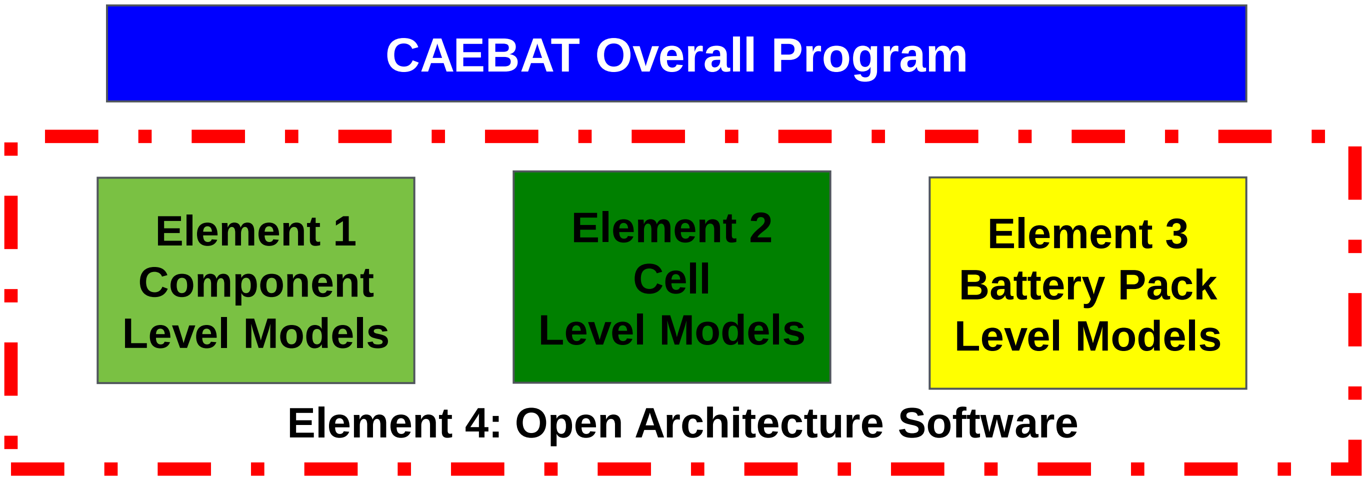
NREL National Renewable Energy Laboratory; Center for Sustainable Energy California; SDG&E connected; UC Davis; UC San Diego Local Impact, National Influence, Global Reach; AV aerovironment

Battery Ownership Modeling

Battery Life Trade-Off Studies

CAEBAT Objectives

- Program is intended to incorporate existing and new models into a battery design suite with the goal of shortening battery design cycles and optimizing batteries (cells and packs) for improved performance, safety, long life, and low cost
- Battery design suite must address multi-scale physics interactions, be flexible, expandable, validated and verified



CAEBAT History

- Initial solicitation issued in 2011 for industry to address Elements 2 & 3
- 3 teams were selected with $7M in DOE funds:
  - EC Power / PSU / Ford / JCI
  - CD-adapco / Battery Design / A123 / JCS
  - GM / ANSYS / E-Sim
- Projects on track to end by CY14
- 2nd solicitation issued in FY13 to expand upon the current state of electric drive vehicular battery computer-aided engineering models
- 3 teams were selected with $4.5M in DOE funds:
  - NREL / ANSYS / MIT
  - EC Power
  - Sandia / Oak Ridge / Colorado School of Mines

2nd Solicitation Project Objectives

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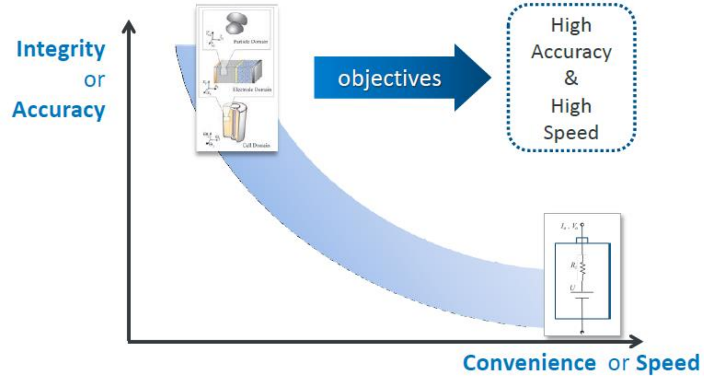
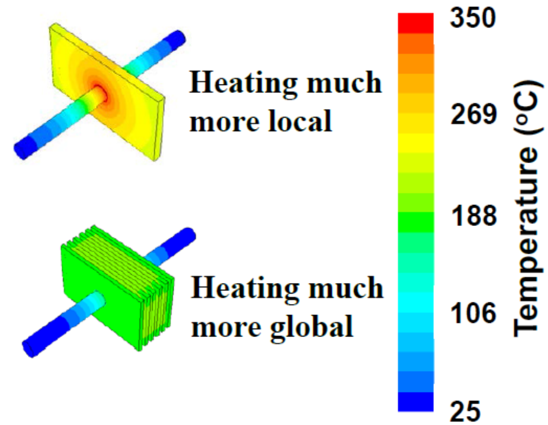
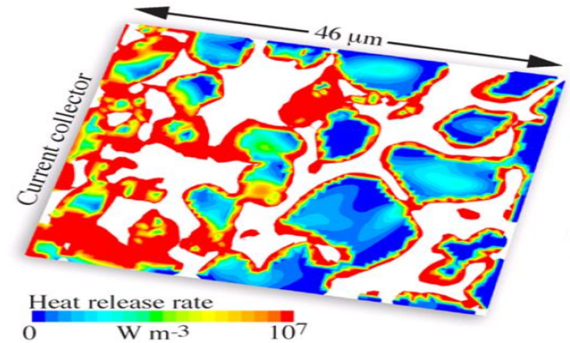
- NREL / ANSYS MIT
  - Develop a computational methodology to improve MSMD model by 100x while maintaining solution accuracy
- EC Power
  - Develop a pack level safety and abuse model
  - Develop mechanism-based, fundamental models for accurately predicting degradation of Li-ion batteries
- Sandia / Oak Ridge / Colorado School of Mines
  - Model gasification and stress induced degradation phenomena under abusive conditions
  - Develop SEI models that can predict the autocatalytic temperature behavior

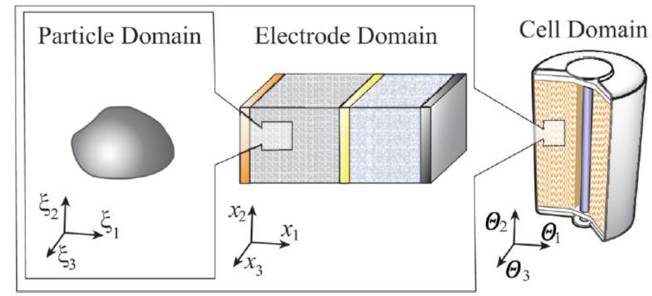


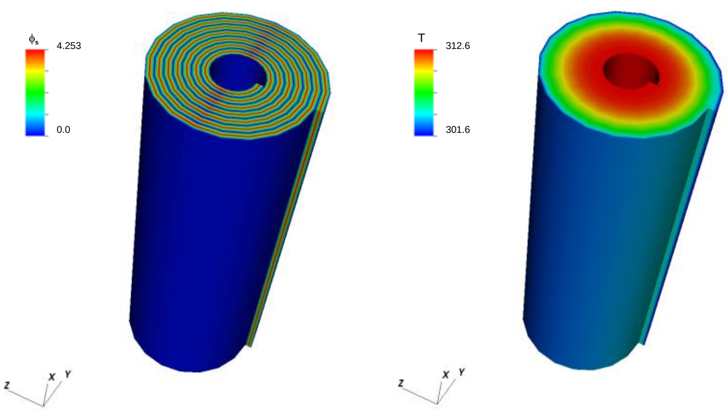


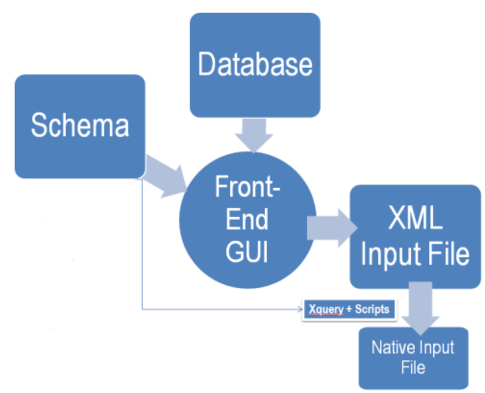


CAEBAT Highlights

- NREL successfully transferred their MSMD framework to industry partners
- All three industry partners have developed commercially available software which predicts electrochemical and thermal performance for battery cells and/or packs
- ORNL has developed input standards for the Battery State and has almost completed creating translators for all three industry partners which successfully link industry models to the open architecture

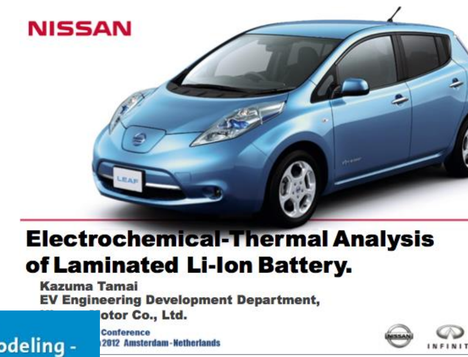


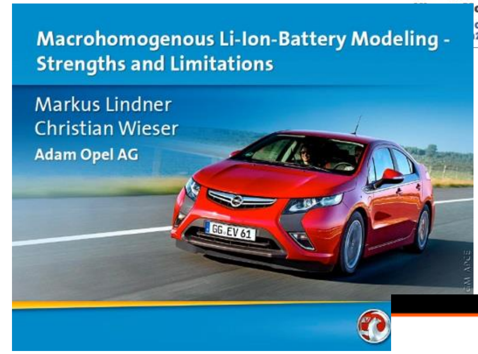


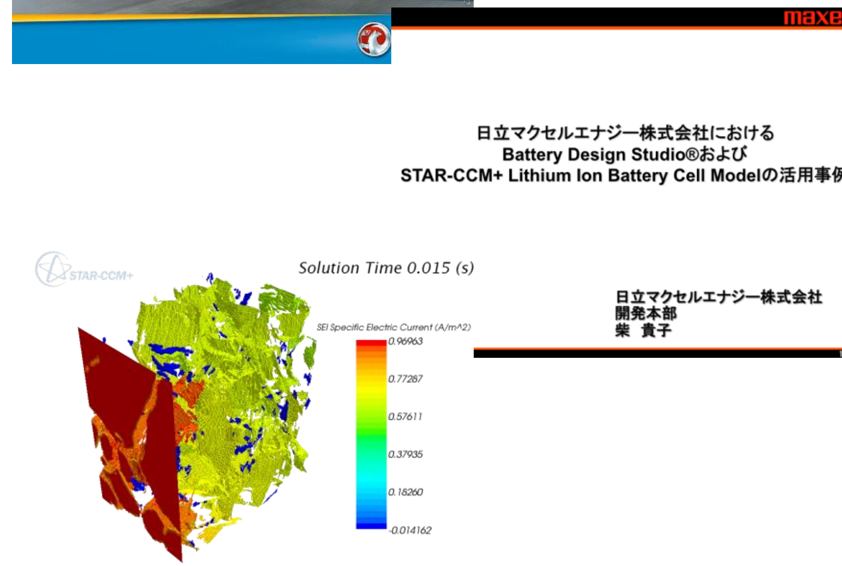


CAEBAT Highlights

- Industry partner successfully incorporated electrolyte properties that were developed in a previous project funded by DOE out of INL
- Software developed in CAEBAT have been used to simulate battery performance by Nissan, FMC, GM, Opel, Ford, Hitachi Maxell, Hyundai Mobis, and Carnegie Mellon University
- The SAE committee on battery testing will develop guidelines on battery testing specifically for modeling as a direct outgrowth of some of the challenges and lessons learned from the CAEBAT program







Summary

- TDA is an important portion of the energy storage portfolio that provides valuable feedback on programmatic performance goals and highlights potential gaps and opportunities
- Test methods and modeling activities are under development to understand the safety and degradation mechanisms associated with energy storage technologies
- Besides our core facilities many activities are transitioning to a competitively awarded process

For More Information…

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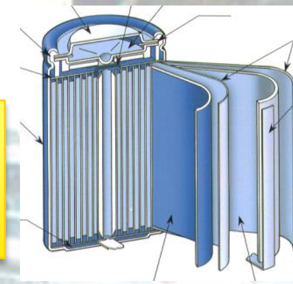
www.vehicles.energy.gov



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