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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 Program

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Project ID: ES116

Energy Storage R&D: FY 2012

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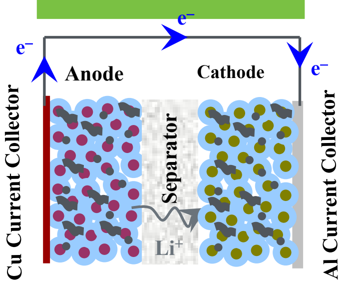
CHARTER: Develop battery technology that will enable large market penetration of electric drive vehicles

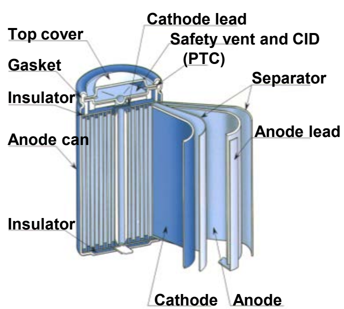
- By *2014*, develop a PHEV battery that can deliver a 40-mile all-electric range and costs $3,400
- By *2020*, develop an EV battery that can store 40 kWh of electricity and costs $5,000

Energy Storage R&D
FY12 $93 M

Exploratory Technology Research $22 M	Applied Battery Research for Transportation $18 M	Battery Development $42 M	Battery Testing, Design & Analysis $11 M



New Materials R&D, Diagnostics, Modeling



Next Generation Cell R&D

Battery Development & Cost Reduction

Standardized Testing Life/Cost Projections Design Tools

Testing (~60% of TDA funding)

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	Performance	Thermal	Abuse
Core Testing Facilities	INL; Argonne National Laboratory	NREL National Renewable Energy Laboratory	Sandia National Laboratories
Developmental Test Methods and Tools	• Technology Life Verification Testing • Smart Battery Status Monitor • Developmental and Applied Diagnostics		• Development of Techniques to Study Internal Shorts • Internal Short Circuit Emulation • Aged Cell Testing

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**
- **Current Test Procedures (posted at http://www.uscar.org)**
  - **FreedomCAR Battery Test Manual for Plug-in HEV**
  - **FreedomCAR Power Assist Battery Test Manual**
  - **Electric Vehicle Battery Test Procedures Manual**
  - **FreedomCAR 42 Volt Battery Test Manual**
  - **FreedomCAR Ultracapacitor Test Manual**
  - **Battery Technology Life Verification Test Manual**
  - **Energy Storage Abuse Test Manual for HEV Applications**
  - **USABC Abuse Test Procedures Manual (EVs)**

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

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Collaboration on International Battery Testing Protocols

- Battery testing is a time-consuming and costly process
- Parallel testing efforts, such as those in the U.S., China, Europe, Japan, and South Korea, may be better leveraged through international collaboration
- The collaboration may establish standardized, accelerated testing procedures and data analysis methods, which may accelerate electric vehicle development and deployment
- Partners in the collaboration: U.S., China, Italy, Austria, S. Korea, and Sweden
- There are three steps in the collaborative effort
  - Collect and discuss battery test protocols from various organizations/countries
    - The battery test protocols from the US, Europe and Japan were collected and compared. The initial comparison showed differences in testing assumptions, approach and philosophy
  - Conduct side-by-side tests on small cells using all protocols for a given application, such as an EV, to determine differences in stress levels and data quality
  - Compare the results, noting similarities and differences between protocols and test sites

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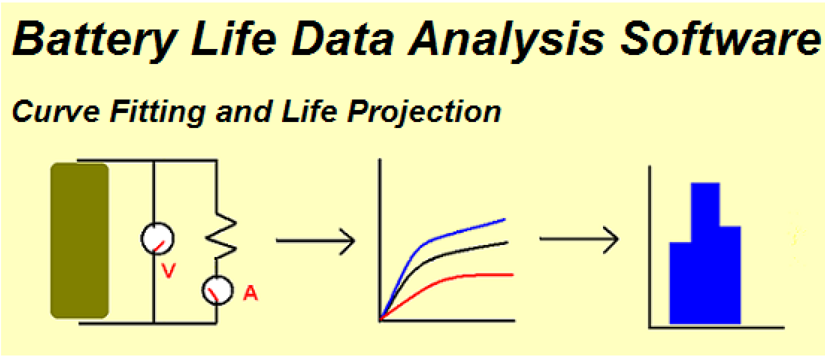
Life Validation Testing

- The Battery Technology Life Verification Test (TLVT) and Battery Life Estimator (BLE) Manuals are designed to predict battery life within a short period of accelerated aging
- The software is based on statistically robust fitting methods using both linear and non-linear approaches
  - Software commercially available at the Argonne Software Shop (http://www.anl.gov/techtransfer/Software_Shop/index.html).
- Memory effect studies using Sanyo cells are underway
  - Results will improve modeling and fitting capabilities (linear and non-linear) in the software package.



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Battery Diagnostic Testing

Need/Objective

- **Need:** Long-term use of lithium-ion batteries in vehicles represents a significant warranty commitment. But there is insufficient knowledge of their aging processes, in particular of the strong path dependence of their performance degradation
- **Objective:** Establish a platform of developmental and applied diagnostic testing to examine mechanistic contributions to cell aging, develop complementary advanced modeling tools, and optimize operational protocols to minimize the aging process

Key Targets

- Aging due to **temperature** variation
- Charge limitations; **self-discharging** behavior
- Contributions to **capacity loss**
- Cell behavior over **thermal regime**
- Optimization of Pouch Cell **Pressure** to increase performance/life
- Prolonging cell life by **current "conditioning"**
- Prolonging cell life by optimization of **usage patterns**

Lithium-ion Chemistry: Sanyo 'Y' Cells

Configuration: 18650
Cathode: $\{LiMn_2O_4 + LiMn_{1/3}Ni_{1/3}Co_{1/3}O_2\}$
Anode: graphitic
V_{max} = 4.2 V (100% SOC)
V_{min} = 2.7 V (0% SOC)
$C_1/1$ discharge capacity: 1.86 Ah

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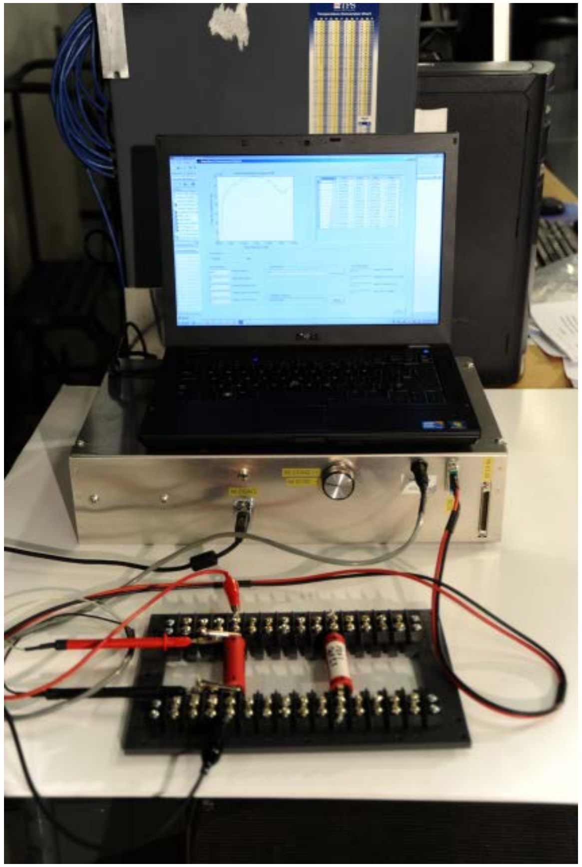
Smart Battery Status Monitor

- Laboratory impedance measurements require costly equipment (~$50,000) and typically take more than an hour to complete
- The Impedance Measurement Box (IMB) enables rapid impedance measurements over a broad frequency range
  - Measures impedance in about 10s and uses low-cost hardware (~$50) that can be embedded in the battery while in the vehicle
- Rapid impedance measurements provide a new diagnostic tool for more accurate onboard battery state-of-health assessment
- The IMB was awarded an R&D100 Award in 2011.
- The IMB development is based on a collaborative effort between a national laboratory, university, and small business



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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 to the variability

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Safety/Abuse Tolerance 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

Design and Analysis

Computer Aided Engineering for Batteries (CAEBAT)

- 3 Industry Awards
  - CD-adapco
  - EC-Power
  - GM
- Multi-Scale Multi-Dimensional Modeling
- Abuse Reaction and Thermal Runaway Modeling

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 · SDGE connected · UC Davis · UC San Diego Local Impact, National Influence, Global Reach · AV aerovironment

Battery Ownership Modeling

Battery Life Trade-Off Studies

Relevance – Need for CAEBAT

- Computer-Aided Engineering (CAE) tools are widely used in many industries to speed up the product development cycle and reduce the number of trial and error attempts
- CAE tools have enabled automakers to reduce product development cost and time while improving safety, comfort, and durability of vehicles and their components
- Although DOE has provided past funding for modeling efforts, they either
  - Included relevant physics details, but neglected engineering complexities, or
  - Included relevant macroscopic geometries and system conditions, but used too many simplifications in fundamental physics
- No mature CAE tools exist for the design and development of electric drive vehicle batteries

Modeling Length Scales

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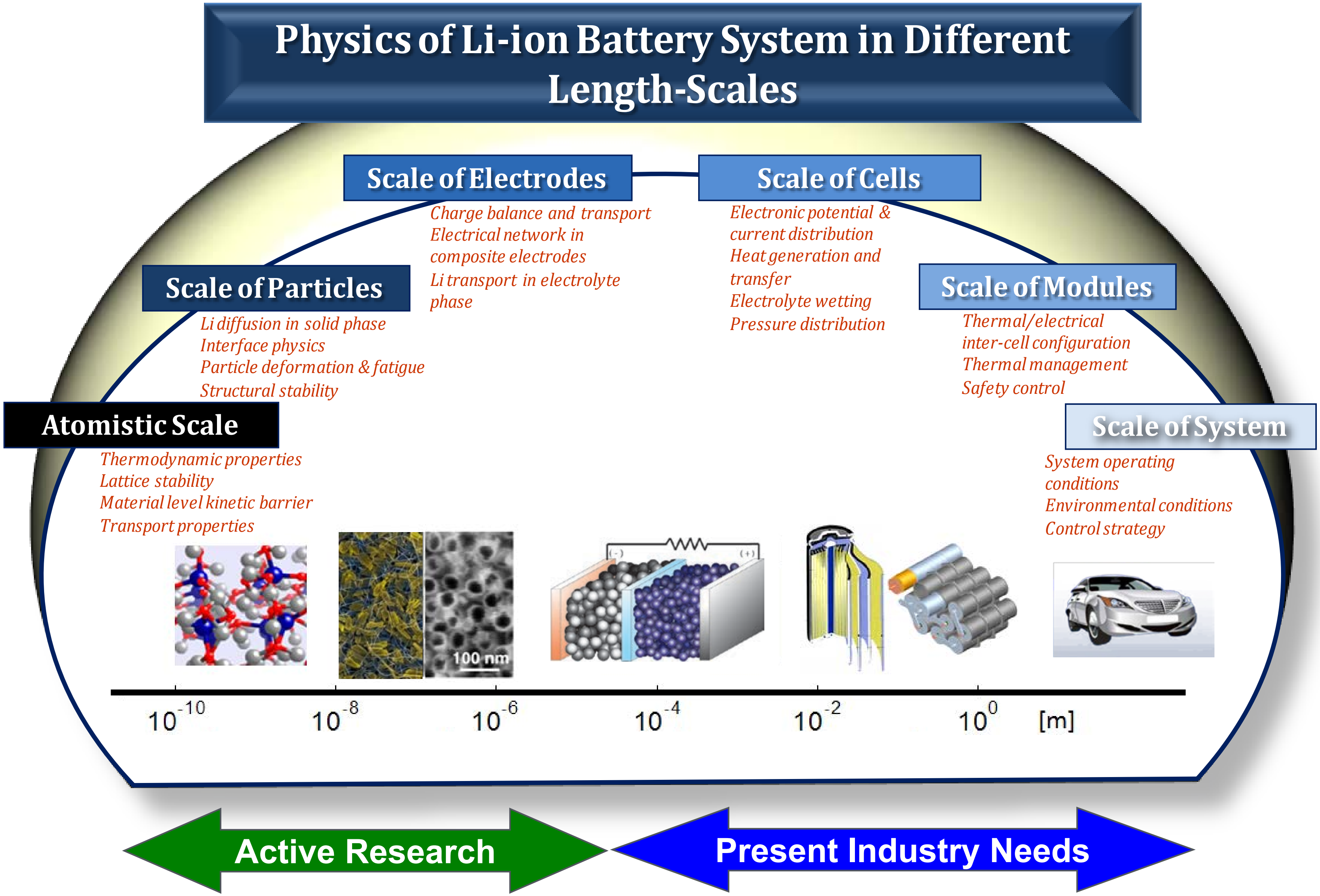
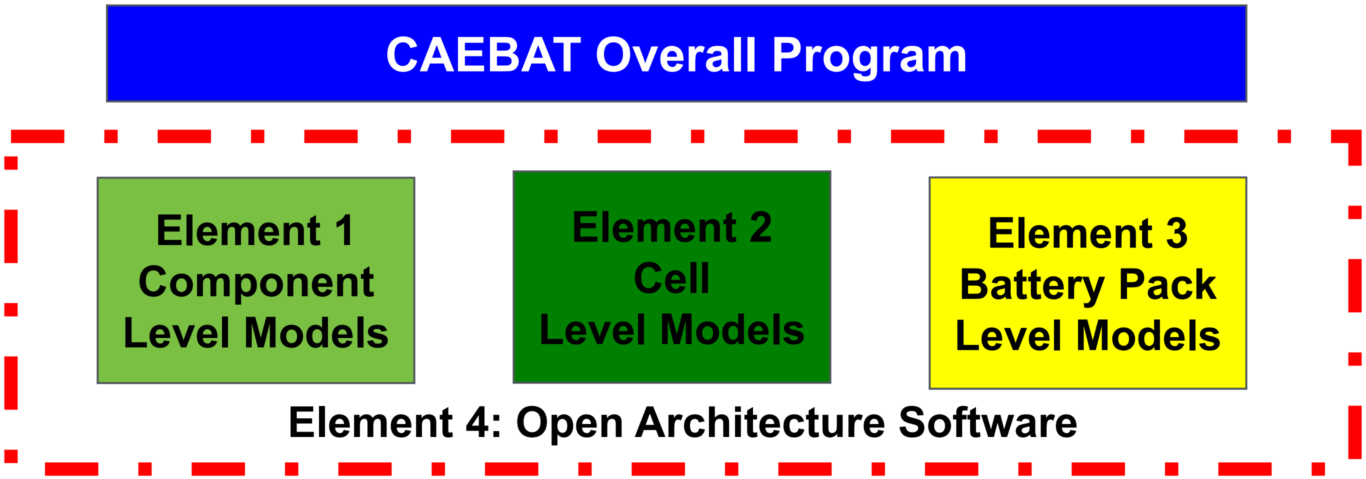


CAEBAT Objectives

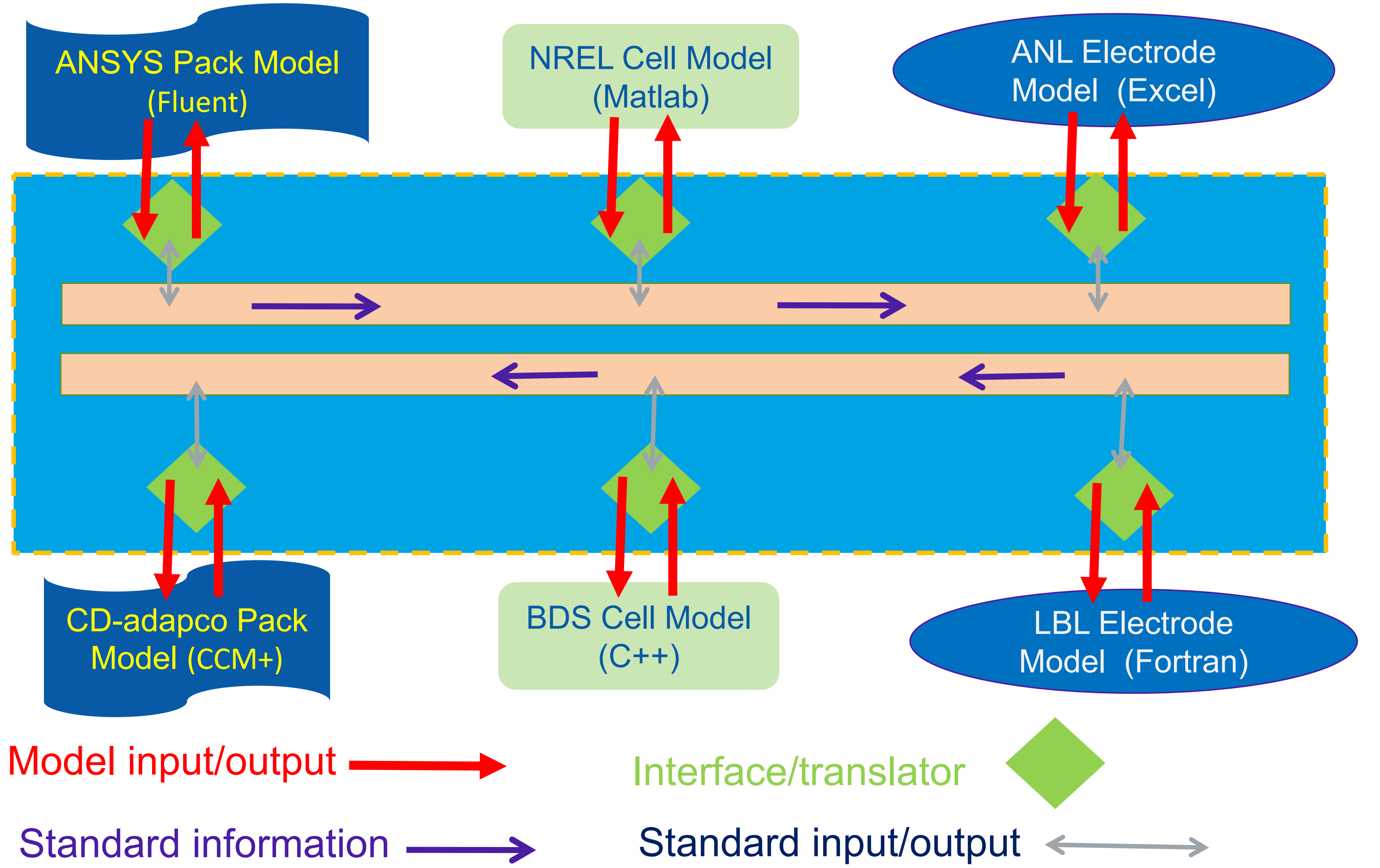
- Program is intended to incorporate existing and new models into a battery design suite with the goal of shortening battery design cycles and optimizing batteries (cells and packs) for improved performance, safety, long life, and low cost
- Battery design suite must address multi-scale physics interactions,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



Industry Collaboration

- Solicitation issued for industry to address Elements 2 & 3
- 3 teams were selected:
  - EC Power / PSU / Ford / JCI
  - CD-adapco / Battery Design / A123 / JCS
  - GM / ANSYS / E-Sim
- Projects started Summer 2011
  - Completed first version release of cell level software
  - Started cell level testing and validation

CAEBAT Final Goal



Multi-scale Model Framework for Better Li-Ion Battery Design

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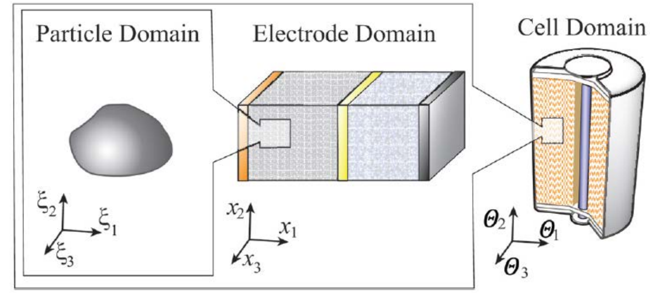
❑ Summary

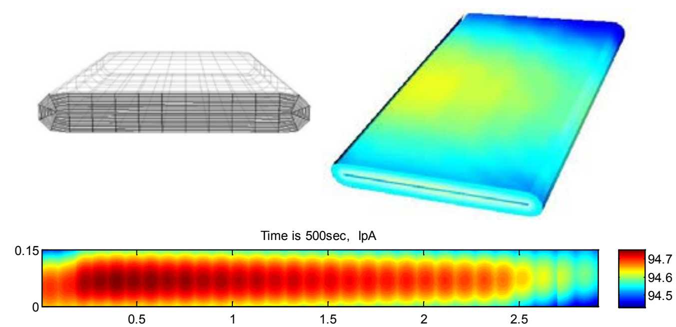
- Ground-breaking methodology for multi-domain modeling of lithium-ion batteries encompassing multi-physics in varied length scales .

❑ Approach

- Developed a multi-domain modeling approach known as the Multi-Scale Multi-Dimensional (MSMD) framework for predictive computer simulation and design of lithium-ion batteries (LIBs) with different chemistries or geometries.
- Introduces multiple computational domains for corresponding length scale physics, and decouples geometries between submodel domains while coupling physics bi-directionally.
- Through the Computer-Aided Engineering for Electric Drive Vehicle Batteries (CAEBAT) program, NREL is sharing know-how with the three award contractor teams.



The MSMD framework resolves intricate LIB geometries into multiple computational domains for corresponding length scale physics.



The MSMD application to a computational study on large format prismatic wound cell behaviors; Transfer reaction current density distribution after 500 sec at 4C discharge of 20Ah cell with continuous tab

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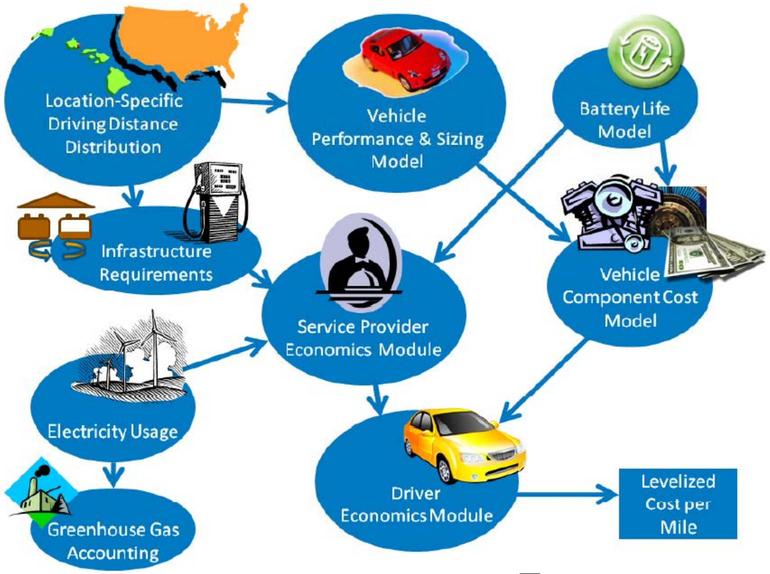
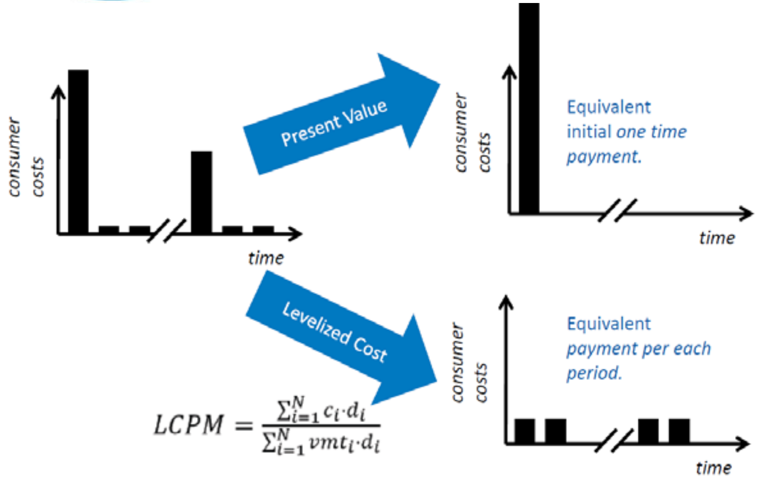
Battery Ownership Model (BOM)

- Many new vehicle technologies, power sources, infrastructure technologies, and business models proposed for transportation
- The main goal is to assist in understanding how various business plans for electric vehicles compare to other technologies
- Present studies
  - **EV Cost Sensitivities**
  - **Service provider / Battery Swapping**
  - **Niche Markets**
  - **Electric Drive Platform Performance Targets**
  - **Charging Strategies**
  - **Secondary Use**
  - **Fast Charging**





$$LCPM = \frac{\sum_{i=1}^{N} c_i \cdot d_i}{\sum_{i=1}^{N} vmt_i \cdot d_i}$$

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Planned Solicitation

- Issue a request for proposals to expand upon the current state of electric drive vehicular battery computer-aided engineering models
- Specific areas of interest include but are not limited to:
  - Improving the computational efficiency of current models
  - Developing models capable of predicting the **coupled** structural, electrical, and thermal responses to abusive conditions
  - Developing advanced life prediction modeling
  - Developing models focused on predicting degradation and failure mechanisms
- Funding and Period of Performance
  - Total DOE and TARDEC funding for this solicitation: $1.5M to $3M/year
  - Expected number of awards: 3-6
  - Length of each project: 1-3 years
  - Industry cost share: 50% of industry effort (cost-sharing is waived for university and national lab participants)

Summary

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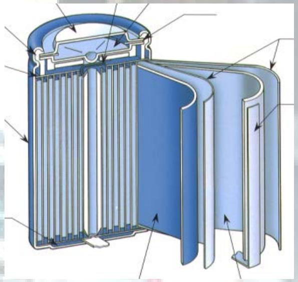
- TDA is an important portion of the energy storage portfolio that provides valuable feedback on programmatic performance goals and highlights potential gaps and opportunities
- Test methods and modeling activities are under development to understand the safety and degradation mechanisms associated with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

For More Information…

www.vehicles.energy.gov



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