INL Electrochemical Performance Testing

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Overview

Timeline
• On-going Activity
• Began in 1985

Budget
• FY 2013: $3.2M (AES)
  $450k (ABR)
• FY 2014: $3.0M (AES)

Barriers
• Testing and analysis strategies are critical to accurately characterizing the performance, life, reliability and cost of advanced energy storage devices for vehicles.

Partners
• USABC – Energy Storage Technical Advisory Committee
• Argonne National Laboratory
  • Testing, Analysis, Life Prediction Tools
• Sandia National Laboratories
  • Abuse Tolerance, Life Validation Methods
• National Renewable Energy Laboratory
  • Thermal Imaging, Analysis, Models
• University of Maryland / Montana Tech / NHTSA
  • Diagnostics, prognostics, state-of-health
Advancing alternative transportation is a top priority within DOE given its potential to help reduce U.S. dependency on oil

**Technical Challenge**

- Adoption of cost effective, safe, reliable and environmentally sustainable alternative vehicles using clean fuels and supported by an appropriate and available fueling infrastructure. (Technology Acceptance)
  - New advanced battery chemistries intended for Plug-in vehicles are being introduced to the automotive industry more often today.
    - DOE supported battery research is a major reason for this positive trend.
  - However, the automotive industry has indicated that most of these new chemistries fail to be adopted due to a lack of adequate developmental testing.
    - Quality testing/validation/analysis is critical to adoption/success.
      - We are not doing enough independent testing to support R&D and enable EV technology.
Relevance & Objectives

- **Technology Assessment**
  - Independent, science based performance assessment of energy storage devices.
  - Testing USABC deliverables against established technical targets.
  - Benchmark testing of non-USABC prototype devices of interest.
  - Advanced state-of-health assessment capabilities.

- **Protocols & Procedures**
  - Internationally accepted manuals for performance assessment of energy storage systems.
  - Continuous development and validation of test and analysis protocols based on DOE / USABC targets and objectives.

- **Quality Results**
  - Flexible state-of-the-art energy storage test facility capable of supporting current and future development activities.
  - Rigorous NIST traceable calibration procedures for in depth uncertainty analysis
  - Temperature controlled testing for reliable and repeatable results.
## Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Program</th>
<th>Description</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>2013</td>
<td>USABC</td>
<td>Deliverables testing 1Q quarterly report</td>
<td>Complete</td>
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<tr>
<td>2013</td>
<td>USABC</td>
<td>Deliverables testing 2Q quarterly report</td>
<td>Complete</td>
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<tr>
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<td>USABC</td>
<td>Deliverables testing 3Q quarterly report</td>
<td>Complete</td>
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<tr>
<td>2013</td>
<td>USABC</td>
<td>Deliverables testing 4Q quarterly report</td>
<td>Complete</td>
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<tr>
<td>2013</td>
<td>ABR</td>
<td>Aging path dependence based on daily thermal cycles, state-of-charge dependence, and temperature hysteresis</td>
<td>Complete</td>
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<tr>
<td>2013</td>
<td>ABR</td>
<td>Phosphazene-based polymer anodes considered for replacement of conventional graphitic carbon anodes</td>
<td>Complete</td>
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<tr>
<td>2013</td>
<td>ABR</td>
<td>Deploy INL core capabilities in support of larger mission for ABR program</td>
<td>Complete</td>
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<td>On Schedule</td>
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<td>2014</td>
<td>USABC</td>
<td>PHEV Manual Revision 3</td>
<td>On Schedule</td>
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<tr>
<td>2014</td>
<td>USABC</td>
<td>EV Manual Revision</td>
<td>On Schedule</td>
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Approach

INL Role – Quality Testing and Applied Research

- DOE-EERE, Vehicle Technologies Program testing mission to support the development of electric drive vehicle and component technology.
- Customers – DOE/EERE, Nat. Labs, USABC, Automotive and Battery industry, Public and Private vehicle fleets, DOD, DOT, EPA, FEMP.
  - Advanced Battery Testing Center
    - Battery and Ultracapacitor technology
    - Cells, Modules, and Full Size vehicle systems
    - Testing and Analysis Procedures
    - Advanced Modeling and Diagnostic Tools
    - New Materials Screening, or Validation
    - Barrier Focused Exploratory and Applied Research
  - Advanced Vehicle Testing Activity
    - Vehicle and Infrastructure Deployment, Testing and Analysis
    - Testing and Analysis Procedures
    - BEV, PHEV, HEV etc.
Approach

• **Science Based Performance Assessment**
  – Develop protocols and standards for the performance assessment of battery/capacitor systems, primarily for electric drive vehicles.
  – Temperature control equipment used for reliable/repeatable testing.
  – Software analysis tools have been developed.
  – Standards developed for data acquisition, analysis, quality, and management.

• **Research and Development**
  – Applied research capabilities to explore basic issues of battery aging, performance and prognostics.
  – Battery life estimation and state-of-health assessment capabilities using novel sensor technology.

• **Vehicle Technology Program Integration**
  – Laboratory testing of energy storage devices complements the ongoing Hybrid & Vehicle Systems research through robust controlled testing procedures that can be compared to real world system applications.
Technical Accomplishments/Progress

- INL science-based battery performance assessment contributes to technology development:
  - PHEV battery cost reduction to $485/kWh per 100k units*.
  - PHEV battery life extended up to 10-15 years for some technologies with 3,000-5,000 deep discharge cycles.

Technical Accomplishments/Progress

- **INL Battery Test Center**
  - Fully operational Sept. 2013:
    - 647 cell test channels
    - 19 module test channels
    - 7 pack test channels
    - Vibration test system
    - ~100 controllable thermal chambers
Technical Accomplishments/Progress

• Expanded Pack Testing Capability
  – Three Bitrode 500V 350A testers
  – Two Bitrode 1000V 500A testers
Technical Accomplishments/Progress

• Walk-in Environmental Chambers
  – Installation completed: July 2013
  – Temperature control range: -68 to 85°C
  – Humidity control range: 5 to 94% relative
  – Interior volume: 1054 ft$^3$
Technical Accomplishments/Progress

- **Published Manuals in FY-12 and FY-13:**
  - Battery Test Manual for 12V Start/Stop Vehicles (Nov. 2013)
- **Manual Revisions ongoing:**
  - PHEV Manual, Revision 3 – see next slide
- **Upcoming Manual Publications:**
  - EV Manual, Revision 3
  - 48-V Manual, Revision 0
INL is an active participant on the USABC Test Methods and Definitions Workgroup.

 Developing / validating proposed changes to HPPC protocols for more consistency between lab testing and vehicle battery use.

**Technical Accomplishments/Progress**

- **Vmax pulse** (applies only to short duration pulses)
- **Vmax_{100}** (100% SOC at BOL)
- **Vmax_{op}** (top of operating range at BOL; fixed at BOL)
- **Vmin_{0}** (0% SOC at BOL)
- **Vmin_{lowT}** (fixed)

Cycling begins at (fixed) supplier specified Vmax_{op} and a fixed amount of energy (CD+1/2CS) is removed, to a point which defines the bottom of the operating window.

**Battery Size Factor**

- Original Methodology
- New Proposed Methodology

**Energy (Wh)**

0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000

0 12500 25000 37500 50000 62500

Discharge Power (W X BSF)

Regen Power (W X BSF)

BOL Power

EOL Power

BOL CS Available Power

EOL CS Available Power

BOL Calculated CS Available Power

EOL Calculated CS Available Power

Energy = Goal + Margin

BOL Calculated CS Available Energy = Goal + Margin

EOL Calculated CS Available Energy = Goal + Margin

BOL Power Margin

EOL Power Margin

BOL AP CS = 49.4 kW

EOL AP CS = 38 kW

Battery Size Factor for this example is 44
INL and Montana Tech collaborated to develop a prototype 50-V Impedance Measurement Box (IMB) for rapid assessment of impedance changes.

Cell string study is presently ongoing:
- **Goal**: to assess the capability of the rapid impedance measurement technique on different architectures of strings of multiple cells as a function of calendar life aging at different temperatures (30, 40, 50° C).

Pretest results:
- Impedance increases with number of cells in series
- Impedance similar for all parallel interconnections.
### Technical Accomplishments/Progress

- **FY-2013 Deliverables Tested**

<table>
<thead>
<tr>
<th>Program</th>
<th>Deliverables Tested</th>
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<tbody>
<tr>
<td>USABC</td>
<td>9 Programs (264 cells and 9 modules)</td>
</tr>
<tr>
<td>Benchmark</td>
<td>5 Programs (46 cells and 14 modules)</td>
</tr>
<tr>
<td>FOA -2011</td>
<td>1 Program (18 cells)</td>
</tr>
<tr>
<td>FOA-ARRA</td>
<td>2 Programs (31 modules)</td>
</tr>
</tbody>
</table>
Response to Previous Year Reviewers’ Comments

• Project not reviewed for 2013
  – No reviewer comments available
Collaboration & Coordination with Other Institutions

- INL continues to enjoy a close testing partnership with Argonne National Laboratory.
  - Reduces unnecessary duplication and creates valuable overlap of capability where its useful.
  - Lishen benchmark testing at both INL and ANL for performance assessment and to ensure consistent testing/analysis between labs.
- INL supplying SNL with aged batteries with known histories for additional abuse testing.
- INL is actively participating in the USABC Test Methods and Definitions and Internal Short Circuit Workgroups.
- Expanded test capability will create additional opportunities for collaboration with other national labs (ANL, LBNL, SNL, NREL), industry and academic institutions.
  - Life prediction models, analysis, mechanisms, diagnostics.
Collaboration
& Coordination with Other Institutions

• INL and SNL are collaborating on a joint NHTSA project to define “state-of-stability” assessment tool following an uncontrolled event (e.g., car crash).
  – IMB rapid impedance measurements on individual cells undergoing abusive conditions are being used for a preliminary study.
  – The prototype 50-V system will be used at SNL for module-level abuse studies.

• INL recently loaned a prototype 50-V IMB to the University of Maryland Center for Advanced Life Cycle Engineering (CALCE).
  – The purpose is to develop advanced diagnostic and prognostic modeling tools for industry applications.
Remaining Challenges and Barriers

• Maintaining a flexible state-of-the-art energy storage device testing facility
  – Adapt to shifting targets and emerging technology
  – Update/modify test protocols and analysis procedures as needed
  – Equipment maintenance, repair, and upgrades

• Expanding lab capability for enhanced data assessment through additional equipment and staffing

• Strengthen and expand collaborative ties with existing Vehicle Technologies Office programs at INL, other national laboratories, and industry
Proposed Future Work

• USABC testing deliverables
  – Continue testing existing deliverables
  – Add new deliverables

• Publish Updated and New Test Manuals
  – PHEV Revision 3
  – EV Revision 3
  – 48 Volt Revision 0

• Expand lab capabilities
  – Incorporate vibration system where appropriate
  – Additional laboratory support for industry and universities (WFOs, etc.)

• Expand ties with on road and laboratory testing to validate and enhance laboratory modeling capability
Summary

• The INL Battery Testing Center is the lead DOE laboratory for advanced automotive battery performance testing.
  – 17,000 square feet of lab space with ~650 test channels for advanced energy storage testing.

• INL is continuing to support DOE and USABC with science-based performance testing and assessment of candidate battery technologies for various vehicle platform applications.
  – Rigorous NIST traceable calibration procedures for in depth uncertainty analysis.

• INL has strong capabilities in advanced battery diagnostics and prognostics for improved state-of-health assessment.
  – On-going research activities in collaboration with DOE, NHTSA, SNL, and University of Maryland.
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Vehicle Technologies Office