

Electric Drive and Advanced Battery and Components Testbed (EDAB)

PI: Jim Francfort

Presenter: Richard “Barney” Carlson

Energy Storage & Transportation Systems

Idaho National Laboratory

Advanced Vehicle Testing Activity (AVTA)

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Timeline

- FY13 – Continue on-road testing, report and present on findings. Identify, obtain and prepare to test the next ESS.
- FY14 – Complete first ESS testing. Initiate the next ESS testing.

Budget

- FY13 – \$ 150k
- FY14 – \$ 250k

Barriers

- Test advanced technology ESS's in on-road conditions
- Test a wide range of ESS's sizes and capabilities (BEV, EREV, PHEV)
- Test power electronics and components in on-road conditions

Partners

- Idaho National Lab - lead
- Intertek Phoenix - testing
- Oak Ridge National Lab - control system
- AVL North America - vehicle integration and ESS design and fabrication

Objective / Relevance

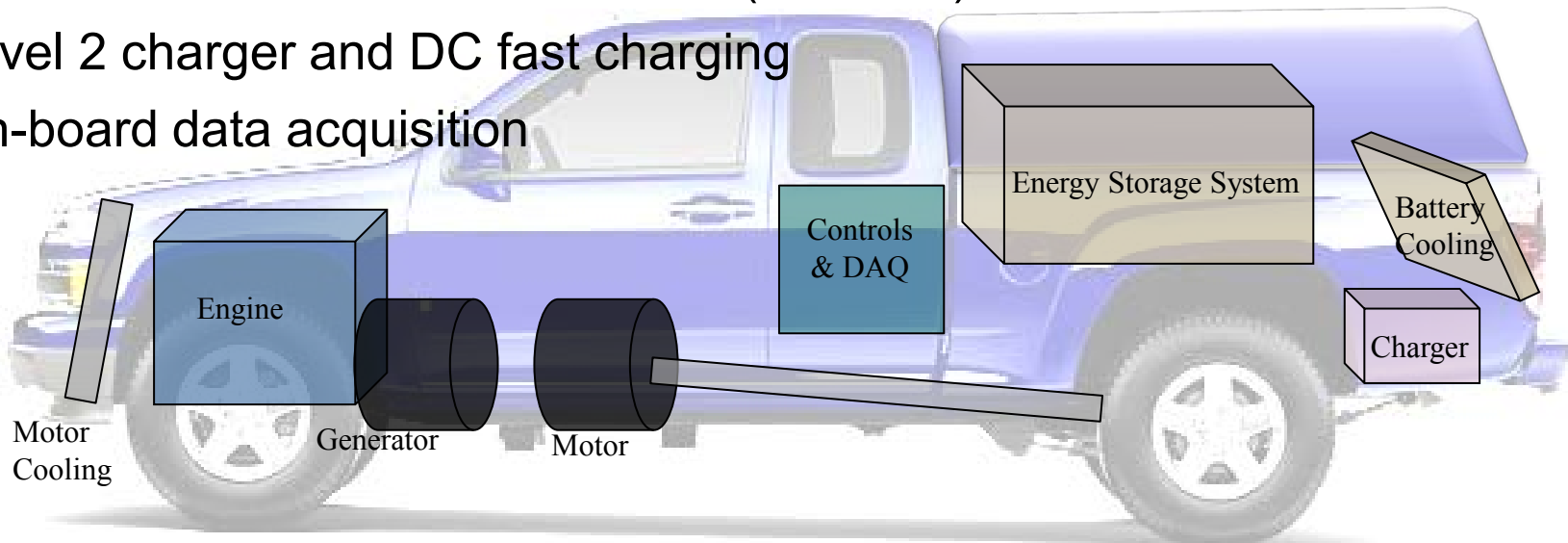
- Provide an on-road and dynamometer capable platform for testing Energy Storage Systems (ESS)
 - Battery Electric Vehicles (BEV)
 - All-Electric Capable Plug-in Hybrid Electric Vehicles (EREV)
 - Blended Plug-in Hybrid Electric Vehicles (PHEV)
- Capture data from ESS performance, capacity fade, and operating condition data during on-road operation
- Capture data from motor and power electronic during on-road operation

Approach (Augmented from previous approach)

1. ESS on-road operation and laboratory testing to capture performance and capacity fade characteristics
2. *Cell testing in a thermal chamber per USABC test procedures to correlate to the on-road test results from the ESS*
3. *Modeling tool “CellSage” for prognostic and diagnostic determination at multiple stage through out the on-road testing*

Approach: EDAB Vehicle Testbed

- Mid sized Pickup truck
 - ESS mounted in truck bed
 - Truck cap will cover / protect ESS
- Series powertrain configuration
- Controls system has three control configurations with a weight / road load emulation algorithm to test ESS for intended operation
 - BEV compact 4 door electric sedan (3000 lbs)
 - EREV mid sized 4 door sedan (3500 lbs)
 - Blended PHEV mid sized SUV (4000 lbs)
- Level 2 charger and DC fast charging
- On-board data acquisition

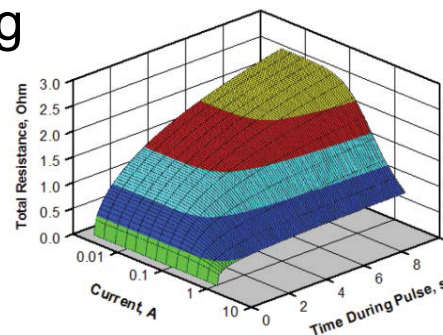


Approach: EDAB Vehicle ESS Test Plan

- Chassis Dynamometer testing (ORNL)
 - Finalize control system calibrations specific to ESS
 - Vehicle baseline testing for each ESS
- ESS Reference Performance Testing (RPT)
 - Beginning of life (BOL)
 - Periodically during on-road testing
 - every 1,500 miles or 30 days of driving (40 to 60 cycles)
 - End of life (EOL)
- On-Road Testing
 - In Phoenix area
 - Approx. 50% city, 50% highway driving
 - Approx. 100 to 150 miles per day
 - For PHEV / E-REV: 75% of miles in EV or CD operation, 25% in CS

Approach: Cell Testing and Diagnostic Modeling

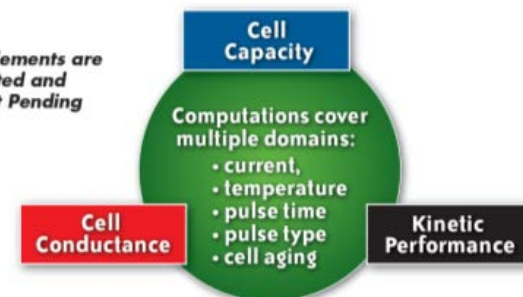
- Cell testing for direct comparison to on-road ESS results
 - Toshiba 20Ah SCiB (Lithium-Titanate) cells
 - Same cells as within the ESS
 - Thermal chamber maintained at 30°C
 - Testing conducted in accordance to USABC Battery Test Manual for Plug-In Hybrid Electric Vehicles revision 2 (Dec 2010)
- **CellSage:** Prognostic and Diagnostic modeling tool used to correlate performance characterization and aging mechanisms with the on-road test results
 - Beginning of on-road testing
 - Middle of on-road testing
 - End of on-road testing



Essential Triad of Battery Metrics

INL Interpretation of Battery Life

Key Elements are
Patented and
Patent Pending



Milestones

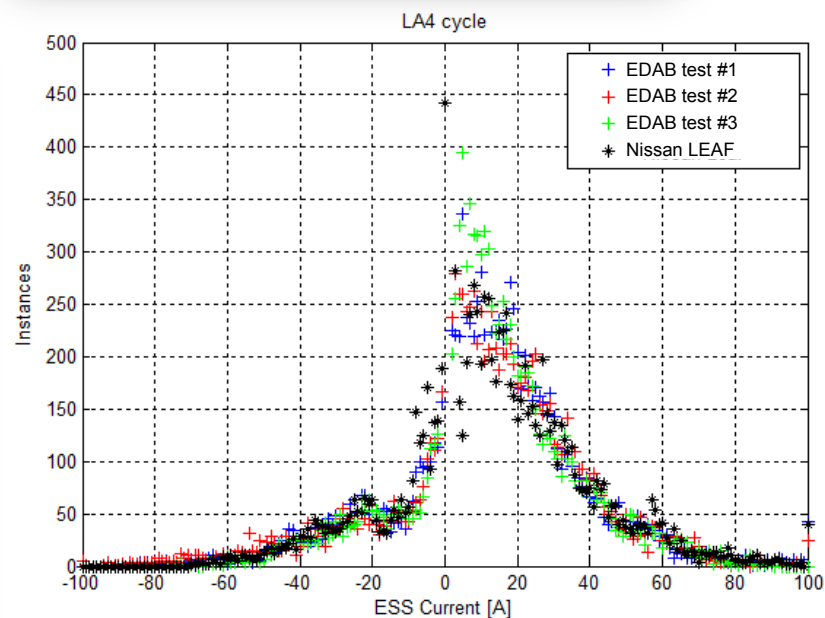
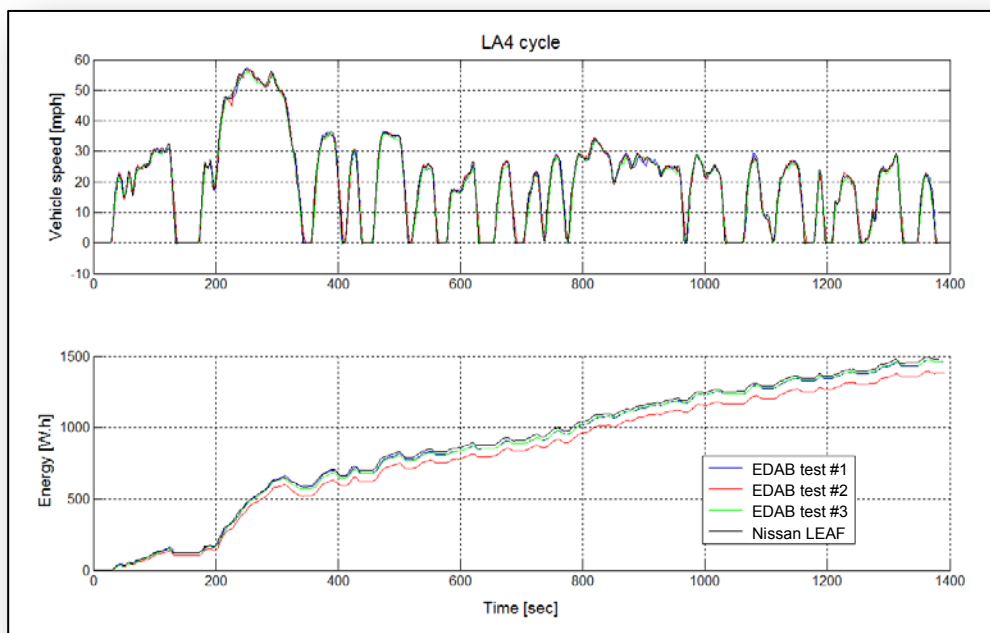
- EnerDel 70 Ah Li-ion ESS
 - April 2011 – received 1st ESS (EnerDel Li-ion 70 Ah rated)
 - March 2012 – on-road testing initiated
 - Dec 2013 – Testing Complete at 27,880 miles
- Toshiba 40 Ah Lithium Titanate ESS
 - March 2014 – integrated Toshiba ESS into the EDAB testbed
 - April 2014 – controls system calibration complete (ORNL)

Technical Accomplishments

- After 27,880 miles of real world driving and charging (412 equiv. full cycles)
 - Measured capacity fade of 17.5% (63.2 Ah to 52.1 Ah) since BOT
 - ESS discharge resistance (at 50% SOC) increased 33% since BOT
- Next ESS has been integrated into the EDAB testbed
 - Toshiba 40 Ah Lithium Titanate ESS
 - EDAB control system calibration is complete to operate the Toshiba ESS in an E-REV operation during on-road testing

Previous Accomplishment: Testbed control system calibrated to ESS

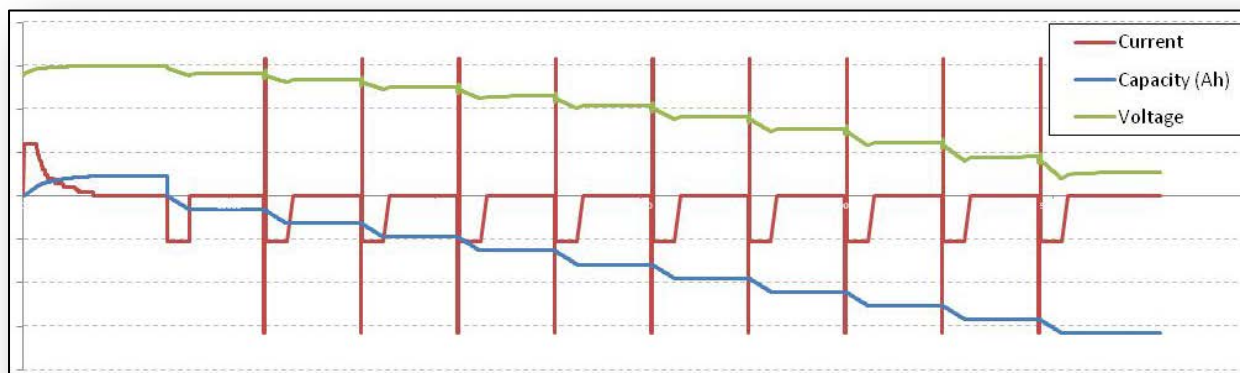
- Control system is calibrated to utilize the ESS within the operating range of a Nissan Leaf®
- Energy throughput over standard drive cycles is nearly identical to Nissan Leaf
- Current profiles are very similar



Technical Accomplishments

EnerDel ESS Testing Complete

- EnerDel 70 Ah pack (Li-Ion 17.5 Ah cells)
 - Pack intended for Th!nk BEV
 - 23 kWh (rated)
 - Mixed Oxide (Modified NMC) cathode
 - Amorphous Hard Carbon anode
 - Passive cooling (sealed enclosure)
- Detailed data collected during real world driving and charging
- Laboratory testing conducted on ESS at regular intervals (approx. 1,500 miles) to quantify change in ESS performance
 - C/3 and HPPC / EVPC tests



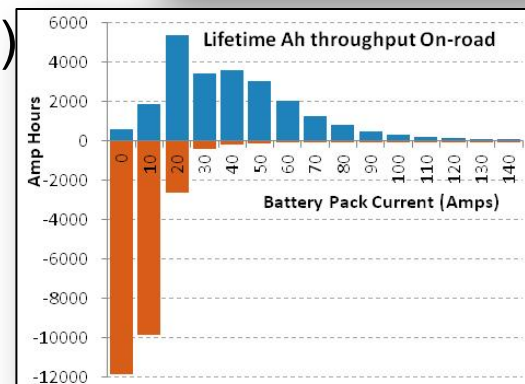
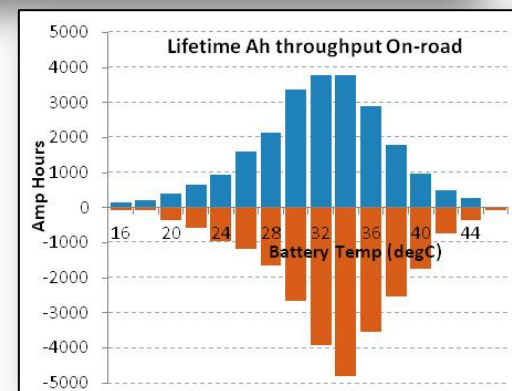
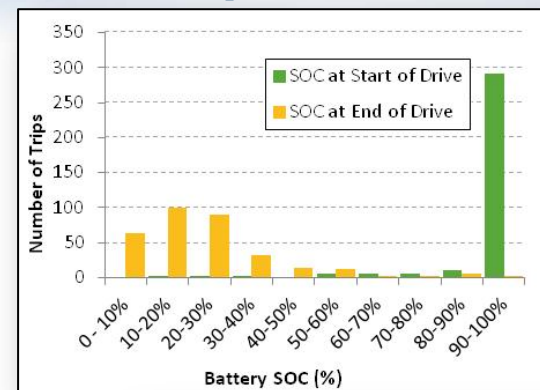
Technical Accomplishments (continued)

Test Results of EnerDel ESS

- On-road testing March 2012 – December 2013

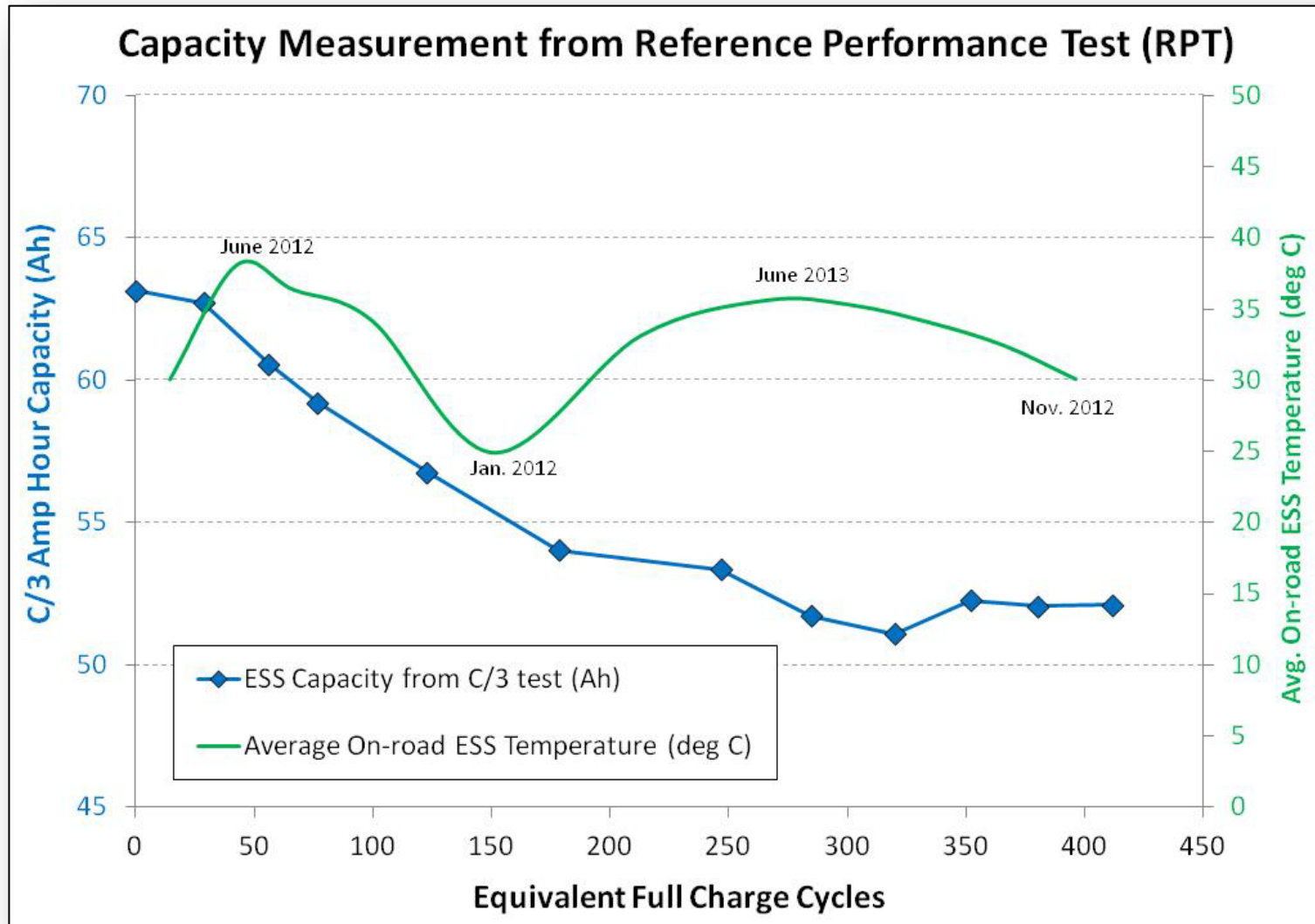
On-road results

- 27,880 miles driven
- 42,500 Ah total throughput
- 17.5% capacity fade
 - 63.2 Ah to 52.1 Ah
 - 20.9 kWh to 17.3 kWh
- 33% increase in discharge resistance (50% SOC)
 - 120 mΩ to 159 mΩ
- 412 Equivalent Full Charge Cycles
- 233 DC Wh/mi (similar to Nissan Leaf operation)
- 54% City / 46% Hwy
- On-road ESS temperature operating between 16°C and 50°C (typically between 30°C & 38°C)
- 90% of ESS operation is <70 Amps (C_1 rate)



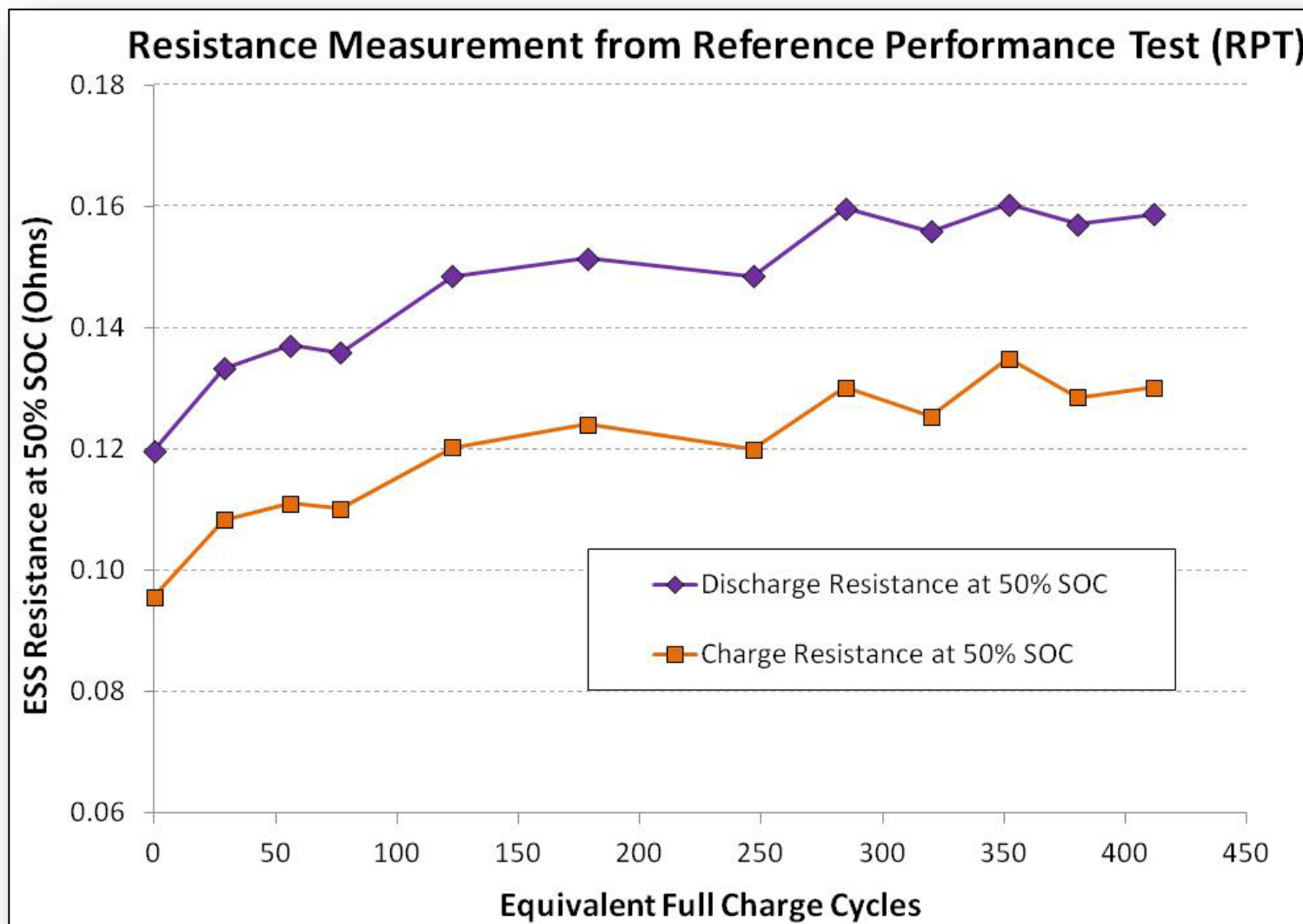
Technical Accomplishments (continued)

Test Results EnerDel ESS



Technical Accomplishments (continued)

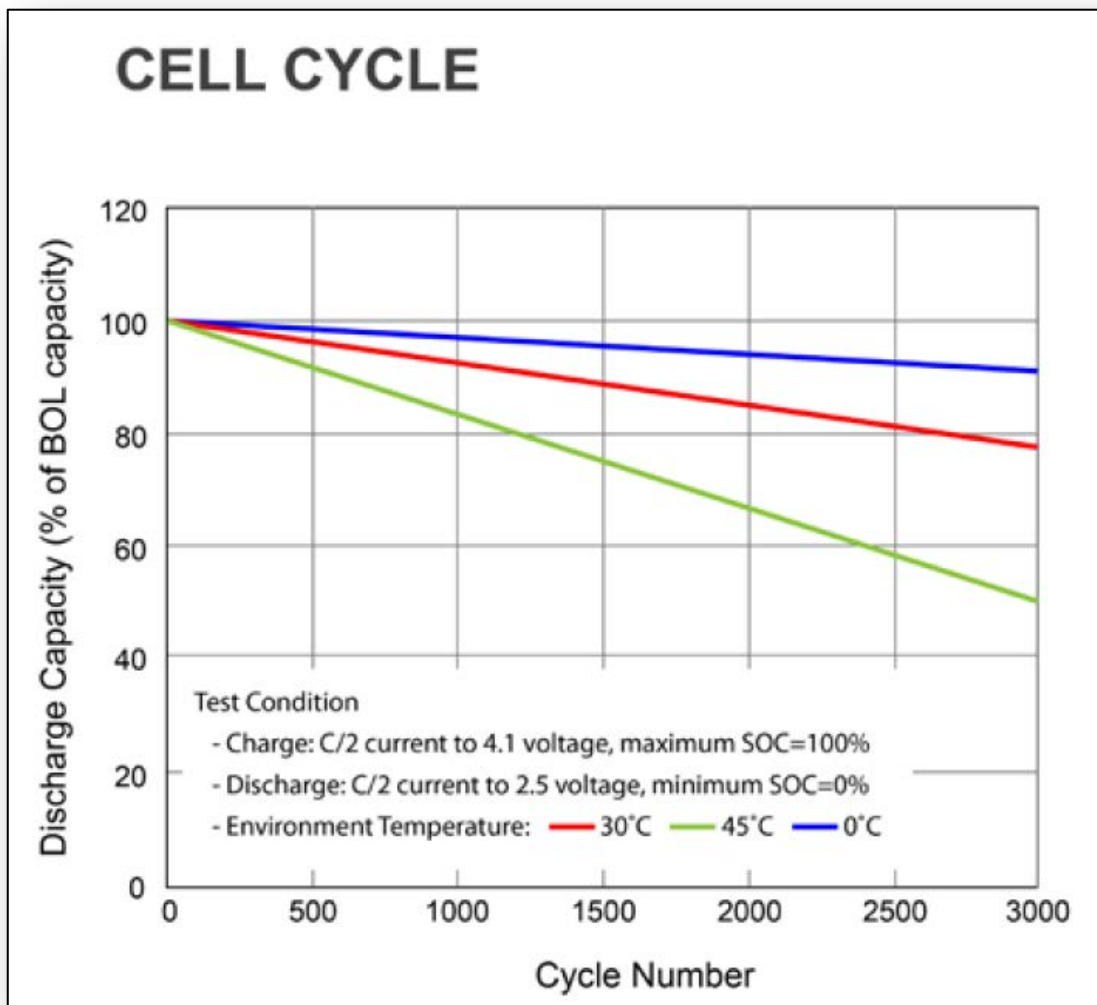
Test Results EnerDel ESS



Technical Accomplishments (continued)

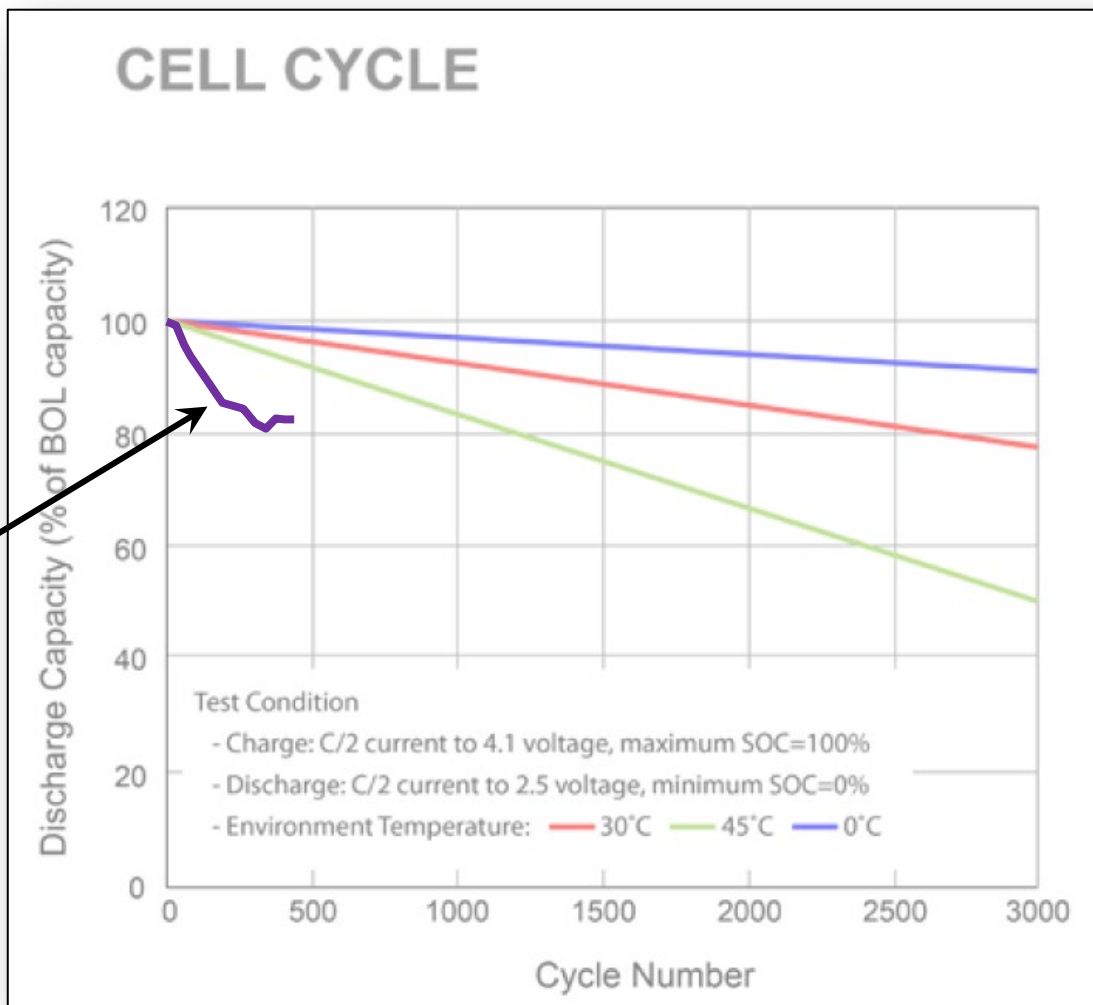
Comparison to EnerDel published results

- <http://www.enerdel.com/pe700-394-a-vigor-battery-pack/>



Technical Accomplishments (continued) Comparison to EnerDel published results

- <http://www.enerdel.com/pe700-394-a-vigor-battery-pack/>



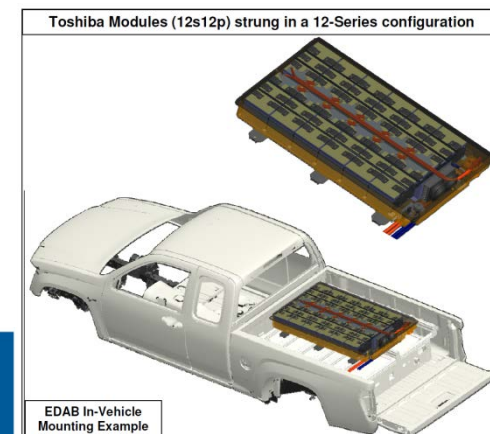
EDAB
On-road
Results

Technical Accomplishments (continued)

Toshiba LTO ESS prepared for On-Road testing

- Specifications were received from several companies
 - Various ESS capacities and applications (PHEV40 and BEV)
- ESS chosen:
 - Toshiba SCiB™ Lithium Titanate (LTO)
 - Manufacture claims include:
 - High Output Performance / High charge & discharge rates
 - Superb Temperature Performance
 - Superior Life
- ESS configuration of Toshiba LTO
 - ESS capacity: 13.2 kWh & 40 Ah
 - 12 modules (20Ah cells paired)
 - Air cooled (conditioned air via R134a)
 - PHEV pack configuration
 - EDAB Emulated Vehicle Platform
 - EREV (Chevy Volt)
 - ESS design and construction by AVL Calif.

TOSHIBA Leading Innovation >>> **SCiB™**



Technical Accomplishments (continued)

Toshiba LTO ESS prepared for On-Road testing

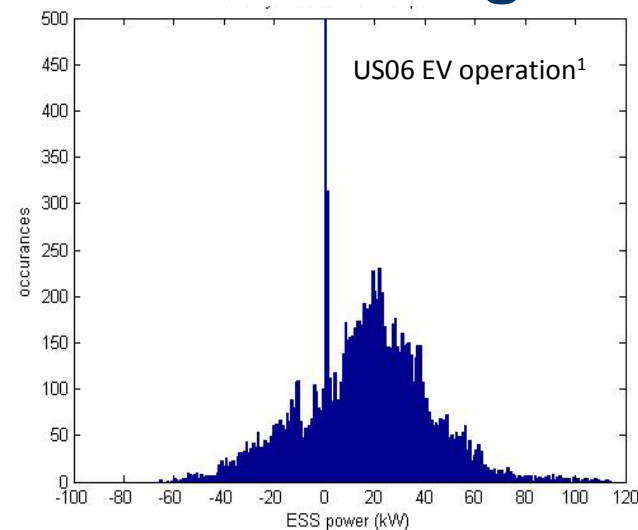
- Module: 12 series 2 parallel cells (20 Ah cells)
- Pack: 12 module (40 Ah) 13.2 kWh total
- Air cooled modules
 - Conditioned by R134a heat exchanger
- 400 Amps max current (10 sec)
 - note: 400A = 10 C rate
- 331 VDC nominal
- ~230 kg (estimate)



Technical Accomplishments (continued)

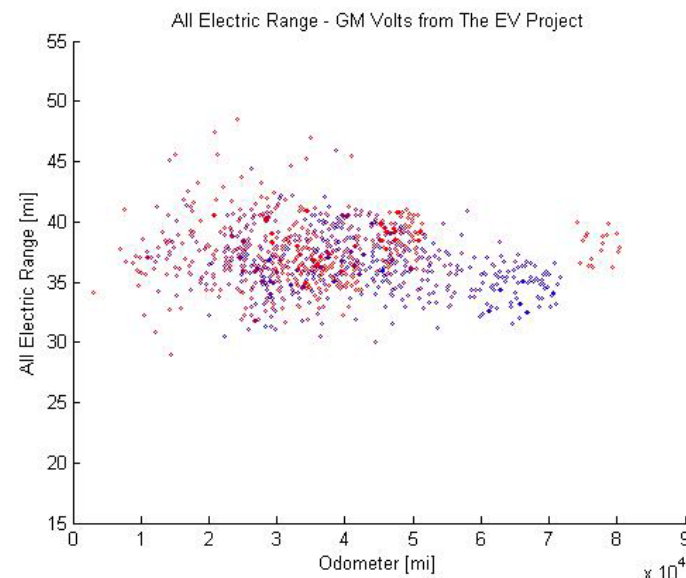
Toshiba LTO ESS prepared for On-Road testing

- Benchmark testing of 2013 Chevy Volt:
 - Usable capacity: 60% of total capacity
 - 10.0 kWh¹ of 16.6 kWh²
 - Power Requirements ~120 kW max.¹
- Data from Chevy Volts with >50,000 miles, shows EV range remains constant with age³
- Typical operation: 75% of miles in EV operation³



Toshiba ESS will be utilized similar to Chevy Volt

- Usable capacity: 60% of initial capacity
 - 8.0 kWh usable for duration of testing
- 400A max. (above 300V) meets 120 kW req.
- EV / Charge Sustaining miles: 75% / 25%
- City / Hwy miles: 50% / 50%



Results from AVTA: 1. Argonne APRF data, 2. Intertek ESS capacity testing, and 3. INL EV Project results analysis

Response to Previous Year Reviewer Comments

- Reviewer: "...called for laboratory testing of the battery. The reviewer suggested that if the manufacturer will not provide useful data, this group ought to conduct pertinent tests independently."
- The EDAB approach has been augmented to now include laboratory cell testing at controlled temperature per USAB test procedures for correlation to the ESS on-road test results
- Reviewer: "...modeling and energy storage system (ESS) development, ...if there was a clear path to delivery and if there were specific recipients for modeling especially."
- On-Road ESS test results and Laboratory cell test results will be used to validate and augment the **CellSage** modeling tool

Collaboration

- Results from ESS testing are provided to U.S. DOE, Tech Teams, and other National Labs for use with modeling tools, energy storage development, and improved understanding of operating conditions of ESS's during driving and charging

Future Work

- Baseline capacity and performance tests of Toshiba ESS (May 2014)
- Commence on-road testing of Toshiba ESS (June 2014)
- Correlation testing on individual cells to be conducted for direct comparison to on-road ESS results
 - Toshiba 20Ah SCiB (Lithium-Titanate) ESS
 - Same cells as within the ESS
 - Thermal chamber regulated to 30°C
 - Testing conducted in accordance to USABC Battery Test Manual for Plug-In Hybrid Electric Vehicles revision 2 (Dec 2010)
- **CellSage:** Prognostic and Diagnostic modeling tool used to correlate performance characterization and aging mechanisms with the on-road test results

Summary

- Testing of the EnerDel 70 Ah ESS is complete
 - 412 equivalent full charge cycles
 - 17.5% capacity fade
 - 33% increase in discharge resistance (50% SOC)
- Initial testing underway for Toshiba 40 Ah Lithium Titanate ESS
 - EDAB control system calibration complete for E-REV operation
 - Baseline capacity and performance test scheduled for May 2014
 - Commence on-road testing scheduled for June 2014
- Provide data/results from on-road operation of Lithium Titanate ESS
 - Power and Capacity Fade results
 - Impact of driving / charging patterns on ESS
 - Temperature operation effects
- Cell testing to be conducted for correlation to on-road ESS results
- CellSage modeling for prognostic evaluation and validation of modeling tool using on-road and laboratory cell test results

Acknowledgement

This work is supported by the U.S. Department of Energy's EERE Vehicle Technologies Program

More Information

<http://avt.inl.gov>

Reviewer-Only Slides

Vehicle Testbed

- Flexibility to test a wide range of ESS
- Up to 48" W x 68" L x 30" H
 - "T" portion of a "t - pack" can be up to 52"
- Load capacity up to 1000 lbs.
- Modular mounting system
- Liquid cooling and air cooling systems for ESS are integrated into the testbed
- Power capability up to 145 kW (propulsion and regenerative braking)
- Testbed is compatible with 340 to 420 VDC (down to 240 VDC with decreased power)
- Controls communications (CAN), safety interlock, charging flexibility (Level 1 up to 50+ kW)

