EP-C-12-014

FEV Literature Review: Electrified Vehicle Durability

Status Update

Presented: EVE-IWG June 8, 2015

FEV Literature Review
Scope of Work

Ongoing work

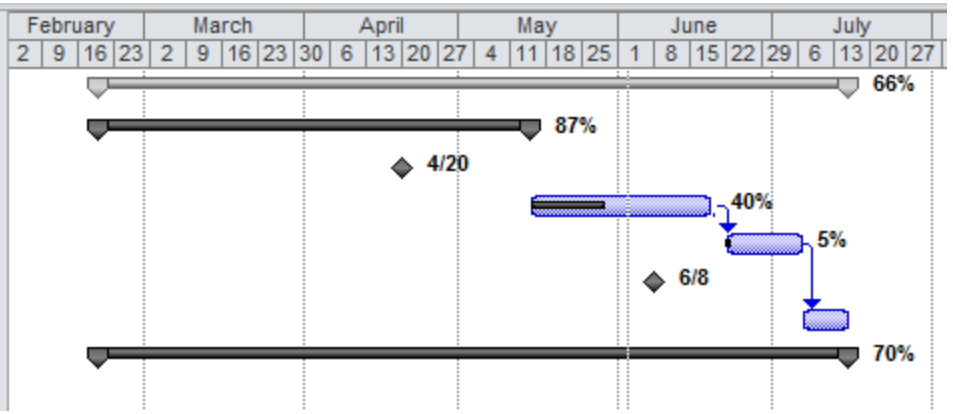
- Task 1: Literature Review
  - Existing definitions of Electrified Vehicle durability
  - Factors affecting Electrified Vehicle durability
  - Existing and emerging test programs or methodologies
  - Synthesis and analysis of the above, and identification of areas of work for EVE-IWG

Upcoming work

- Task 2: Additional Test Program and Methodology Recommendations
  - FEV will provide its own recommendations for test programs and methodologies
- Task 3: Written Final Report
  - Written report detailing the conclusions from tasks 1 & 2
- Task 4: Presentation of Written Final Report
  - PowerPoint presentation & .pdf of written report

FEV Literature Review Timeline

WBS	Task Name	Duration
0	Literature Review: Electric Vehicle Battery Durability	101 days
1	Literature Review	59 days
2	EVE #14	0 days
3	Test Program and Methodolgy Review	25 days
4	Final Written Report	10 days
5	EVE #15	0 days
6	Electronic Presentations / Summary Report	7 days
7	Project Management	101 days



FEV Literature Review
Factors Effecting EV Durability

- **Depth of Discharge of Battery**
  - Percentage of total energy left in battery
- **Static State of Charge of Battery**
  - The level of charge of the battery when the vehicle is in a standby mode
- **Charging Rate**
  - The rate at which the battery is charged
- **Drive Cycle**
  - Whether it is a city, highway, or combined cycle
- **Temperature**
  - The temperature of the high voltage system components
- **Driver Aggressiveness**
  - Whether the driver accelerates fast and brakes hard or the opposite
- **Environment**
  - The general location the car is in such as hot and dry or cold and snowy
- **Daily Usage**
  - The amount of miles accumulated daily

FEV Literature Review
Example of Electrified Vehicle Testing Methodologies

- **Elevated Storage Temperature**
  - The vehicle will be stored at an elevated ambient temperature for a period of two months. Capacity will be tested weekly to determine loss of capacity
- **Rapid Charge/Discharge**
  - The vehicle will be charged and discharged at a much faster rate than normal for 20 cycles without a rest period between cycles
- **Thermal Shock Cycling**
  - The vehicle will be quickly cycled from a high temperature environment of 80°C to a cold temperature environment of -40°C for a total of 5 cycles
- **Mechanical Vibration**
  - The vehicle will be placed on a shaker table and subjected to a series of vibration events for a long period of time
- **End-of-life Vehicle and Battery Testing**
  - This testing is conducted on a HEV after it accumulated 160,000 test miles, characterizes the effects of high mileage on fuel efficiency and traction battery pack capacity

- **Hybrid Electric Vehicle End-of-Life Testing** *[3] [12] [13] [14] [15] [16]*
  - This technical report details the end-of life fuel efficiency and battery testing on six HEVs
  - The end-of-life testing was conducted after each vehicle has been operated for approximately 160,000 miles, characterizes the effects of high mileage on fuel efficiency and traction battery pack capacity

- **Hybrid Electric Vehicle Battery Test Results** *[3] [12] [13] [14] [15] [16]*
  - This report provides test results for BOT and EOT battery testing conducted on the 2010 Ford Fusion, Honda Civic, Toyota Prius, Honda CR-Z, Hyundai Sonata and Honda Insight, from both laboratory and on-road test configurations
  - The battery laboratory test results include those from the static capacity test and the Hybrid Pulse Power Characterization Test, vehicle test results include those from acceleration testing and fuel economy testing

- **PHEV Battery Test Results** *[2]*
  - This paper discusses the results of static capacity test, EV characterization test, constant power discharge test, acceleration test and fuel economy test on a 2011 Chevrolet Volt

- **Comparison of PHEV Battery Life Across Geographies and Drive Cycles** *[20]*
  - This paper applies a semi-empirical life model of the lithium-ion chemistry to investigate calendar degradation for various geographic environments and simplified cycling scenarios. This paper specifically considers aging scenarios for PHEVs with 10 and 40mile nominal electric range

FEV Literature Review
Test Laboratory Examples

Idaho National Laboratory

- 160,000 Mile Fleet Tests [12]
  - HPPC (Hybrid Pulse Power Characterization) and static capacity tests are conducted to assess the condition of the vehicles when the vehicle is new and at 160,000 miles
- Cold Weather On-road Testing of a Chevrolet Volt [1]
  - The vehicle was driven every day in the winter and spring months over a specified course. Then it was fully charged and let to sit overnight in the cold until the next morning when the procedure was repeated

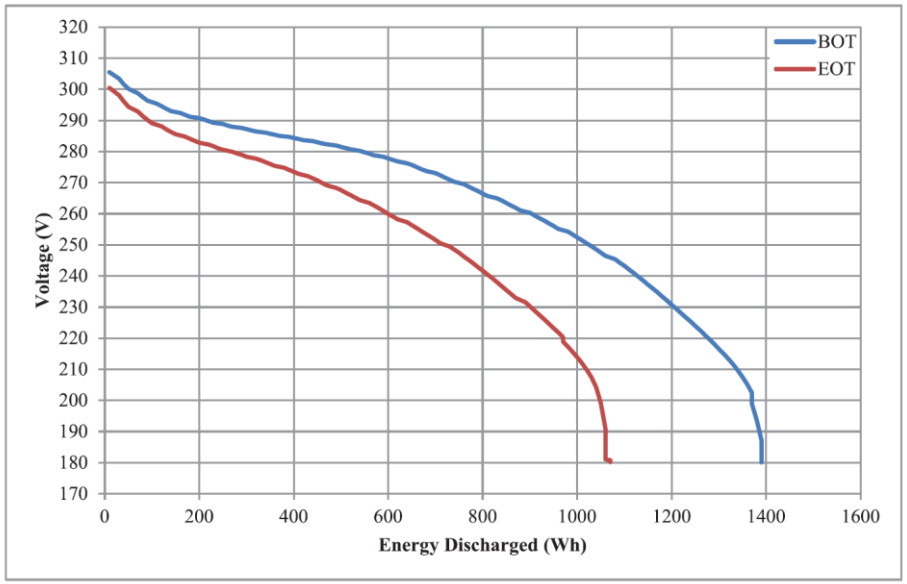


Figure 1. Voltage versus energy discharged during the static capacity test

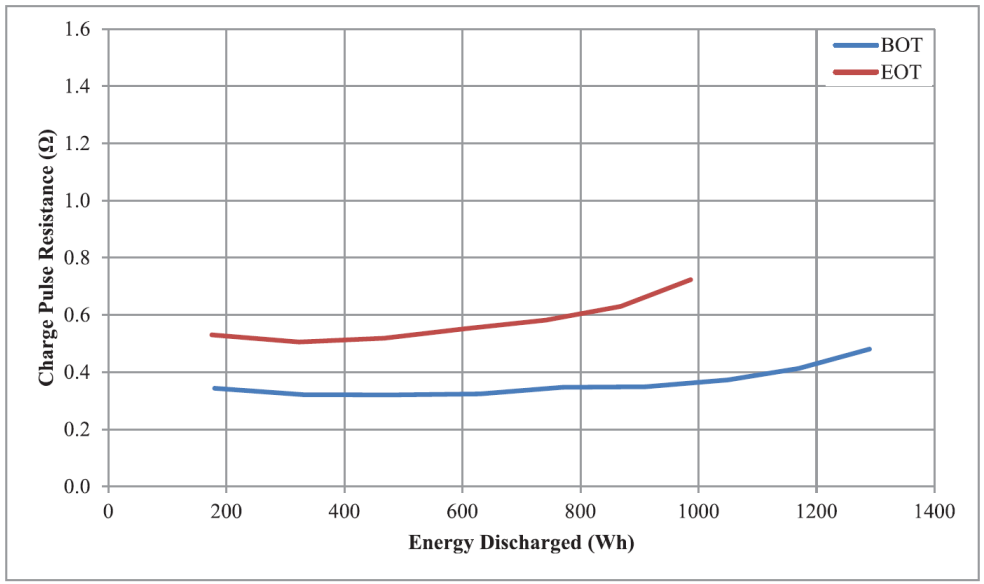


Figure 2. Ten-second charge pulse resistance versus energy discharged

National Renewable Energy Laboratory

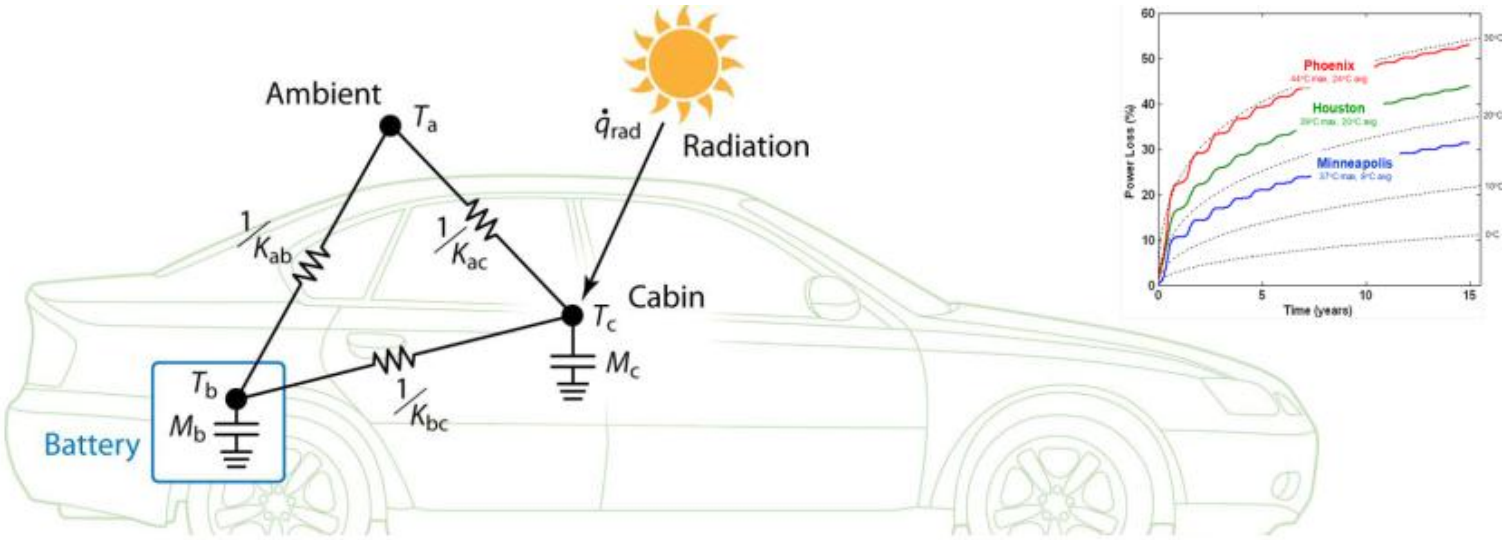
- Impact of Temperature Extremes on Li-ion Battery for Vehicle Applications [10]
  - This paper discusses that how the extremely temperature (-20 and 45) effect the battery life, the results show that the battery has poor cycle life and faster deration in high temperature, also the polymeric within the cell tend to become brittle in cold temperature

- Opportunities for Electric-Drive Vehicle Battery Health Management [9]
  - An analysis of battery life for PHEV considers 782 duty-cycles from travel survey data, superimposed with climate data from multiple geographic locations around the United States
  - Based on predicted wear distributions, opportunities for extending battery life including modification of battery operating limits, thermal and charge control are discussed

FEV Literature Review
Test Laboratory Examples

- Electric Vehicle Battery Thermal Issues and Thermal Management Techniques [7]
  - This paper explains why battery life and performance are extremely sensitive to temperature exposure and why thermal management is a must for batteries

- Simulated Impacts of Life-Like Fast Charging on BEV Batteries [5]
  - This paper assess the impact of realistic fast charging scenarios on battery response including thermal and degradation effects



National Traffic Safety and Environment Laboratory – Japan

- **Evaluation of the influence on batteries in PHEV [19]**
  - This paper focused on construct a test method for the evaluation of battery degradation.
  - The influence of thermal load on the capacity reduction is firstly detailed. Then the degree of influence of two load terms on the capacity reduction are compared. In addition, an example of an accelerated test by raising the ambient temperature is also discussed.

FEV Literature Review
Selection of Reviewed Literature

(1) John Smart. (2015). Advanced Vehicle Testing Activity Cold Weather On-road Testing of the Chevrolet Volt. United States. doi:10.2172/1177240

(2) Tyler Gray, Matthew Shirk, and Jeffrey Wishart. (2013). 2011 Chevrolet Volt VIN 0815 Plug-In Hybrid Electric Vehicle Battery Test Results. United States. doi:10.2172/1097168

(3) Tyler Gray. (2013). 2010 Honda Insight VIN 0141 Hybrid Electric Vehicle Battery Test Results. United States. doi:10.2172/1073775

(4) James Francfort, Donald Karner, Ryan Harkins, and Joseph Tardiolo. (2006). Hybrid Electric Vehicle End-Of-Life Testing On Honda Insights, Gen I Civics And Toyota Gen I Priuses. United States. doi:10.2172/911275

(5) Neubauer, J., Wood, E., Burton, E., Smith, K., & Pesaran, A. (2014). FY14 Milestone: Simulated Impacts of Life-Like Fast Charging on BEV Batteries (Management Publication). United States. doi:10.2172/1167072

(6) Wood, E., Neubauer, J., Brooker, A. D., Gonder, J., & Smith, K. A. (2012). Variability of Battery Wear in Light Duty Plug-In Electric Vehicles Subject to Ambient Temperature, Battery Size, and Consumer Usage: Preprint. United States.

(7) Rugh, J. P., Pesaran, A., & Smith, K. (2013). Electric Vehicle Battery Thermal Issues and Thermal Management Techniques (Presentation). United States.

(8) USABC, Electric Vehicle Battery Test Procedures Manual. United States.

(9) Smith, K., Earleywine, M., Wood, E., & Pesaran, A. (2012). Battery Wear from Disparate Duty-Cycles: Opportunities for Electric-Drive Vehicle Battery Health Management; Preprint. United States.

(10) Pesaran, A., Santhanagopalan, S., & Kim, G. H. (2013). Addressing the Impact of Temperature Extremes on Large Format Li-Ion Batteries for Vehicle Applications (Presentation). United States.

FEV Literature Review Continued…

(11) John Smart, Jim Francfort, Don Karner, Mindy Kirkpatrick, Sera White. (2009). Advanced Vehicle Testing Activity: Plug-In Hybrid Electric Vehicle Testing and Demonstration Activities. United States.

(12) Tyler Gray, Matthew Shirk, and Jeffrey Wishart (2014). 2010 Honda CR-Z VIN 4466 Hybrid Electric Vehicle Battery Test Results. United States.

(13) Tyler Gray, Matthew Shirk, (2013). 2010 Ford Fusion VIN 4757 Hybrid Electric Vehicle Battery Test Results. United States.

(14) Tyler Gray, Matthew Shirk, and Jeffrey Wishart. (2013). 2010 Honda Civic Hybrid Ultra Battery Conversion 5577 - Hybrid Electric Vehicle Battery Test Results. United States.

(15) Tyler Gray, Matthew Shirk,. (2013). 2010 Toyota Prius VIN 0462 Hybrid Electric Vehicle Battery Test Results. United States.

(16) Tyler Gray, Matthew Shirk, and Jeffrey Wishart. (2014). 2011 Hyundai Sonata VIN 3539 Hybrid Electric Vehicle Battery Test Results. United States.

(17) Brant Price, Eric Dietz and Jeff Richardson, Life Cycle Costs of Electric and Hybrid Electric Vehicle Batteries and End-of-Life Uses. United States.

(18) Blake Dickinson, Jose Baer, Omourtag A. Velev and David Swan, Performance, Management and Testing Requirements for Hybrid Electric Vehicle Batteries. United States.

(19) Tetsuya Niikuni, Kenichiroh Koshika, Terunao Kawai. (2010). Evaluation of the influence of JC08-based cycle stress on batteries in plug-in hybrid electric vehicle. Japan.

(20) Smith, K., Earleywine, M., Wood, E., Neubauer, J., & Pesaran, A. (2012). Comparison of Plug-In Hybrid Electric Vehicle Battery Life Across Geographies and Drive Cycles. United States.