EP-C-12-014 WA 3-01

FEV Literature Review: EV Battery Durability

Status Update

Presented: April 20, 2015

Scope of Work – Based on EPA Contract Work Assignment

Ongoing work:

- Task 1: Literature Review
  - Existing definitions of battery durability for BEV, PHEV and HEV
  - Factors effecting battery durability
  - Existing and emerging test programs or methodologies
  - Synthesis and analysis of the above and identification of areas of work for EVE-IWG

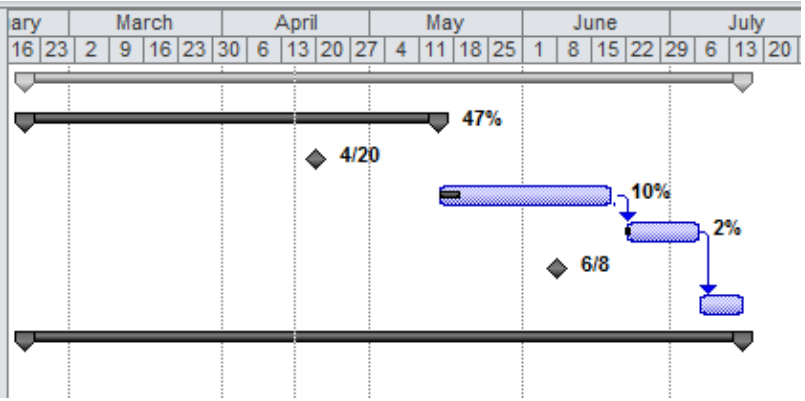
Upcoming work:

- Task 2: Additional Test Program and Methodology Recommendations
  - FEV will provide 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

Project Timeline

WBS	Task Name	Duration	Start	Finish
0	**Literature Review: Electric Vehicle Battery Durability**	**101 days**	**Fri 2/20/15**	**Wed 7/15/15**
1	**Literature Review**	**59 days**	**Fri 2/20/15**	**Thu 5/14/15**
2	EVE #14	0 days	Mon 4/20/15	Mon 4/20/15
3	**Test Program and Methodolgy Review**	25 days	Fri 5/15/15	Fri 6/19/15
4	**Final Written Report**	10 days	Mon 6/22/15	Mon 7/6/15
5	EVE #15	0 days	Mon 6/8/15	Mon 6/8/15
6	**Electronic Presentations / Summary Report**	7 days	Tue 7/7/15	Wed 7/15/15
7	**Project Management**	**101 days**	**Fri 2/20/15**	**Wed 7/15/15**



Structure of Literature Review

- Introduction
  - Discussion of the task from EPA / EVE
- Brief Review of Electric Powertrains
  - BEV, HEV, PHEV
- Brief Overview Types of Batteries Used in BEV, HEV and PHEV Applications
- Defining Battery Durability
- Analysis of Battery Degradation Mechanisms
  - Emphasis on effects on durability
- Analysis of Existing and Emerging Test Programs for Evaluating EV Battery Durability

Number of Resources

- SAE Standards/Papers - 5
- IEEE Papers - 8
- US National Laboratory Publications - 11
- ISO Standards - 1
- Industry Standards – 2

Additional publications and other sources, including international, will be investigated further

Selection of Reviewed Literature

Standards/Manuals

- *Battery Technology Life Verification Test Manual Revision 1*, INL/EXT-12-27920, December 2012
- *Battery Test Manual for Plug-In Hybrid Electric Vehicles*, INL/EXT-14-32849, September 2014
- *Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing*, SAE Standard J2464, November 2009.
- *Fiscal Year 2013 Annual Progress Report for Energy Storage R&D*, DOE/EE-1038, February 2014
- *FreedomCAR Electrical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications*, SAND 2005-3123, June 2005

Papers

- E. Wood, J. Neubauer, A. D. Brooker, J. Gonder and K. A. Smith, "Variability of Battery Wear in Light Duty Plug-In Electric Vehicles Subject to Ambient Temperature, Battery Size, and Consumer Usage," in International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium 26, Los Angeles, California, 2012.
- L. Gaines, J. Sullivan, A. Burnham and I. Belharouak, "Life Cycle Analysis for Lithium-Ion Battery Production and Recycling," in 90th Annual Meeting of the Transportation Research Board, Washington, D.C, 2011.
- L. Gaines and J. Sullivan, "A Review of Battery Life-Cycle Analysis: State of Knowledge and Critical Needs," October 1, 2010.

Factors Effecting Electric Vehicle Durability - Preliminary List

- Environment
  - Hot weather
  - Cold Weather
- Drive Cycles
  - BEV
  - HEV
  - PHEV
- Charging Rate and Charging Frequency
- Vehicle Storage/Inactivity

Factors Effecting Battery Durability - Preliminary List

- Chemical composition
  - Cathode
  - Anode
  - Electrolyte
  - Separator
- Total Pack Energy
  - Depth of Discharge
  - Static state of charge
  - Charging rate
  - Discharging rate
- Temperature (Pack / Ambient)

Examples of Testing Methodologies for Electric Vehicle Batteries

- Elevated Storage Temperature
  - The battery 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 battery 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 battery 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
- Overcharge
  - The battery will be charged from 100% SOC until it reaches 200% SOC or until the battery fails. The charge current and voltage will vary depending on whether the test is emulating an EV or HEV

Examples of Testing Methodologies for Electric Vehicle Batteries

- Overdischarge
  - The battery will be discharged at a C/1 rate from 100% SOC for 1.5 hours or until 50% of all subassemblies have reached voltage reversal for 15 minutes
- Short Circuit
  - The battery will be hard shorted with a conductor of ≤5 mΩ for 10 minutes or until another event occurs that prevents completion of the test
- Partial Short Circuit
  - A portion of the battery will be hard shorted with a conductor of ≤5 mΩ for 10 minutes or until another event occurs that prevents completion of the test
- Mechanical Vibration
  - The battery will be placed on a shaker table and subjected to a series of vibration events for a long period of time

Next Steps

- Continue research for literature review with expansion of international reference sources
- Provide recommendations from experience for test programs and methodologies
- Final written report and presentation