Item 4:

Electrified Vehicle Battery Performance & Durability

Presented by: USA, Canada
EVE-13 meeting
January 12, 2015

Outline

1. Review, EVE-12 meeting discussion on Battery durability
2. Continued discussion:
   a) Battery durability definition
   b) Factors affecting battery durability
   c) Battery degradation mechanisms
3. Proposal for work:
   a) Motivation, Deliverables
   b) Research method, Timeline
4. Next steps

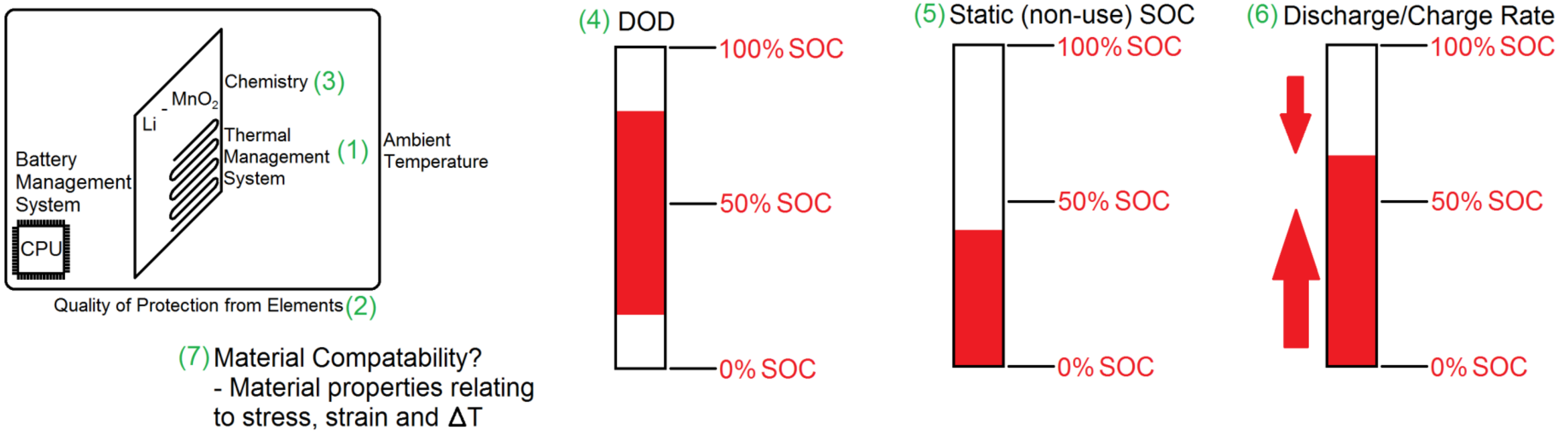
Review:
EVE-12 meeting discussion on Battery durability

- EVE should continue the investigation of xEV battery durability as a vehicle-level issue
- EVE should consider this topic under Part A and B of the new mandate
- Potential issues to be addressed under Part A:
  - Establish a definition of battery durability
    - What criteria should be established for full useful life requirements?
  - Identify all factors that effect battery durability
  - Work to support the design of an appropriate test program or methodology for evaluating battery durability
    - Where test cycles and procedures are considered, the WLTP will be the basis

Battery Durability Definition

- Adopt an existing definition
  - Contracting parties
  - Stakeholder specific definitions
  - International standards
- Create a new definition for electrified vehicle durability
  - Adapt existing durability concepts currently being used in regulations
- Based on the discussions to-date, the definition of battery durability and/or a potential methodology for determining durability could have a significant influence on battery design.

Continued discussion:
Factors affecting battery durability



(1) Battery Cell Temp = f(BMS, TMS, Amb Temp, Chemistry, Rate of Discharge, Enclosure, Material properties)
(2) Protection from Elements - Resistance to vibration, physical impacts, exposure to elements and moisture
(3) Chemistry - Some chemistries have a relative propensity to increase internal resistance to ion exchange
(4) DOD - Lower depths of discharge have been shown to 'extend' the battery life (# of cycles)
(5) Static (non-use) SOC - High SOC levels on a static battery tend to 'stress' the battery, whereas low SOC levels can lead to the voltage falling below a threshold such that the battery is unusable
(6) Discharge/Charge Rate - High charge or discharge rates 'strain' a battery. Parts of the battery will swell or shrink during charge/discharge cycles and this is exacerbated by increasing the charge/discharge rate
(7) Material Compatability - The material properties of the battery and related components must be appropriate for thermal and physical stress and strains expected to be endured.

Continued discussion: Battery degradation mechanisms

- Table 1: Lithium-ion anode aging- causes, effects, influences
- Vetter, J. et al. *Aging mechanisms in lithium-ion batteries,* Journal of Power Sources 147 (2005) 269-281.

Cause	Effect	Leads to	Reduced by	Enhanced by
Electrolyte decomposition (→SEI) (Continuous side reaction at low rate)	Loss of lithium Impedance rise	**Capacity fade** **Power fade**	Stable SEI (additives) Rate decreases with time	High temperatures High SOC (low potential)
Solvent co-intercalation, gas evolution and subsequent cracking formation in particles	Loss of active material (graphite exfoliation) Loss of lithium	Capacity fade	Stable SEI (additives) Carbon pre-treatment	Overcharge
Decrease of accessible surface area due to continuous SEI growth	Impedance rise	**Power fade**	Stable SEI (additives)	High temperatures High SOC (low potential)
Changes in porosity due to volume changes, SEI formation and growth	Impedance rise Overpotentials	Power fade	External pressure Stable SEI (additives)	High cycling rate High SOC (low potential)
Contact loss of active material particles due to volume changes during cycling	Loss of active material	**Capacity fade**	External pressure	High cycling rate High DOD
Decomposition of binder	Loss of lithium Loss of mechanical stability	Capacity fade	Proper binder choice	High SOC (low potential) High temperatures
Current collector corrosion	Overpotentials Impedance rise Inhomogeneous distribution of current and potential	Power fade Enhances other ageing mechanisms	Current collector pre-treatment (?)	Overdischarge Low SOC (high potential)
Metallic lithium plating and subsequent electrolyte decomposition by metallic Li	Loss of lithium (Loss of electrolyte)	Capacity fade (power fade)	Narrow potential window	Low temperature High cycling rates Poor cell balance Geometric misfits

Continued discussion: Battery degradation mechanisms

- Potential means of assessing battery durability is to examine the two degradation effects (capacity fade and power fade) and rank the conditions which contribute to the degradation effects
- However, battery chemistry, battery management system, and thermal management systems have highly significant impacts on the condition ranking.

Effects	Conditions or factors, i.e. High SOC			
Capacity Fade	C_1	C_2	C_3	C_4+
Power Fade	P_1	P_2	P_3	P_4+

Proposal for work

- Motivation
  - There is limited knowledge of xEV battery durability, which presents a risk to Regulators and manufacturers
    - HEVs that are currently credited by regulations for low emissions for their whole lifetime could contribute to vehicle emissions more as the battery ages
- Deliverables:
  1. To highlight the importance of xEV battery durability
  2. To outline the factors affecting durability
  3. To inform the decision of GTR development in Part B of the EVE mandate: a standardized way of evaluating durability
     - At this time it is unclear what a GTR would contain

Proposal for work

- Research method:
  - Literature review:
    - Definition of xEV battery durability, factors affecting xEV battery durability
    - Existing test programs or methodology for evaluating battery durability
- Timeline:
  - January – June 2016: Complete work on Part A
    - Jan – December 2015: Literature review
    - Jan – March 2016: Analysis of the review, draft Part B proposal
  - June 2016: Present informal documents on status of Part A and proposed GTR development requests (Part B) to GRPE, AC.3
  - November 2016: AC.3 decision to authorize GTR development (Part B)

Next steps

- Request for participation in the literature review
- Develop a detailed proposal for the literature review and acquire funding
- Develop a detailed roadmap for the next EVE meeting

Additional slides

Proposal for work

- **Potential challenges**
  - Time constraints: Simulating aging of a battery to test durability may be difficult given the 1 year time frame
  - Complexity of battery management systems
  - Requirement for companies to release proprietary information about their BMS and thermal management systems to run battery tests; need manufacturers on board with research
  - Variety of battery chemistries (i.e. all batteries are not the same and chemistries may impact durability)
  - Bench aging techniques of batteries are still in the early stages of development

Proposal for work

- **Potential sources of information**
  - Battery test procedure manuals published by US Advanced Battery Consortium and US Department of Energy
  - EVE Reference Guide from first EVE mandate
  - Data reported by private citizens
  - Idaho National Laboratory testing reports
  - ANSI report, SAE J1798 and ISO 12405-2:

4.1.1.3 Battery Testing – Performance and Durability

Gap: **Battery performance parameters and durability testing.** There is a need for further work on EV battery performance parameters and environmental durability test requirements. ***Recommendation:*** Complete work on SAE J1798 and if possible consider harmonization with ISO 12405-2. ***Priority:*** Mid-term. ***Potential Developer:*** SAE, ISO. ***Grid Related:*** No. ***Status of Progress:*** Yellow. ***Update:*** No change. There is not a lot of progress to date on SAE J1798.