Status report of Part B of the November 2016 mandate for the Electric Vehicles and the Environment Informal Working Group (EVE IWG)

APRIL 2019

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1.0 Introduction

The EVE mandate of the November 2016 report (ECE-TRANS-WP29-2016-116e), described three main objectives for part B in the framework of the 1998 Agreement by the Electric Vehicles and the Environment Informal Working Group (EVE IWG). These objectives were the following:

1) Developing an amendment to Global Technical Regulation (GTR) No. 15 to establish a procedure for determining the power train performance of electrified vehicles.

2) Continuation of research on the topic of battery performance and durability, with the goal of returning to AC.3 seeking authorization for relevant activities (including GTR development) once the additional research is completed and;

3) Approach the Group of Experts on Energy Efficient (GEEE) and possible the UNECE Executive Secretary, to request that they continue the work on the method of stating energy consumption with the support of the IWG on EVE.

The first objective was set to conclude by November 2019 with the establishment of the GTR by AC.3 in the Global Registry. The second objective was set to conclude by November 2018 and the third by June 2018. The second and third objectives were extended to submit report deliverables for all three objectives at the same time at the January 2019 Working Party on Pollution and Energy (GRPE) session.

2.0 Executive Summary

The follow sections of the status report summarizes the background, motivation, old and new research, discussion points and statuses for each of the three objectives of Part B of the EVE mandate[1]. These objectives being research on in-vehicle battery durability and performance, GTR drafting for system power determination, and finding a group to lead the work on upstream emissions for a method of stating energy consumption.

Concerning the task for research on in-vehicle battery durability and performance, there continues to be progression for the research. The EU Commission with Canada's support has led much of the research in this area. Currently the EU Commission's work is pending a publishing in an academic journal[2]. Other groups continue to make presentations on their research and contribute to the EVE IWG's overall research in this area. Despite research efforts, there remains considerable uncertainty whether there is sufficient knowledge of the battery complexities to move forward with a GTR. Some members feel that the research should be stopped at this time.

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[1] ECE-TRANS-WP29-2016-116e

[2] M. De Gennaro, E. Paffumi, G. Martini, A. Giallonardo, S. Pedroso, A case study to predict the capacity fade of the battery of electric vehicles in real-world use conditions, submitted to Case Studies on Transport Policy, 2018

From research progress, the EVE IWG has explored different approaches on how to evaluate in-vehicle battery performance and has discussed which durability requirements could apply to different vehicle architectures on air pollutants, energy consumption/CO_2 output, and range. Agreements on all aspects and areas is not certain yet due to changing chemistries and markets of in-vehicle batteries and complications to regulate all aspects.

The EVE secretariat with the help of the GRPE secretariat continues the path of finding a group to take on the leadership involving the method of stating energy consumption project on upstream emissions. The Group of Experts on Energy Efficiency and the Group of Experts on Cleaner Electricity Production (CEP) were approached by the EVE secretary to discuss taking over leadership of the method of stating energy consumption work on upstream emissions. The project seems to fall more in line with CEP's work which includes a number of cross-sectoral activities under the leadership of UNECE. The CEP group has since followed up with interest in leading the group.

The first section of the mandate, that focuses on the development of a Global Technical Regulation (GTR) for the powertrain performance of electrified vehicles is continuing the development on the GTR and continuing validating the test procedures. Since the November AC.3 meeting, it was decided that the GTR will become a separate GTR. The EVE IWG group continues to develop the test procedure and GTR draft.

3.0 Battery performance and durability

3.1 Background

This section of the report summarizes the progress to date of the EVE IWG's work on in-vehicle Battery Performance and Durability.

The previous work of EVE IWG during Part A of the current EVE mandate indicated that while sufficient knowledge and capability existed to evaluate specific electrified vehicle designs for in-vehicle battery performance and durability, it was not clear if a vehicle-level test procedure that fairly compares all types of battery chemistries and constructions, in all applications could be developed. Additionally, there was some concern among EVE members that developing a procedure prematurely may unduly influence battery design and material choice while the technology is still evolving.

Four approaches to battery durability were considered since the establishment of Part A of the mandate. These options were to:

A. Pursue the development of Durability Test profiles
    a. Through identification of factors known to affect battery degradation (driving cycles, temperature, charging rate, frequency, calendar time, parking time)
B. Seek to identify deterioration factors (DFs) to estimate the end of life
C. Investigate testing with aged or age-emulated battery
D. Use simulation to determine DF or expected degradation
    a. Through a simulation model that predicts the degradation resulting from the application of arbitrary lifetime usage profiles

3.2 Battery Performance and Durability and the EVE Mandate

Under the current Part B of the mandate, the EVE IWG timelines are as follows:

(a) November 2016 - June 2018: research in-vehicle battery performance and durability, develop a detailed work plan, continue consultation with the WLTP, and draft requests for relevant activities.

(b) June 2018 – Present a first draft status report on the research work and proposals for subsequent work (if appropriate) to GRPE and present informal documents on the status of research work and proposals for subsequent work (if appropriate) for review by AC.3

(c) November 2018 – Approval of the authorization to develop a GTR by AC.3 if appropriate

At the 26th EVE IWG meeting in Japan, there was a decision made to adjust the timeline as there was uncertainty about whether to progress with a GTR concerning battery durability and the subsequently, the work on the in-vehicle battery durability and performance was still ongoing. The timeline was adjusted to provide a report in January 2019 along with the deliverable of the final GTR of the system power determination testing procedure.

3.2.1 Motivation

The primary motivation for the EVE mandate on battery performance and durability stems from the recognition that the environmental performance of electrified vehicles may be affected by degradation of the battery system over time. For hybrid electric vehicles that are often equipped with both a conventional and electric powertrain, this can be of particular concern as the criteria pollutant emissions from the conventional powertrain could be impacted by the degradation of the battery. As stated in the Electric Vehicle Regulatory Reference Guide[3], loss of electric range and loss of vehicle energy efficiency are concerns with battery degradation and its impact on environmental performance. Both of these can affect not only the utility of the vehicle to the consumer, but also the environmental performance of the vehicle. Loss of environmental performance is important in particular because governmental regulatory compliance programs often credit electrified vehicles with a certain level of expected environmental benefit, which might fail to be realized over the life of the vehicle if sufficient battery degradation occurs.

As battery degradation is not currently subject to uniform standards, there is a desire to understand the potential for battery degradation to affect environmental performance of electrified vehicles. There is also a need to consider regulations to ensure that the battery durability of an electrified vehicle is sufficiently controlled to maintain the expected environmental performance for the life of the vehicle, particularly in the case of hybrid vehicles where emissions are of concern.

The IWG was therefore presented with the task of gathering information related to this topic, and to make recommendations concerning the possibility of establishing a GTR for this purpose.

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[3] https://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/electric_vehicle_ref_guide.html

3.3 Previous Findings

At EVE 16, a literature review of factors affecting battery durability was prepared by FEV Consulting and presented to the EVE IWG. From the presentation, it was clear that the problem of establishing battery durability for representative usage scenarios, chemistries, and configurations is extremely complex.

IWG members noted the following considerations:

- The factors which affect battery durability vary among different chemistries and usage conditions, and have differing importance to environmental performance.
- Battery aging is very path dependent, making it difficult to reliably model the actual life of an in-use battery by means of a single simplified test protocol.
- Influences on durability that occur during vehicle operation are not necessarily the same as those that occur while parked. For example, a vehicle parked in a hot environment for long periods of time may experience degradation due to elevated battery temperature, while a vehicle being actively operated in the same environment may avoid degradation because the battery is being actively cooled.
- Ambient temperatures have mixed relevance to battery durability. Manufacturers have the option to actively manage the temperature of the battery itself so that actual battery cell operating temperatures are rarely the same as ambient air temperatures.

Some members noted that any steps to predefine battery aging conditions may lead manufacturers to optimize performance for test conditions rather than for the range of actual usage likely to be experienced by customers. That is, if a test procedure is more demanding than necessary to demonstrate full useful life in the field, it might compel manufacturers to over-specify battery performance and unnecessarily increase cost; or if the test procedure is not demanding enough it may have little value in ensuring that environmental goals are met during the life of the vehicle.

The IWG also identified and discussed some quantitative approaches to predicting battery degradation that have recently been described in the literature. The IWG acknowledged research conducted by researcher Jeff Dahn at Dalhousie University, in which a technique known as high-precision coulomb counting is used to predict future degradation rates by measuring loss of charge in early cycling of battery cells.[4] The IWG also acknowledged a research initiative at Pennsylvania State University in which a formula was developed for battery degradation using inputs describing state of charge, how often the battery charges or discharges completely, operating temperature, and current. It was concluded that both methods appear to be best suited to cell-level analysis in a research environment, and so do not

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[4] More information can be found here: http://www.dal.ca/diff/dahn/research/adv_diagnostics/hpc_additive_studies.html

appear to be readily adaptable to vehicle-level testing. Both methods primarily attempt to quantify the future rate of formation of solid-electrolyte interphase (SEI) on a carbon-based Li-ion anode, they presumably would not reflect other mechanisms of degradation, nor mechanisms that would apply to non-carbon anodes or non-Li-ion chemistries. Since these methods are still in the research stage and still undergoing verification and development, the IWG felt that they are of limited value for application as a regulatory norm for battery durability determination.

Members of the IWG also discussed the possibility of defining durability in terms of the total amount of energy that a battery must deliver during its useful life in order to achieve the environmental performance expected in a given application. Evidence of this capability might then be established by testing the ability of a battery to deliver this energy through a series of appropriately specified charge and discharge cycles. The potential capability of such a test to deliver reliable estimates of durability for arbitrary usage cycles, chemistries and configurations were not examined. Considerable further research would be required to evaluate the applicability of this method. For example, it is not immediately clear what the appropriate test conditions would be, or how to validate the test results for vehicles of varying degree of electric propulsion as well as different usage conditions.

The following work of the EVE IWG looked at approaches to develop testing methods of vehicles or batteries. These approaches were the following:

a) Approach A:Pursue Development of Durability Test profiles
b) Approach B:Seek to identify deterioration Factors (DFs)
c) Approach C: Investigate Testing with Age or Age-emulated batteries
d) Approach D: Determine Deterioration Factors with Simulation

Approach A: Pursue Development of Durability Test profiles

The goal of approach A was to investigate the potential for the development of durability test profiles for the testing of vehicles or batteries, for use by a manufacturer to demonstrate compliance with a durability standard. The test profile could be any combination of factors known to affect battery degradation, including but not limited to factors such as: driving cycle, ambient temperature (during use and storage), internal battery temperature (related to thermal management effectiveness and driving cycle), charging rate at the charger, frequency and type of charging, calendar time, idle storage time, etc.
This approach could likely be feasible if:

(a) There exists one or more accelerated test profiles applicable to a vehicle or a battery that would effectively and fairly predict degradation over a specified useful life (kilometers and years).
(b) The test profile must be possible for a manufacturer to complete within a reasonable amount of time (e.g. 1 year or less).
(c) The test profile should not disadvantage chemistries that work well in real-world use, but respond poorly to accelerated testing. That is, the transformation from a test outcome to a predicted

degradation must either be the same for all chemistries and designs, or must be identified uniquely for each chemistry and design.

At EVE 22, members from JRC agreed to develop a proposal of what a potential battery durability test profile under this approach might look like. At this time, JRC continues to complete research in this area and improve the platform of their Transport Technology and Mobility Assessment (TEMA) model[5] as part of their proposal. Information on the inputs and outputs of this model can be found in figure A1 located in the appendix of this report. General parameters related to the vehicle technologies, battery architecture and environmental temperature conditions should be specified together with average duty cycle and charging information. Figure A1 summaries also the implemented chemistries and output from the model.

Approach B: Seek to identify deterioration Factors (DFs)

This approach would work to identify default DFs for use in vehicle certification, most likely by observing vehicles in use, and also considering the need to uphold environmental performance. In this approach, vehicles could be tested for environmental performance at or near their beginning-of-life and environmental performance at the end-of-life would be estimated by applying a default DF to represent expected degradation at EOL. A manufacturer could petition for the use of a different DF upon presentation of evidence to support it.

To identify a DF, they could be developed by observing vehicles in use; to identify the DF's they achieve during useful life in the hands of average customers, with the assumption that customer satisfaction and reliability is upheld and that environmental performance is maintained.

Approach C: Investigate Testing with Age or Age-emulated batteries

Approach C, investigates the possibility of a test protocol that involves testing a vehicle that has been configured to act like a deteriorated vehicle (by means of a special test mode that activates software changes, or a special test configuration involving specific hardware changes).

One approach that was discussed was the possibility of testing a vehicle with an aged battery. Procuring a properly aged battery would be a difficulty. While the ideal aged battery would be one that has been used for the full useful life in the hands of a typical customer (e.g. 240,000 km in 15 years), this is obviously not practical, meaning that alternatives must be considered to emulate such an ideally aged battery.

This approach could likely be feasible if:

a) For testing with an aged battery approach, a suitable/aging test profile (perhaps a result of Approach A) would need to be developed to age the battery
b) Feasibility requirements under approach A also apply

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[5] EVE-27-09e.pdf

c) For a hardware or software-emulated aging approach, a set of default DFs (as suggested in approach B would also be needed to define the operating limits of the age-emulation

Approach D: Determine DF by Simulation

This approach considers the development of a battery simulation model that would be sufficiently detailed to predict the degradation that would result from the application of arbitrary lifetime usage profiles. This would then be used to determine default DFs for various vehicle types and applications. This would be an alternative to Approach B, where DFs would be developed from empirical data. The model would likely be a very low-level model capable of using inputs such as battery chemistry, cell design, BMS, thermal management capabilities, etc. and predict degradation that would result from application of a test profile.

This approach could likely be feasible if the following conditions are met:

a) It must be possible to develop such a model with the resources available to EVE.
b) The model must be applicable to a wide variety of chemistries and designs likely to be used by manufacturers going forward.
c) The DFs thus derived by this analytical method should be possible to validate by comparison to empirical field or test data.

3.4 Points of Agreement

With regard to any of the approaches (A through D), it was identified that different types of electrified vehicles would likely present different requirements and may therefore be best suited to different approaches. Environmental goals, durability requirements, and implications of degradation are likely to differ substantially among different types of vehicles.

At EVE 22 it was discussed that as a minimum requirement going forward, the IWG should populate the following matrix by identifying which cells in the matrix represent a WLTP objective for regulation.

The following matrix (Figure 1) shows environmental goals on the horizontal, and vehicle types on the vertical.

	Air pollutants	CO_2/ Energy Consumption	Electric Driving Range
HEV			
PHEV			
PEV			

Figure 1 Matrix of environmental goals and vehicle types

Following the creation of these matrices, members have discussed a variety of views which are still draft views. Consensus views on the matrix topics are the following.

HEV – Air Pollutants

On the Hybrid Electric Vehicles (HEV), for air pollutant durability requirements, some EVE IWG members had the view that the durability should be 160,000km for air pollutants for HEVs and PHEVs (the same as conventional vehicles) and that there should be a 100,000 km check via in-service conformity protocol. This however is still under discussion and no consensus view have been reached yet. Japan has suggested that the EVE IWG could consider the use of deterioration factors for degraded batteries from OVC-HEVs and NOVC-HEVs since DF's are already available for internal combustion engine type vehicles. Japan also recommends that manufacturers provide clear explanations that indicate that the pollutant management system can still maintain appropriate pollutant levels as the battery degrades.

HEV – CO_2 / Energy Consumption

Views on CO_2 and energy consumption are that there should not be a limit as it does not make sense to require a manufacturer to be responsible for a certain target. However; despite there being no set limit on CO_2 or energy consumption value for these vehicles, it could be checked by type approval authority during in-service conformity so some requirement should be in place.

PHEV – Air Pollutant

The consensus view for plug-in hybrid is the same as those for hybrid electric vehicles. There is also an additional view that PHEVs should be tested after running 80,000 km at type approval.

PHEV - CO_2 / Energy Consumption

There are no consensus views on this topic. Suggestions in previous meetings by the EVE IWG have been to maintain the same durability requirements as those of HEV.

PHEV – Range

There were no consensus views on this topic yet but a number of simplified views reached with pros and cons mentioned of each are provided below. Table 2 also notes some suggestions from the EVE group that could be considered.

Table 1: PHEV Range Views

Simplified view	Pros	Cons
Electric driving range of PHEV shown to have correlation with how frequently vehicle is plugged in	Minimum all-electric range increased likelihood vehicle will be plugged in	Manufacturers can't control how frequently consumers choose to plug in
Customers make PHEV purchase decisions at least partly on all-electric range, and this is a good case where customer-manufacturer relationship/warranty can manage this concern	Manufacturers currently need to make sure they meet customer expectations, and need is not clear	
Consider splitting requirements for blended PHEV vs range extended PHEV	Vehicles are used differently and buyers normally have different consideration when buying	This makes the topic of EV durability even more complicated, and the EVE is already far from consensus on this

How to correlate degree of hybridization and consider that the way a PHEV is used is likely to change over the life of the vehicle	Longer durability requirements likely to increase use of EV range and reduce ICE operation	EV vs ICE operation will be difficult to measure and is not something manufacturer can control

PEV – CO2/Energy consumption

There are no consensus views on this topic yet, but one simplified view is that more energy consumed by the plug-in electric vehicle (PEV) could mean that there might be greater upstream emissions and therefore a standard warranted. Pros to setting a standard of this kind would limit environmental impacts of upstream emissions. Cons would be that upstream emissions are out of the control of manufacturers, and therefore not appropriate to consider as part of a durability requirement.

PEV - Range

There were some consideration that PEVs should have the same durability lifetime as for other categories, however with current technologies it would be technically impossible. There is also another consideration of defining the durability requirement as a function of a base range with a threshold; however this would be inappropriate to have a specific criteria due to factors affecting durability performance.

Matrix summary of views

Specific views expressed in the initial matrix, described in figure 1 can be shown in table 2 below. These views only include views explicitly submitted by members. It does not include points still in discussion at EVE from various members.

Table 2. Matrix summary of views and or suggestions

	Air pollutants	CO_2/ Energy Consumption	Electric Driving Range
HEV	EVE group view: no consensus view yet	EVE group view: some consideration at WLTP & other areas for higher threshold EVE group view: HEV CO_2 emission durability lifetime should always be the same as air pollutant durability lifetime	x
	EU position: HEV/PHEV pollutants should refer to useful life 160,000 km and in service conformity check requirements at 100,000 km		
	Japan position: Suggestion to use deterioration factors for degraded batteries from OVC-HEVs and NOVC-HEVs since DF's are already available for internal		

	combustion engine type vehicles. Recommendation that manufacturers provide clear explanations that indicate that the pollutant management system can still maintain appropriate pollutant levels as the battery degrades.		
PHEV	EU position: The same position as HEVs	EVE group view: PHEV should always have the same CO_2 emission durability lifetime requirement as HEV	EU group view: some concern about requiring durability for this value, since some manufacturers have ICE operate in certain conditions regardless of battery condition (i.e. above 80 km/h)
PEV	x	EU position: this criteria is not needed	
		EVE group view: The only reason to establish energy consumption requirement for PEV is if there will be an associated requirement to assess or include upstream emissions	EVE group view: There should be the same battery durability lifetime on range as other vehicle architectures. Could consider longer durability requirement for PEV range (i.e. [80% or 70%] at 150,000 km or 200,000 km; 8 or 10 years;) Could consider defining durability requirement as a function of base range, perhaps within a threshold (i.e. [80 km to 350 km] base range)

Although these are official views expressed, there have notably been other ideas discussed such as using warranty labelling or a warranty requirement. Previous versions of the matrix can be found in documents

3.5 Updated Findings

EVE IWG members have been conducting research to inform the EVE IWG's decisions on the matrix to determine a path forward.

The EU JRC has conducted research on approach A as discussed in the background section of this report. Approach A investigates the potential for the development of durability test profiles for use in the testing of vehicles or batteries and could be a method to estimate battery life.

Other groups have also presented their research related to in-vehicle battery durability. To date, there have been presentations on battery cell testing to assess the durability of EV batteries in different temperature conditions[6], the effect of low temperature on pollutant emissions of hybrids, and a presentation on assessing the impacts of electric vehicle mileage, accumulation and charging[7].

The durability cell testing has been completed in part to fulfill determine possible deterioration factors that could be used to assess battery life as in approach B.

The research and testing conducted on the impacts of mileage, accumulation and charging on electric vehicles has also contributed to the work of the EU JRC.

3.5.1 EU JRC research on approach A

The visible effects of electrochemical ageing of battery cells are a loss of energy capacity and a decrease of output power of the cell. An ageing model must aim at reproducing these two effects while considering the input variables identified above, such as, driving cycles, environmental and battery temperature, charging rate and frequency, calendar time and parking time. The estimation models can be classified in five main categories: electrochemical models, equivalent circuit based models, performance-based models, analytical models and statistical models. Based on this overview and in the framework of this activity, EU JRC has developed a dedicated in-vehicle battery durability assessment module within its Transport Technology and Mobility Assessment (TEMA) platform, based on performance-based models as this class of models is the most suitable to be used with large-scale real-world driving data[8]. TEMA is in fact a modular big data platform designed to reproduce mobility behaviors of vehicles from datasets of navigation system data of conventional fuel vehicles and quantify possible impacts of new vehicle technologies on real-world mobility while supporting transport policy assessment.

In particular, recent capacity and power fade performance-based models for Lithium-ion batteries from literature have been combined with information on battery and vehicle architectures and with real world vehicle driving data from different geographical areas of Europe to develop a scenario-based analysis for predicting in-vehicle performance degradation of automotive traction batteries. The analysis includes the calendar and cycle capacity fade of three Li-ion variants (LiFePO4, NCM with spinel Mn and NCM-LMO) in different vehicle architectures (PHEV and BEV of different driving range segments) combined with five different recharging strategies to explore the effect of different driving duty cycles related to different mobility patterns and environmental temperatures. The results show the effect that environmental

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[6] EVE-28-17e is the latest presentation document on this topic

[7] EVE-28-08e

[8] EVE-28-13e

temperature and duty cycle have on calendar and cycling ageing in in-vehicle battery durability assessments[9].

Figure 2 summarizes the logical steps of the in-vehicle battery durability TEMA module. Studies are on-going to explore the possibility to generalize the model (steps #1 and #3 in particular), in such a way that only fitting coefficients of the cell calendar and cycle testing data or average values related to the duty cycle might be given as input to the model, avoiding time resolved information on driving behavior and battery parameters.

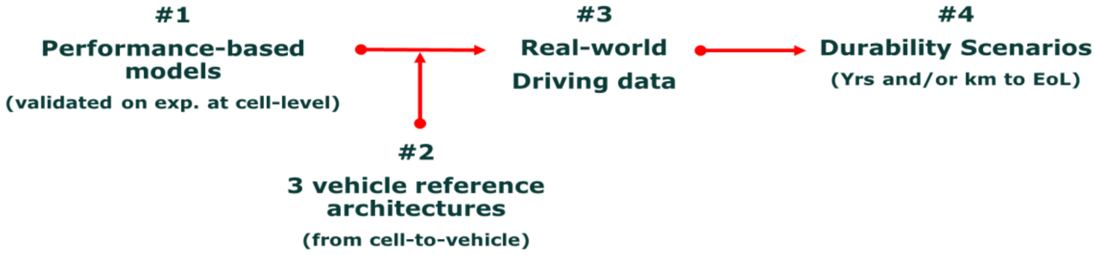

Figure 2 JRC TEMA In-vehicle battery durability module logical steps

The results simulating electric vehicle performance have been compared with electric vehicle lifetime performance testing data provided by Canada ECCC and Transport Canada. The forecast deterioration using the TEMA platform and measured deterioration using real-world test data showed good agreement with the tested BEV models. The ability to relate deterioration of cell level performance characteristics (which are well understood) with pack level performance characteristics (which can be much more difficult to predict) is one of the key results of this work.

Despite the assumptions and limitations of the assessment model, the results constitute a step forward in the topic of in-vehicle battery durability combining the revision of calendar and cycle capacity fade models for electrified vehicle traction batteries with large-scale real-world driving data and validation with an experimental mileage accumulation test campaign. The presented approach may serve as basis for determining the key influencing parameters and the needed assumptions in view of the approaches A to D above.

3.5.2 Durability testing of electrified vehicle batteries

The EV durability research conducted by Canada evaluates the durability of electrified vehicle batteries under low temperature conditions and investigates methods that could be used to generate battery deterioration factors and/or artificially age batteries for regulatory testing. This work serves in part to

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[9] M. De Gennaro, E. Paffumi, G. Martini, A. Giallonardo, S. Pedroso, A case study to predict the capacity fade of the battery of electric vehicles in real-world use conditions, submitted to Case Studies on Transport Policy, 2018.

fulfill the research needed to determine if approach B, discussed in section 2.1 and 2.3 is an appropriate method to assess the durability of batteries for a GTR. Approach B investigates the identity of default deterioration factors.

The objectives of the project established were to investigate the performance of the cells in different temperature conditions, investigate new faster techniques to determine durability and to propose solutions that improve low temperature characteristics that maintain normal operating temperature performance of batteries.

The research has since analyzed the performance of electrified batteries through testing of the battery cell charge and discharge rates at different temperatures and analyzed the cell components for factors that can contribute to cell durability.

The use of high precision cycling was investigated to assess its ability to estimate battery life. The high precision cycler counts every coulomb in and out of the batteries to obtain a coulombic efficiency which is an indicator of cycle life. The method of using high precision cycling is slow and takes approximately 80 hours for a full cycle. Due to the length of time, it is best used for shorter amounts of cycles. The results obtained from this method can lead to a trend of predicting lifetime and can indicate capacity loss. So far, results of cycling the battery cells using the high precision cycling technique have shown that the batteries have retained very high efficiencies.

The analysis of rate performance in different temperature conducted on two PHEVs and a PEV indicated that one of the PHEVs showed very good rate capability while the others were not doing as well when exposed to temperatures at 45° C. The finding was consistent with other research data. The trend was that as the c-rate[10] increases there is less energy coming out of the cells.

The analysis of normalized discharge capacities in different temperatures indicated that the discharge capacities were generally above 80%. The absolute capacities were found to be dependent on how the cell was loaded. The tests for assessing the discharge capacities of the cells takes a long time however and this section of the research continues to be investigated.

Analysis of electrolyte compositions in cells as part of this research was also investigated and it was found that there are a few electrolyte types that appear to affect the batteries performance in cold or hot weather.

This research so far highlights that the batteries are extremely well performing but are subject to durability issues when exposed to different environmental conditions and loading factors. The continued work in this area would help to improve the EVE IWG's knowledge of the specific factors affecting the battery life and the best methods for determining battery lifespan.

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[10] C-rate is the measure of the rate of a battery when it is discharged relative to its maximum capacity

3.6 Recommendations and path forward

There have been a number of views expressed on the areas of CO2/energy consumption, electric vehicle driving range and air pollutants of hybrid electric vehicles, plug-in hybrid electric vehicles and plug in electric vehicles as summarized in section 3.4.

Pending the conclusion of these views, it is still to be determined the path forward on in-vehicle battery durability and whether a GTR is warranted. Possible path forwards upon decision are to:

a) Begin development of a battery durability GTR
b) Continue research on the topic of battery durability
c) Cease work on the topic
d) Another alternative

Given the complexity of the battery chemistries and evolving technologies in this field, Japan and OICA have openly expressed that a GTR on in-vehicle battery durability is pre-mature. The European Commission has expressed a desire for regulation to ensure the durability of vehicle batteries.

Meanwhile, there are some discussions amongst EVE members that given the specific nature of the evolving technologies and the conclusion of research completed, a warranty requirement of some kind could resolve issues of battery durability. Norway has expressed particular interest in considering a warranty for in-vehicle batteries where energy labelling on products and their performance capabilities is used.

4.0 GTR development of power determination of vehicle systems

4.1 Background

The work of EVE IWG during Part A of the current EVE mandate indicated that sufficient knowledge and capability existed to develop a suitable procedure for determining powertrain performance of electrified vehicles. Since this time a procedure for determining powertrain performance was requested by the WLTP IWG and the EVE IWG sought authorization by AC.3 to develop an amendment to GTR No. 15 to establish a procedure for determining the powertrain performance of electrified vehicles. The plan for this work was established as:

I. Consideration of the concepts:
  - Reference Method – Chassis dyno testing and calculation
  - Candidate Method – Component testing and calculation
II. Consideration of the open points
  - Load Collectives and Maximum Power
  - Reference Method => Chassis Dyno Testing with completed vehicle and calculation to determine System Power
  - Candidate Method => Component Testing and calculation to determine System Power
  - Customer Information and other information with added value
III. Determination of work plan with task list and including allocation of work load

IV. Proof of concepts: Studies with different types of HEVs including. series HEV, REX and PEVs
V. Test, refine / improve and validation of the method(s)
VI. Drafting of the gtr
VII. Proposal for a draft amendment to GTR No. 15
VIII. Approval at GRPE, voting at WP.29 AC.3

4.2 Determining the powertrain performance and the EVE Mandate

The Electric Vehicles and the Environment (EVE) Informal Working Group is mandated by the WP.29 and has been formed to examine environmental issues related to all types of road vehicles (motorcycles, passenger cars, light, medium and heavy-duty vehicles) with electrical propulsion, including pure electric vehicles (PEVs), hybrid electric vehicles (HEVs) and plug-in hybrids (PHEVs). Over the course of its first mandate, the group developed a "EV Regulatory Reference Guide" for environmentally-related EV requirements, which was officially published on 28 August 2014. In addition to the identified regulatory gaps listed in Chapter 5 of the Guide, the group was tasked with conducting additional research and analysis related to a regulatory requirement to determine the system power of electrified vehicles. The WLTP IWG found that this topic warranted further investigation, however, it could not be tackled by their group due to the limitations of their mandate and resources.

A clear demand for an improved power determination procedure comes from the members of the WLTP IWG. The subgroup "Electrified Vehicles" is in need of a total system power specification for the purposes of classification and downscaling.

System power ratings are also useful for other purposes. Among others, it may serve as customer technical information, may be used by regulators (as basis for taxation programs) or by insurance providers (as a classifier for determining premiums).

4.3 Findings and Research

4.3.1 Findings prior to GTR development

At EVE-22, the EVE members agreed that the ISO method presented the best option as a basis for development of a test procedure by the EVE IWG. This method is very similar to the SAE's "Method 1"[11] from SAE J 2908. It shows good verifiability, and as a measure of vehicle performance it is comparable to ICE rated power, which makes comparisons between ICE ratings from conventional vehicles and maximum HEV system power ratings relatively straightforward. However, validation of the ability of the method to effectively serve the purposes of WLTP as envisioned will be necessary.

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[11] SAE J 2908 Vehicle Power Test for Electrified Power Trains; https://doi.org/10.4271/J2908_201709

The ISO method includes two variations (referred to informally as the German method and the Japan method). For the purposes of the GTR draft and this report, the German method is referred to as Test Procedure 2 (TP2) and the Japanese method is referred to as Test Procedure 1 (TP1).

Test procedure 1 is based on the sum of the engine power and adjusted battery power and is determined by using measured engine speed as an indicator of power output with reference to the methods described in ISO 1585 and UN regulation 85 engine test results. Intake manifold pressure and/or fuel flow rate is used to verify the engine power. Battery power is measured in the form of current and voltage, and adjusted to account for accessory power and losses in the electric motor. TP2 is based on power at the axle, measured by means of axle (or wheel) torque and speed, and adjusted for losses in the gearbox (and the tires if applicable).

There was some debate as to whether the GTR should select a single method, or provide a choice between the two variations. It was generally decided that having two methods would be acceptable (as long as the results are the same given the correct inputs), because it provides the opportunity to choose the method that best fits the data or equipment that are available, or the powertrain architecture being tested.

While there is reason to expect that the two methods should in theory deliver equivalent results, this remains to be investigated in more detail. It could be said that both methods include some uncertainty in that both methods call for certain information to be estimated or assumed. The German method, TP2 relies on an estimated gear efficiency, while the Japan method, TP1 requires an estimated electrical component efficiency. To the degree that these estimates may diff from the actual efficiencies that pertain to a specific vehicle, there is potential for TP1 and TP2 test results to differ as well.

It was also recognized that the state of charge (SOC) of the REESS could affect measured power. After technical discussions with experts from the WLTP –IWG Subgroup EV, the members of the EVE IWG agreed on the concept to determine the maximum HEV system power with REESS fully charged.

The ISO procedure on which the GTR is to be based has already undergone a phase of validation testing by Japan as part of the process of completing the ISO standard. It is anticipated that the procedure will need to be modified to conform with the specific requirements and intent of a GTR. Accordingly, a validation program has begun, in which the emerging GTR test procedure is being applied by several different laboratories. Several contracting parties volunteered to assist with the validation program, including ECCC (Canada), Joint Research Centre (JRC), EPA, and KATRI. Several contracting parties volunteered to assist with the validation program, including ECCC (Canada), Joint Research Centre (JRC), EPA and KATRI.

At EVE 22, the co-chair from Japan requested that EVE leadership take on the task of drafting the GTR, with initial priority placed on the reference method over the candidate method.

Accordingly, a drafting group has since been formed to begin writing the technical report.

It was also suggested that at some point in the near future, a parallel effort should also be undertaken to further develop the candidate method by means of testing at laboratories of the contracting parties, but at the time it was considered a secondary goal.

4.3.2 Validation test findings of procedure to date

Canada, U.S. EPA, South Korea and the EU JRC in collaboration with OICA began validation-testing in June 2018 for the purposes of validating the draft global technical regulation on determining the power of electrified vehicles.

Prior to the GTR validation program, Japan had tested a 2015 Toyota Yaris, 2015 Honda Fit and a 2016 Mitsubishi outlander PHEV as part of the development of the ISO procedure. The GTR validation program adds the following vehicles to the data set. Canada tested the 2016 Chevrolet Volt and the 2018 BMW 530e at their River Road Facility. Korea tested the 2017 Hyundai Ioniq Hybrid at the Korea Automobile Testing and Research Institute (KATRI). The U.S. EPA tested a 2013 Malibu Hybrid and a 2013 Chevrolet Volt at the U.S. National Vehicle and Fuels Emissions Laboratory. The EU JRC in collaboration with OICA tested two vehicles, a HEV and a PHEV, at the JRC Facility in Ispra, Italy.

At the time of this writing (December 2018), EPA has completed a first phase of testing on the 2013 Chevy Volt and 2013 Malibu Eco, and has circulated a test report describing the results. Canada has completed testing of the 2016 Chevy Volt and a test report is imminent. JRC completed testing of their vehicles, and is awaiting clearance from the sponsoring manufacturers to share the results in full with the EVE group.

The results of this testing will be discussed at a meeting of the EVE system power determination subgroup on the morning of January 9, 2019, in Geneva.

The preliminary results of the testing indicate that significant questions remain with respect to the ability of the test procedure as currently written to provide consistent results suitable for the purpose of the GTR. Specifically, there is some evidence that TP1 and TP2 may in some cases deliver significantly different results when conducted according to the test procedure as currently defined. In addition, there is some evidence that the variation between the results of TP1 and TP2 may be different depending on the vehicle powertrain architecture. The EVE IWG plans to discuss the available results in detail at the January 2019 meeting, and develop proposals for how the GTR might be improved to mitigate these concerns. Also, it is anticipated that a second phase of validation testing may be necessary to fully resolve some of these issues.

4.4 Recommendations and Path Forward

The current goal of the EVE IWG is to continue development of the working draft of the GTR. While validation testing continues, preliminary testing results have shown differences between the results obtained through TP1 and TP2, indicating that there is a need to account for these differences. The EVE IWG continues to work through these concerns and to reflect the findings in the text of the draft GTR. Since the decision in the recent 2018 November AC.3 meeting to draft a separate GTR to GTR No. 15, the

EVE IWG will also work to ensure that the GTR draft is amended to meet the requirements of a separate GTR.

If the GTR is complete by the expected timeline of November 2019, a possible path forward would be to cease the topic once the GTR is approved.

5.0 Method of stating energy consumption

5.1 Background and EVE Mandate

The EVE mandate on the method of stating energy consumption stems from the recognition that a common method which can be used to state and compare the energy used by vehicles (i.e. MPG, L/100km, or kWh/100km, etc.) is an important environmental issue. Advanced EVs represent a promising opportunity to reduce overall energy consumption and, by using electricity, EV's are potentially able to displace petroleum-based fuels. EV sales are expected to see rapid growth in the future, in part because of increasingly stringent regional CO_2 regulations. However, the development of electric vehicles will lead to displaced emissions from the vehicle to electricity grids; depending on the GHG accounting methods used, the influences of electric vehicles on a region's emissions profile may be underestimated if only emissions in transportation are considered. A standardized method for calculating and stating life-cycle energy consumption and the associated GHG emissions for electrified vehicles is recommended for consideration. Specifically, this method should consider the upstream emissions of vehicle energy.

Accounting for upstream emissions related to electrified vehicles being operated in all electric modes was identified in the Guide (OR-1855-EVE-TRANS-WP29-2014-81e-Proposal for an Electric Vehicle Regulatory Reference Guide) as an important environmental performance metric for electric vehicles. This topic of upstream emissions, an important environmental consideration, requires knowledge from both vehicle industry and energy industry. The GRPE mandate focuses on vehicle level performance. The upstream emissions are closely related to fields of energy, and experts from corresponding areas are preferred.

The current EVE mandate as outline the following for the timelines on the work of method of stating energy consumption:

Method of stating energy consumption:

(i) November 2016: Approval to approach the Group of Experts on Energy Efficiency (GEEE), and possibly UNECE Executive Secretary about continuing work on the method of stating energy consumption;

(ii) November 2016 - June 2018: EVE supports work of GEEE or another group on method of stating energy consumption as needed;

(iii) June 2018:

a. Report status of work on method of stating energy consumption to GRPE;

b. Report status of work on method of stating energy consumption to AC.3.

At the EVE 27 meeting with GRPE, it was decided that the final report on the status of work on the method of stating energy consumption would be presented in January 2019 along with the status on the in-vehicle battery durability and progress of the GTR for the determination of system power.

5.2 Findings

The EVE IWG developed a Microsoft Excel based model to evaluate the energy consumption of electrified vehicles during Part A of the EVE mandate. Although the EVE IWG feels this model would be suitable for the information-sharing purposes outlined in Part A of the EVE mandate, the current model is best used to make one-off evaluations of the energy consumption of a specific vehicle with a user-defined mix of source electricity.

The group noted that upstream emissions are considered as part of vehicle GHG regulations in the U.S. and Canada, but all agreed that the upstream emissions are outside the control of a vehicle manufacturer and would vary from country to country.

The Group of Experts on Energy Efficiency (GEEE) considers both regulatory and policy dialogue to address financial, technical and policy barriers to improve energy efficiency on sharing experiences and best practices in the field of energy efficiency, which is a broader mandate than the EVE IWG.

In order to better formulate the method, the EVE IWG approached the GEEE to request that they continue the work on the method of stating energy consumption. The EVE IWG feels that the GEEE may be a suitable home for this work due to their explicit focus on these types of issues. As noted in their mandate – "Group of Experts focuses on sharing experience and best practices in the field of energy efficiency in the United Economic Commission for Europe (ECE) region".

It was agreed upon by the GEEE that they would take over and continue the work on the method of stating energy consumption research and developed excel model with support of the EVE IWG as needed.

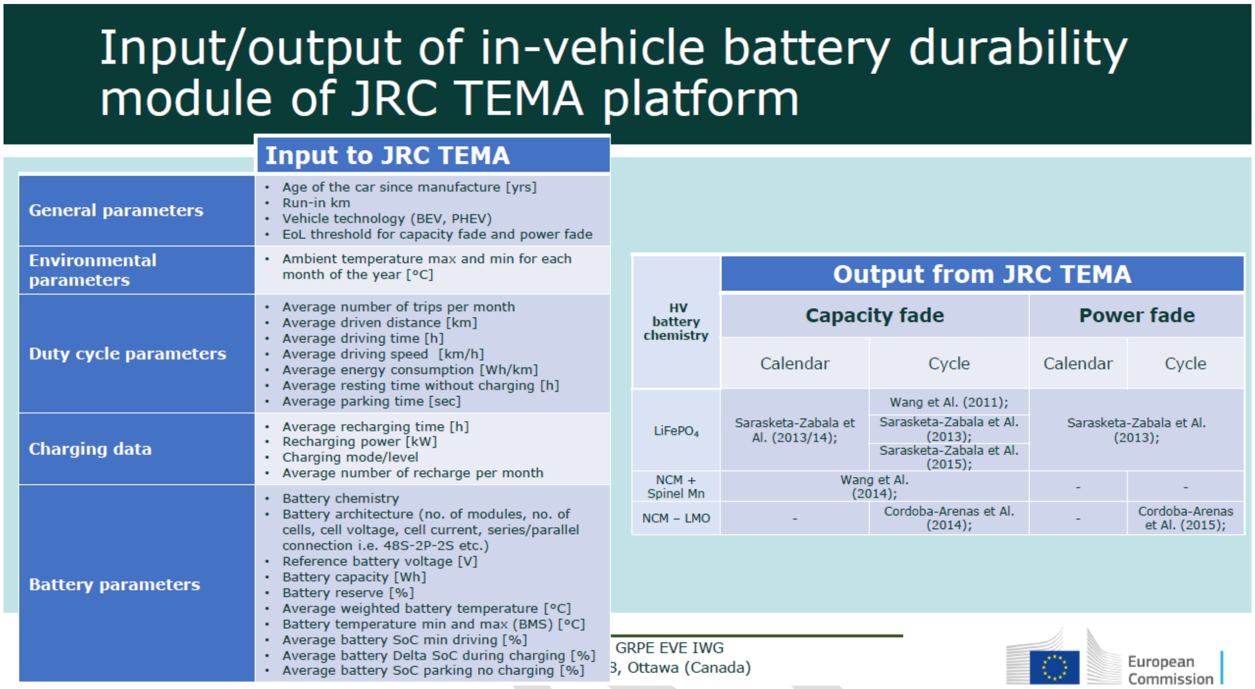
6.0 Conclusions

6.1 Path forward and recommendations

The EVE IWG's three mandate tasks of completing a GTR on the topic of system power determination by November 2019, researching in-vehicle battery durability to determine whether a GTR is required, and the tasks of finding new leadership to take on the work on energy consumption continue to progress. The mandate of drafting a GTR is expected to conclude with the publication of the final GTR by November 2019. The topic of in-vehicle battery durability continues to be researched. The EVE IWG has not decided yet whether a GTR is needed. Possible path forwards on this topic include going forward with a durability requirement, continuing research on the topic, stopping research on the topic or another feasible approach. There are a variety of views expressed in discussions so far of how to best approach in-vehicle battery durability and assessing the needs of a GTR. It appears that the path forward on battery durability still needs discussion to arrive at consensus conclusions for a path forward.

The EVE IWG group has spent two years looking for another home within the UNECE framework to take on the work on the method of stating energy consumption topic. At this time, there has not been a group to show particularly strong interest yet in assuming leadership of the work. The topic on the method of stating energy consumption addresses the concerns of upstream emissions of vehicles and is not a vehicle performance issue that could be addressed by the EVE IWG. The path forward on this topic would be to close it seems there is no group interested in assuming leadership of the work.

7.0 Appendix



Input/output of in-vehicle battery durability module of JRC TEMA platform

	Input to JRC TEMA
General parameters	• Age of the car since manufacture [yrs] • Run-in km • Vehicle technology (BEV, PHEV) • EoL threshold for capacity fade and power fade
Environmental parameters	• Ambient temperature max and min for each month of the year [°C]
Duty cycle parameters	• Average number of trips per month • Average driven distance [km] • Average driving time [h] • Average driving speed [km/h] • Average energy consumption [Wh/km] • Average resting time without charging [h] • Average parking time [sec]
Charging data	• Average recharging time [h] • Recharging power [kW] • Charging mode/level • Average number of recharge per month
Battery parameters	• Battery chemistry • Battery architecture (no. of modules, no. of cells, cell voltage, cell current, series/parallel connection i.e. 48S-2P-2S etc.) • Reference battery voltage [V] • Battery capacity [Wh] • Battery reserve [%] • Average weighted battery temperature [°C] • Battery temperature min and max (BMS) [°C] • Average battery SoC min driving [%] • Average battery Delta SoC during charging [%] • Average battery SoC parking no charging [%]

HV battery chemistry	**Output from JRC TEMA**			
	Capacity fade		**Power fade**	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + Spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

GRPE EVE IWG
3, Ottawa (Canada)

Figure A1. JRC TEMA Model inputs and outputs