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Report of the Working Party on Pollution and Energy (GRPE) on its ninety-second session

Addendum 7

Adopted amendments to ECE/TRANS/WP.29/GRPE/2025/7

The text reproduced below was adopted on the basis of ECE/TRANS/WP.29/GRPE/2025/7 amended by GRPE-92-43 (see para. 67. of the report) proposing a new UN GTR on “In-Vehicle Battery Durability for Electrified Heavy Duty Vehicles”. Changes from ECE/TRANS/WP.29/GRPE/2025/7 can be found in GRPE-92-43, available on the meeting webpage[*].

[*] https://unece.org/transport/documents/2025/03/informal-documents/evetrackproposal-amend-ecetranswp29grpe20257, accessed 15 April 2025

UN Global Technical Regulation on In-vehicle Battery Durability for Electrified Heavy Duty Vehicles

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A. Introduction

1. Owing to the pressing need to reduce emissions of greenhouse gases (GHG) and other air pollutants, the market share of electrified vehicles is expected to grow in the future. A key component of these vehicles is the traction battery that is used to store and deliver energy to power the movement of the vehicle and the systems within it. Improvements in the performance of batteries to deliver increased driving range, reduced charging times and greater affordability are a significant focus for manufacturers and technological developments in this area are expected to accelerate the uptake of electrified vehicles by consumers.

2. The primary motivation for this GTR stems from the recognition that the environmental performance of electrified vehicles may be affected by excess degradation of the battery system over time. Currently, the United Nations Global Technical Regulation No. 22 specifies test procedures and minimum performance requirements for the battery durability of electrified light-duty vehicles. As electrification is also extending to heavy-duty vehicles, such as buses, coaches and trucks, there is a need to consider battery degradation in the context of these vehicles as well. One key difference between light-duty and heavy-duty vehicles is that for several truck categories, a significant share of the energy stored in the vehicle may be used for purposes other than propulsion. For example, for cooling, in the case of refrigerated trucks for the transport of perishable goods or certain medical supplies; or to mix concrete in the case of concrete mixers. Another difference is the greater diversity of powertrain configurations and applications. The present GTR builds on the GTR No. 22 by providing test procedures and minimum performance requirements for the battery durability of electrified heavy-duty vehicles.

3. This GTR applies to vehicles of categories 1–2 and 2, that have a technically permissible maximum laden mass exceeding 3,855 kg, that (a) are Heavy-Duty Pure electric Vehicles (HD-PEVs) or Heavy-Duty Off-Vehicle Charging Hybrid Electric Vehicles (HD-OVC-HEVs), and (b) have one or more originally installed batteries, as defined in this GTR. At the option of the Contracting Party, a lower minimum technically permissible maximum laden mass may be applied.

4. The Contracting Party shall make a decision about the applicability of this GTR to small volume manufacturers and special purpose vehicles as well as special axle formulas for their jurisdiction.

5. Vehicle category trailers and semitrailers, which are not commonly electrified at this time, are not considered within this version of the GTR.

6. Loss of vehicle usable battery energy and loss of electric range are both primary concerns for electric vehicles. Loss of electric range could lead to a loss of utility, meaning affected vehicles might be driven less and therefore displace less distance travelled than might otherwise be driven by conventional vehicles. Loss of vehicle efficiency could affect upstream emissions by increasing the amount of electricity needed per vehicle distance travelled. Both 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 of particular concern because governmental regulatory compliance programs often credit electrified vehicles with a certain level of expected environmental benefit, which might not be realized over the lifetime of the vehicle if excess battery degradation occurs.

7. In addition to changes in range and energy consumption, hybrid electric vehicles are often equipped with both a conventional and electric powertrain, and for these vehicles the criteria pollutant emissions from the conventional powertrain could be impacted by the degradation of the battery over time.

8. This GTR therefore aims to provide a harmonised methodology to address these concerns by introducing a method by which the health of the battery can be monitored over time and introducing minimum performance requirements for the durability of the battery in

an optional annex. In order to address regional considerations, a Contracting Party may optionally elect to enforce Minimum Performance Requirements (MPR*i*) from these tables.

B. Procedural background

9. The Informal Working Group (IWG) on Electric Vehicle and the Environment (EVE) was set up in June 2012 following the approval by WP.29/AC.3 of ECE/TRANS/WP.29/AC.3/32. This document established two distinct IWGs to examine environmental and safety issues related to Electric Vehicles (EVs): the IWG on EVE, reporting to the Working Party on Pollution and Energy (GRPE), and the IWG on Electric Vehicle Safety (EVS), reporting to the Working Party on Passive Safety (GRSP). The proposal was supported by the European Commission, the United States of America, China, and Japan.

10. A second mandate for the IWG on EVE, divided into Parts A and B was approved in November 2014 by AC.3 to conduct additional research to address several recommendations that grew out of the first mandate, and develop UN GTR(s), if appropriate. The second mandate was separate from the IWG on EVS.

11. Part A of the second mandate of the IWG on EVE (ECE/TRANS/WP.29/AC.3/40) included "battery performance and durability" as one of the topics authorized for study and potential GTR development. Specifically, Part A authorized activity "to further develop the recommendations for future work outlined in the Electric Vehicle Regulatory Reference Guide by: (i) conducting additional research to support the recommendations; (ii) identifying which recommendations are suitable for the development of (a) global technical regulation(s) (GTR(s)) by the World Forum for Harmonization of Vehicle Regulations (WP.29); and (iii) developing a work plan. The work of the IWG on EVE on battery performance and durability under Part A of the EVE mandate was reported to WP.29 in a status report as informal document WP.29-170-31 at the 170th meeting of WP.29, 15-18 November 2016.

12. At the close of Part A the IWG on EVE recommended that GRPE and WP.29 endorse the option of extending the mandate of the IWG on EVE to continue active research into the topic of battery performance and durability without committing to the development of a GTR at that time. This was endorsed and work continued on this topic within Part B of the mandate.

13. The IWG on EVE presented a draft status report to GRPE in May 2019 on the research of in-vehicle battery durability and performance. The status report indicated that there was sufficient information to allow a UN GTR for in-vehicle battery durability to be started. The IWG on EVE recommended at the 79th GRPE in May 2019 that the UN GTR on in-vehicle battery durability be developed under a new mandate.

14. The EVE IWG published UN GTR No.22 (In-Vehicle Battery Durability for Electrified Vehicles), in the UN Global Registry on March 09, 2022.

15. Due to the focus of UN GTR No. 22 on light-duty vehicles and developments in the heavy-duty vehicle sector, the EVE IWG has been authorized to begin development of a new standalone UN GTR on in-vehicle battery durability for electrified heavy-duty vehicles, at the 190th session of World Forum for Harmonization of Vehicle Regulations (WP.29). Phase 1 of the work included:

(a) Initial draft development and working document submission to GRPE and AC.3 for consideration as a new UN GTR.

(b) Considering alternative test methods including chassis dynamometer testing.

Future development of the GTR within Phase 2 is described in Section F of this rationale.

C. Technical background

Battery degradation in electrified vehicles

16. The effect of battery degradation on environmental performance is likely to differ significantly among the various electrified vehicle architectures (Pure Electric Vehicle

(PEV), Off-Vehicle Charging Hybrid Electric Vehicle (OVC-HEV) and Not Off-Vehicle Charging Hybrid Electric Vehicle (NOVC-HEV)). The primary forms of battery degradation are capacity degradation and power degradation. Capacity degradation is the loss of energy capacity, resulting in a loss of electric driving range (for PEVs and OVC-HEVs) and possibly increased use of the engine during hybrid operation (for NOVC-HEVs). Power degradation is the loss of battery power, which can also lead to increased use of the engine for OVC-HEV and NOVC-HEVs and possibly reduced performance of the vehicle overall.

17. There are at least six major vehicle operating parameters that affect in-vehicle battery durability. Each differs in importance depending on electrified vehicle architecture:

(a) Discharge rates, as determined by vehicle duty cycle and operator use including, but not limited to, vehicle speed, auxiliary loads, Power take-off (PTO) and non-traction purpose applications, towing, payload and ambient conditions;

(b) Charge rates, as determined by type (normal, ultra-fast, Mega Watt Charging System (MCS), dynamic charging systems) and frequency of charging;

(c) State of charge (SOC) window used in system operation of the battery and the amount typically used between charge events (depth of discharge);

(d) Battery temperature during operation (operation includes all temperature exposures from vehicle purchase through retirement, both while being operated and during periods of charging and inactivity);

(e) Time (calendar life);

(f) Other uses not reflected in calendar life or distance travelled, such as V2X, that is, Vehicle to Grid, to Facility, to Home, to Load, or any Power Take-Off (PTO)/auxiliary operations or non-traction purposes during stand-still or in motion.

18. The extent and nature of battery degradation that will occur is a result of complex mechanisms and is heavily dependent on battery cell chemistry and operating conditions. A variety of physical and electrochemical processes influence the durability of battery cells and these have been documented comprehensively within a literature review commissioned by the IWG on EVE. For typical lithium-ion batteries, the primary mechanisms leading to capacity degradation were summarised as:

(a) Loss or deposition of cyclable lithium or a loss of balance between electrodes;

(b) Loss of electrode area; and

(c) Loss of electrode material or conductivity.

19. These ageing processes are often further complicated by the fact that many of the mechanisms are associated with a rise in cell impedance, leading to a reduction in maximum cell power.

Management of battery degradation

20. Whilst manufacturers have found it possible to establish the durability of specific battery implementations sufficiently to bring the products to market with some degree of confidence that normal provisions for customer satisfaction and warranty terms are being met, not every manufacturer is establishing durability in the same way. Manufacturers employ a wide variety of testing regimes often tailored to specific product configurations, applications, customer groups, and geographic considerations.

21. To reduce the effect of capacity degradation, manufacturers may choose to slightly oversize a PEV or OVC-HEV battery to allow the battery performance to be maintained by widening of the state-of-charge (SOC) window to make more energy capacity available as capacity degrades. Manufacturers may also choose battery chemistries that are optimised for battery life and durability. Others may choose to account for degradation by warranting the battery to a specified degree of capacity retention (that is less than the physical battery capacity) over a specified period of time or distance travelled. In the latter case, the consumer

is expected to understand that a potential reduction in the usable battery energy is to be expected during the lifetime of the vehicle.

22. A number of further measures are employed by manufacturers to limit battery degradation. These typically include, but are not limited to, the use of properly optimised battery management systems (BMS) and battery thermal management. BMS can reduce stress on the battery and prolong battery life by controlling some operations to protect the battery cells, maintain cell charge balancing and moderate the battery temperature. For example, BMS might control enhanced cooling systems, limit fast charging events through modulation of the charging current, control the available state of charge window, keep the cell voltages balanced, or reduce the maximum available torque as necessary to protect battery health. The inputs to BMS can include anything from ambient conditions and driver behaviour to individual cell metrics. Each manufacturer, vehicle, battery and cell could have unique and highly optimised BMS, that are updated and improved with every iteration and even updated during the lifetime of a specific vehicle. Another important factor is the battery thermal management capability. While some batteries are only passively cooled by ambient air, others are actively cooled and heated by use of forced air, liquid coolant, or refrigerant, which leads to greater BMS control over battery operating temperature and hence longer life.

Prediction and/or estimation of battery degradation

23. Accelerated ageing is a familiar technique used by many manufacturers as a component of their battery durability testing methods. This technique assumes that a regime of rapid ageing cycles can be translated to a projected useful life in service. However, it is uncertain whether the translation from accelerated ageing to an in-use life projection is equally applicable to all forms of lithium-ion chemistries either currently in use or in the future.

24. One of the major mechanisms by which capacity and power degradation occurs in these chemistries is the microscopic fragmentation that accompanies swelling and contraction of anode and cathode materials during cycling. Specific chemistries differ significantly in this respect, suggesting that the relation between rapid cycling and long-term cycling may also differ significantly. An accelerated test that accurately projects useful life for one chemistry may therefore predict poor life for another chemistry, even though both chemistries may achieve an equal life in actual use.

25. Furthermore, accelerated ageing cannot take into account the real use of batteries inside vehicles and therefore can only partially estimate the real degradation.

26. To monitor degradation in-use, most manufacturers employ some form of in situ, on-board capacity estimation through the BMS. This estimation can vary in accuracy and precision depending on a number of factors including the sensors and estimation algorithm used, the charge/discharge behaviour of the user, and the cell type and cell model parameters. Proprietary algorithms are used to handle inaccuracies and output an estimate that can be utilised by other systems within the vehicle.

27. There are currently no requirements on the accuracy of on-board monitors and the estimates generated are not typically easily accessible to the vehicle user. The IWG on EVE has therefore made a decision to set the performance requirement in this field.

D. Technical rationale and justification

28. The mandate of the first phase of this GTR on in-vehicle battery durability includes the development of an initial draft working document based on the equivalent GTR for light-duty vehicles (UN GTR No. 22), modified to account for the different context, issues and requirements associated with heavy-duty vehicles. The draft working document was based on the development of:

(a) Requirements for reading and/or displaying battery health information and usage data from the vehicle;

(b) Requirements for electrified vehicle battery durability performance criteria;

(c) A provisional in-service conformity test which will include generic usage criteria and a statistical method; and

(d) A reference certification procedure to verify compliance.

29. This section sets out key considerations of the IWG on EVE in developing the respective elements for Phase 1 of the GTR, as set out above.

State-of Certified Energy (SOCE) monitor

30. GTR No. 22 recognised that, whilst the term State of Health (SOH) is commonly applied to refer to the health of a battery at a given point in its life, this term is not defined or measured in a consistent way. It was therefore decided to define a new related metric for use within the GTR: the State of Certified Energy (SOCE). This metric represents a percentage of the original, certified battery energy that remains at a given point in the lifetime of a battery. In calculating SOCE, battery energy is based on the Usable Battery Energy (UBE), which has a clear definition in several established battery test procedures. The SOCE is intended to act as a metric for providing information to consumers and also for assessment against Minimum Performance Requirements (MPR, if elected to be enforced by regional authorities.

31. The IWG on EVE decided to exclude NOVC-HEVs from the current scope of this GTR. While batteries of NOVC-HEVs can experience degradation, NOVC-HEVs have no electric range, and their battery UBE is not typically determined at certification. Moreover, battery degradation in an NOVC-HEV is likely to result in degradation of fuel economy, which can be detected by existing in-service conformity practices. The IWG on EVE decided to exclude fuel cell hybrid vehicles (FCHV) and off-vehicle charging fuel cell hybrid electric vehicles (OVC-FCHV) from the current scope of this GTR. The IWG will continue to consider the need for extending this GTR to NOVC-HEVs, FCHVs and OVC-FCHVs in the future.

32. From discussions within the IWG while developing UN GTR No. 22 it was concluded that it would not be appropriate to define the process or algorithm by which the SOCE monitors determine their estimated values. It would be highly complex to define an algorithm that could accurately account for the battery management strategies in use within the market. Instead, it was decided to allow manufacturers to establish their own means to estimate these metrics, whilst ensuring the accuracy through an in-use verification procedure. The decision not to define the process or algorithm was deemed appropriate in the context of heavy-duty vehicles and this GTR as well.

Battery performance requirements

33. The battery durability requirements set out within this GTR are defined in terms of MPRs. MPRs are expressed as a minimum allowable value of SOCE after a given length of time or distance travelled. The energy discharged from the battery is monitored in view of a future revision of the MPRs metrics. This follows a similar format applied by manufacturers when providing warranty for electrified vehicles.

34. In determining appropriate MPR values for this GTR, the IWG on EVE considered inputs from stakeholders within the IWG, which is summarised in paragraphs 35. through 41. below.

35. A warranty analysis was conducted by the United Kingdom (UK) to understand the current warranty offering from manufacturers for electric heavy-duty vehicle batteries. The review primarily focused on the UK market, but values seemed consistent with typical offerings in other markets. The review showed that batteries for category 2 vehicles not exceeding 12 tonnes are covered for failure for between 3 to 8 years and typically up to 160,000 km[†]. Warranties that define failure in terms of a specific capacity retention specified between 70 and 80 per cent retention, most commonly 70 per cent. For category 2 vehicles exceeding 12 tonnes the review showed that batteries are covered for failure for between 3

[†] Only one vehicle manufacturer provides warranty up to 800,000 km

to 6 years and typically up to 300,000 km[‡]. Warranties that define failure in terms of a specific capacity retention specified most commonly 80 per cent. It has been highlighted by manufacturers that warranty offerings are not based solely on the technical performance of the battery and include further considerations from a commercial and customer satisfaction perspective. Nevertheless, the review provides an insight into the degree of confidence in products currently on the market.

36. The European Commission's Joint Research Centre (JRC) has developed a dedicated in-vehicle battery durability assessment module within its 'Transport tEchnology and Mobility Assessment' (TEMA) platform. This module is built upon performance-based models as this class of simulation model is the most suitable for large-scale real-world driving data. TEMA is a modular big data platform designed to reproduce mobility behaviours of vehicles from navigation system datasets of conventionally fuelled vehicles and quantifies possible impacts of new vehicle technologies on real-world mobility while supporting transportation policy assessment.

37. TEMA combines recent performance-based capacity and power fade models for lithium-ion batteries from literature with information on battery and vehicle architectures, together with real-world vehicle driving data from different geographical areas in Europe, to develop a scenario-based assessment enabling the estimate of in-vehicle performance degradation of automotive traction batteries. The analysis includes the calendar and cycle capacity fade of different lithium-ion variants ($LiFePO_4$, NCM with spinel Mn, NCM-LMO, NCA, NCM-LTO, LFP-LTO,…) in different vehicle architectures (OVC-HEV and PEV of different driving range for both light and heavy duty vehicle categories), combined with different recharging strategies reflecting use-cases for passenger and commercial vehicles to explore the effect of different driving duty-cycles related to different mobility patterns, mission profiles and environmental temperatures.

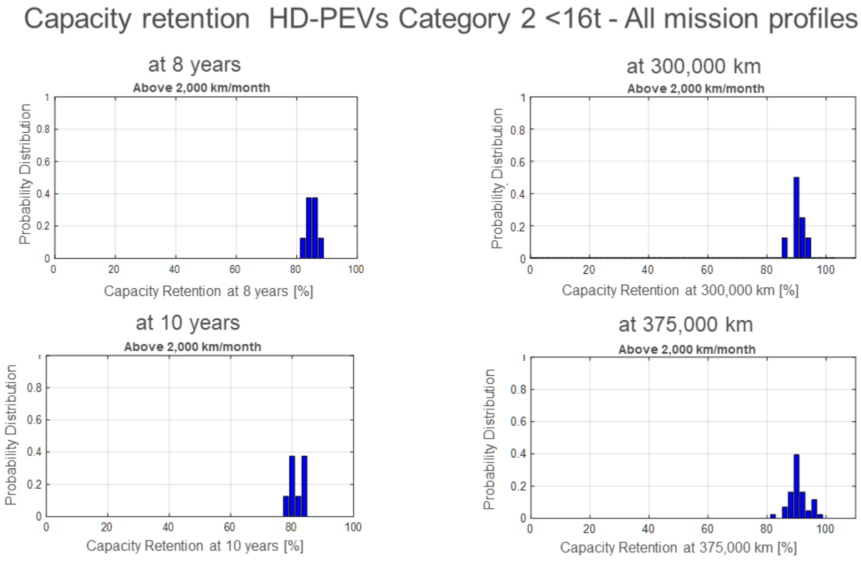
38. The TEMA model was extended to address electrified HDVs' battery ageing by estimating the energy capacity retention of traction batteries after a variety of distances, time periods and energy throughput rates, to enable the evaluation of MPRs for the different HDV categories and mission profiles. The TEMA model explores electrified HDVs' in-vehicle battery durability scenario studies based on both the 2019/1242/EU regulation vehicle categories, mission profiles and annual mileages as well as data of vehicles from literature reviews obtaining similar results from both methods. New recharging strategies, resembling the most common recharges forecasted for HDVs (ultra-fast, MCS, opportunistic or at depot,…), have been integrated within TEMA alongside PTO applications, such as concrete mixer, crane, construction or garbage compaction, as represented in the literature. A good correlation was found between the results of the TEMA simulations and the warranty analysis data provided in the informal document EVE-61-08e. The simulation results indicated that common MPRs may be established for different vehicle categories and mission profiles.

39. Example TEMA modelling results in Figure I/1 a) for HD-PEV of category 2 vehicles not exceeding 16 tonnes and mission profiles either charged with ultra-fast charging or MCS at lunch time show greater than 75 per cent capacity retention after 8 years or 300,000 km and 70 per cent capacity retention after 10 years or 375,000 km, while in Figure I/1 b) for category 2 vehicles exceeding 16 tonnes and mission profiles either charged with ultra-fast charging or MCS at lunch time show greater than 60 per cent capacity retention after 12 years or 700,000km and 55 per cent capacity retention after 15 years or 875,000km. This result is generally consistent with prevailing warranty practices observed in the warranty survey. It has to be noted that the results refer to worst case scenarios of battery ageing, extrapolating the validity of the model, to suggest not so stringent MPRs in view of future revisions of the battery performance based on data from the field. An additional 5 per cent of margin has been added to the values as a first proposal.

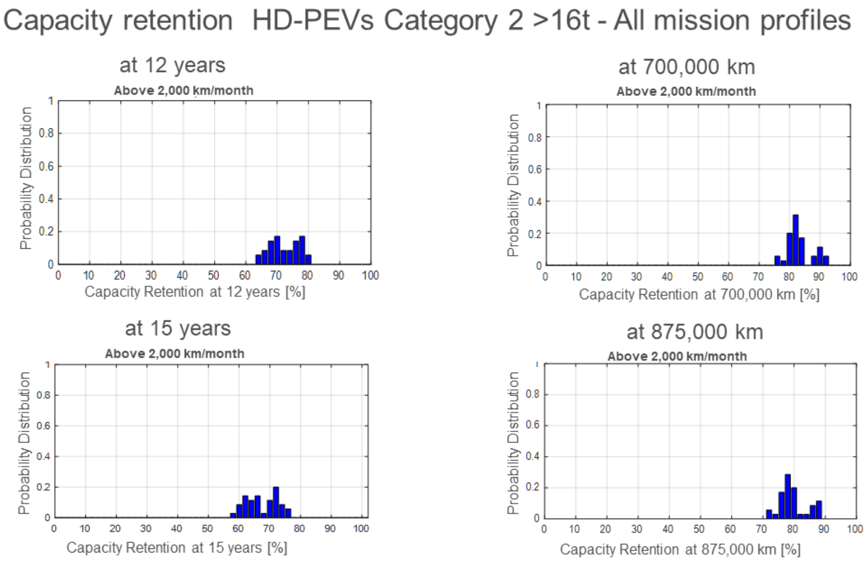
Figure I/1

‡ Only one vehicle manufacturer provides warranty up to unlimited km

Example of a capacity retention curve generated from JRC TEMA modelling for different HD-PEV categories and mission profiles



a)



b)

40. The TEMA model has also been adapted to reproduce data from literature referring to in-service buses in China, with reliable results despite the different assumptions made to mimic the mission profiles of the buses. Overall, the published study incorporates 240 million rows of raw data from 60 electric vehicles operating for over 4 years.

41. MPR values were proposed by Japan and China Automotive Technology and Research Center (CATARC). Japan proposed the same value of 70 per cent capacity retention after 6 years or 150,000km for all the vehicle categories (Category 1-2 and 2), while CATARC differentiated the MPR for vehicle category and mission profile, based on Chinese field data.

42. Following the consideration of available evidence and views of stakeholders within the IWG on EVE, a set of MPR values were introduced in an optional Annex based on different time and distance combinations with an eventual future introduction of an energy throughput metric, which will be monitored during the first phase. This approach allows coverage of the wide range of distance-based, or PTO, application requirements needed across Contracting Parties and provides the option for a Contracting Party to optionally apply

the MPRs and metrics as appropriate for their market. Following discussion within the IWG on EVE, the same MPRs were set for OVC-HEVs and PEVs.

43. Attention was given to a possible correlation between the different vehicle classes and groups across the regions for the MPRs and metrics of the tables in the optional Annex of the GTR.

44. Electrified vehicles of categories 1–2 and 2, that have a technically permissible maximum laden mass exceeding 3,855 kg (or lower if required by Contracting Parties) are at an earlier stage of adoption within the fleets of many Contracting Parties and subsequently in-use data relating to battery durability is scarce for these vehicles. For this reason, the collection and monitoring of field data is recognised to be of key importance for the future revision of the MPRs and metrics. It was highlighted by manufacturers that the understanding and estimation of PTO applications currently presents an increased challenge compared to only drive and charge behaviour. A concept related to virtual distance was introduced to cover the V2X, PTO and non-traction purpose of the vehicles, similar to UN GTR No. 22, but adapted for HDVs.

45. Battery longevity is a key consideration for consumers and regulating agencies, therefore there is an incentive for manufacturers to accredit batteries that perform beyond the minimum requirements of this GTR. To allow manufacturers to market or quantify the benefits of any improved battery technology they may have installed within their vehicles, the GTR allows for a Declared Performance Requirement (DPR), based upon a higher value of SOCE. To ensure the accuracy of any declared values, the DPR would be considered to act in place of the MPR for the purposes of in-use verification. The DPR is not intended to indicate a regulatory warrantied value. Manufacturer warranties are beyond the scope of this GTR. A manufacturer may wish to warranty batteries beyond the MPR without attaching additional warranty benefits to a DPR.

In-use verification

46. To ensure the accuracy of the SOCE monitors and also ensure that MPRs are being met, a two part in-use verification process has been introduced, as in UN GTR No. 22, with Part A verifying the accuracy of the monitors and Part B verifying the battery durability against the MPR, where applicable. The IWG on EVE decided to postpone the Part C verification of the accuracy of the virtual distance to address HDV V2X, PTO and non-traction applications to the Phase 2 of this GTR.

47. Part A verification verifies the accuracy of the SOCE monitor in the vehicles by comparing the read and measured SOCE value for a sample of vehicles. It involves the measurement of the UBE under the defined test procedures of Annex 3 of this GTR and the determination of a measured SOCE by dividing the UBE measured value by the respective values from certification derived with the same test procedure, if applicable. The same test method must be applied at certification to the SOCE monitor family concerned and during in-service testing Part A verification, if applicable and in accordance with regional provisions, unless there is an agreement between the regional authority and the manufacturer.

48. These measured values can then be compared to the on-board values from the SOCE monitors to ensure the accuracy is within a specified tolerance. A pass or fail decision on a sample of vehicles will be reached through a statistical process, which evaluates the average of the differences of the measured and on-board-indicated SOCE from a series of vehicles tested. After testing a minimum of 3 vehicles a decision on either a pass or fail decision or on testing a further vehicle will be reached, on the basis of a statistical formula considering the quantitative deviation of the latter average from a value A and the variance of these differences over the whole test series with a tolerance of 5 percent granted for a single test due to technical reasons. The method proposed is particularly suitable for cases where a quantity (such as SOCE) is likely to differ from the 'true' measured quantity continuously and reflects the method used for evaluating the conformity of production (CoP) in UN Regulation No. 154 and in UN GTR No. 22.

49. The resolution of the on-board values from SOCE was set to 1 part in 100, and the required accuracy defined by a statistical process as described above.

50. In the case of HDVs, there is not a reference certification test procedure at vehicle level to be referenced for the measurement of the UBE. Therefore, the IWG on EVE aimed to define a test procedure allowing the UBE determination through testing the battery in the vehicle. Moreover, the test procedure shall allow a repeatable and robust UBE measurement, but without being excessively and unduly demanding, given the size and variety of heavy-duty electrified vehicles in the market and relative scarcity of suitable testing facilities worldwide.

51. The European Commission Joint Research Centre (JRC) presented a proposal to measure the UBE using a bidirectional power supply system in a temperature-controlled environment, ensuring proper preconditioning of both the vehicle and the battery while controlling the discharge power such that it is representative of in-service vehicle use. The measurement of the UBE by a discharge at constant power using a bidirectional power supply has been considered as a suitable compromise between the feasibility of the test and its accuracy. A test campaign was carried out by Japan to explore the possibility of this test method and assessing the comparison with dyno test results with the aim to propose a best value for the constant c-rate to apply during the bidirectional power test.

52. In order to ensure the feasibility of the test for all Contracting Parties and for all types of heavy-duty electrified vehicles, even those that do not allow battery discharging through a power supply system, it was proposed and then agreed to adopt three types of tests for the measurement of the UBE, plus an alternative method based on a chassis dynamometer:

- Method 1a: Discharge by driving on a test track using characteristic regional speeds;
- Method 1b: Discharge by driving on the road;
- Method 2: Discharge using a bidirectional power supply system; and
- As an alternative to these test procedures, the battery may be discharged using a constant and transient cycles test method using a HDV chassis dynamometer

53. A technical breakout group was set up led by the European Commission Joint Research Centre (JRC) to discuss and define the boundary conditions of the test procedures. In particular, the topics of acceleration to the target speeds of Method 1a and Method 1b, the average speed setting and discharge power tolerances, the end-of-discharge conditions, the driver breaks, and all the other influencing factors of the test procedures, such as road gradients and the ambient temperature, were discussed and a proposal was prepared for the whole IWG on EVE. The test repetitions for enhancing the test results were also addressed together with the charging power settings. During the 69th IWG on EVE session, it was considered appropriate to remove the test repetitions for all the test methods, due to the extra testing burden imposed. A table prescribing the specifications for the bidirectional power supply system has been added in Method 2 with the agreement to revise it in Phase 2, in particular in relation to the altitude requirements and related evidence.

54. Method 1a and Method 1b have a less controlled temperature. A provision has been added to guarantee the consistency of the UBE measured results at type approval and in-service testing by requiring a soak and pre-conditioning at given temperature and allowing the operation of an internal pre-warming system of the battery, if available. External pre-warming systems, that are not integral to the charging station, are not allowed. Considering the road grading in Method 1b, the proportional cumulative positive altitude gain over the entire trip was added, requiring that it shall be less than 1,200m / 100km.

55. The test ends with a discharged battery when the break-off criterion is reached, specifically defined for the different test methods and vehicle configurations.

56. A specific discussion around the break-off criterion for the different test methods for both HD-PEVs and HD-OVC-HEVs was held. A 4 consecutive second or more driving power cut criterion was introduced for HD-PEV tests, while for HD-OVC-HEV tests, a new criterion related to the variation of the energy consumption in the last defined km driven during the test with respect to the energy consumption over the total driven distance minus the last defined km. For the alternative method, criteria similar to UN GTR No 15 dyno tests were introduced as options to be elected by the Contracting Party. It was recognised that there

was a possibility of a future revision of the break-off criterion for the HD-OVC-HEVs when more data from the field is available for these vehicles.

57. It is allowed to use static battery discharging systems in the last part of the test to complete the discharge if agreed with the responsible authority during Method 1b, to comply to the safety rules in place. The discharge power of the system should be representative of the characteristic driving speed. The break off is reached when the discharging power experiences a drop of 10 per cent of the target discharge power for 4 seconds.

58. In Method 2, relating to the bidirectional power supply system method, the discharge takes place at a constant power derived from the characteristic speed of the vehicle, in a temperature-controlled environment. The test ends with a discharged battery when the discharging power experiences a drop of 10 per cent of the target discharge power for 4 seconds.

59. Chassis dynamometer testing was retained as an alternative method. This method, which is more similar to the test procedure for LDVs, was initially discarded for HDVs, due to the limited availability of testing facilities worldwide, and the complexity of the test procedure. Constant and transient cycle test methods using heavy-duty chassis dynamometers refer to regional regulations.

60. Pilot phase testing was organised by industry to verify several steps of the test procedures outlined above, informing regulation development discussions in support of drafting the text of this GTR.

61. As Part A verification is expected to involve a relatively small number of sample vehicles to limit the testing burden, it is important to ensure that the sample result is not unduly impacted by the abnormal use or poor maintenance of a vehicle within the sample. A vehicle survey has therefore been introduced within Annex 1 containing information designed to ensure that the vehicle has been properly used and maintained according to the specifications of the manufacturer. Any vehicles not meeting the required criteria may be removed from the test sample. In the future, data collected from the field may support future improvement and revision of the Annex 1 requirements.

62. Due to the accuracy of the SOCE monitor being assured through verification in Part A, it is possible to verify the battery durability of a sample of vehicles within Part B through remote collection of the on-board SOCE value, together with information on the age of the vehicles, distance travelled and energy utilised. Where a vehicle has been equipped with V2X capabilities, PTO applications or non-traction purposes, an equivalent virtual distance will be calculated in relation to the V2X, PTO and non-traction purpose discharge energy. This will be summed with the distance travelled to calculate the total distance.

63. It is recognised that SOCE values read from a sample of vehicles are likely to be in the form of a distribution, with values for individual vehicles dependent on the vehicle usage and any inherent variation in the performance of the vehicle or traction battery. Where a vehicle has been used abnormally (e.g. with prolonged periods of storage or being regularly used in extremes of temperature) may give rise to more significant degradation of battery health. To reduce the impact of vehicles that may have been used abnormally, it was decided to make the overall pass decision dependent on more than or equal to 90 per cent of monitor values read from the vehicle sample being above the MPR as defined in the GTR No. 22. This approach thereby ensures that the MPR is being met by the significant majority of the vehicles sampled, whilst accounting for abnormal usage. A decision was taken to revise this requirement based on available data from the field related to HDVs.

64. To further minimise influence of abnormally used vehicles, a maximum of 5 per cent of the values taken from smaller durability families that consist of less than 500 vehicles may be excluded from the verification sample in Part B with appropriate reasoning. The decision on the number of vehicles in the sample may be taken by the responsible authority based on risk assessment methodology, but in principle should not be less than 500.

65. To support this two part in-use verification process, whilst minimising the burden of increased testing for manufacturers within Part A, two family concepts were developed within the GTR. This includes the concept of a monitor family for use in Part A and a battery durability family for Part B. This is likely to reduce the need for additional testing where

multiple battery durability families may have the same characteristics with respect to verification of the SOCE monitors. In addition, the Part A in-use verification for the vehicles in the same monitor family may be combined between different regions with the agreement of all Contracting Parties involved. This contributes not only to minimise the testing burden but also to increase the verification robustness. However, this concept shall not be applied for Part B since battery degradation might be different in different regions due to different usage patterns and ambient conditions.

66. Paragraph 1.1 of Annex 3 referring to the vehicle selection during certification and during Part A verification has been added to clarify the vehicle testing criteria. However, a decision was taken to revisit this paragraph in Phase 2.

67. The family definition for Part A and Part B, and also Part C may be subject to review based on field data.

68. A list of values to be read from the vehicle has been introduced in Annex 2 of this GTR, containing information designed to survey the vehicle usage together with the SOCE. This list of values has been updated in relation to the specific metrics and requirements of HDVs and other upcoming regulatory frameworks. However, the IWG on EVE considered it appropriate that a further revision of this list of parameters should be considered in Phase 2 of this GTR, in particular in relation to the battery temperature to be read from the vehicle, as evidence requires.

E. Technical feasibility, anticipated costs and benefits

69. Adding SOH monitors to electrified HDVs , updating these monitors to ensure that the specific requirements within this GTR are met, and allowing for SOH information to be provided to the consumer, may entail some development costs for manufacturers.

70. The Part A verification of SOCE accuracy will involve additional testing by manufacturers and, optionally, by authorities who choose to further verify monitor accuracy.

71. Any costs associated with verification within Part B are likely to be borne by the authorities of the Contracting Parties applying this regulation and will depend on the extent and means by which they choose to collect data for verification. Costs may be borne by the manufacturer in the case of a fail for a battery durability family, relating to the costs of measures agreed with the relevant authorities to bring those vehicles into compliance.

72. This GTR is likely to give rise to benefits for manufacturers and authorities through the prevention of inferior products. Introduction of inferior products within the market could undermine the market by reducing market acceptance of electrified HDVs, and disadvantage manufacturers that have invested in the development of technology aimed at ensuring battery durability.

73. Battery life is important to achieving the environmental benefits associated with electrified vehicles, and is a key concern for prospective consumers of electrified vehicles. The vehicle’s usable battery energy upon entry into the used vehicle market is also a significant point of consideration for the consumer and is not easily understood in the absence of access to accurate battery health monitors. The availability of both accurate battery state of certified energy and assurances on battery longevity for consumers that is provided by this GTR are therefore likely to have a positive impact on the value retention of electric vehicles and confidence in buying an electrified vehicle.

F. Future development of the GTR

74. The mandate for development of this GTR encompassed the future development of improvements to the GTR within Phase 2 including, but not limited to:

(a) Continue development of alternative test methods including chassis dynamometer testing.

(b) Consider the need for battery replacement provisions.

(c) Explore the applicability of vehicle group O (trailers and semi-trailers) within the scope of the regulation.

(d) Future amendments as new data and continued research, analysis and testing lead to new developments

(e) Reconsider the MPRs regarding mileage and lifetime thresholds and consider the appropriateness of energy throughput as threshold, based on the monitoring exercise for energy throughput.

(f) Consider the need of further segmentation of the MPR thresholds by vehicle category/application.

(g) Consider MPR setting for HDV OVC-HEVs.

75. The concept of a Normal Usage Indices (NUI) is a data field stored on the vehicle that represents a history or assessment of lifetime usage patterns of the vehicle that are influential to battery degradation. For example, one NUI might characterise temperature exposures during the lifetime of the vehicle, while another might characterise charging rates or number of ultra-fast charging events. The definition of NUIs was highlighted as one possible matrix for data collection for the future revision of the MPR and metrics.

76. The implementation of this GTR by Contracting Parties will enable the collection of further data on SOCE to better inform our understanding of battery health degradation. This information will, in turn, allow further refinement of the GTR, including MPR values, based upon the latest available battery technologies employed within the market. This will be important given the rapid development of technology in the field of battery technology for electrified vehicles.

II. Text of the GTR

1. Purpose

This Global Technical Regulation (GTR) provides worldwide harmonised methods to determine in-vehicle battery durability performance of Heavy Duty Pure Electric Vehicles (HD-PEVs) and Heavy Duty Off-Vehicle Charging Hybrid Electric Vehicles (HD-OVC-HEVs).

Minimum performance requirements for in-vehicle battery durability of HD-PEVs and HD-OVC-HEVs are introduced in an optional annex.

2. Scope and application

This GTR applies to vehicles of categories 1–2 and 2, that have a technically permissible maximum laden mass exceeding 3,855 kg, that (a) are HD-PEVs or HD-OVC-HEVs, and (b) have an originally installed battery as defined in this GTR.

At the option of the Contracting Party, a lower technically permissible maximum laden mass may be applied.

The Contracting Party shall make a decision about the applicability of this GTR to Small Volume Manufacturers and special purpose vehicles and special axle formulas for their jurisdiction.

Electrified trailer and semi-trailer vehicle categories are out of the scope of this GTR.

3. Definitions

The following definitions shall apply in this GTR.

3.1. *"Battery"* means, in the context of this GTR, any assembly of rechargeable electrical energy storage systems (REESS) installed in an electrified vehicle and used mainly for traction purposes.

3.2. *"Originally installed battery"* means the battery that is installed in the vehicle at the time of manufacture and that is configured according to the manufacturer's design/certification, or if the vehicle is manufactured without an installed battery, the battery that is installed in the vehicle when it is first operated on the road.

3.3. *"Usable battery energy (UBE)"* means the energy supplied by the battery from the beginning of the test procedure used for certification until the applicable end of test criterion of the test procedure as defined in Annex 3 of this GTR.

3.4. *"Certified usable battery energy"* ($UBE_{certified}$) refers to the UBE that was determined during the certification of the vehicle, according to Annex 3 of this GTR.

3.5. *"Measured usable battery energy"* ($UBE_{measured}$) means the UBE determined at the present point in the lifetime of the vehicle by the test procedure used for certification, according to Annex 3 of this GTR.

3.6. "*Odometer*" means that part of the odometer equipment, which indicates to the driver the total distance recorded by the vehicle since its entry into service.

3.7. "*Gross Vehicle Mass (GVM)*" of a vehicle means the maximum mass of the fully laden solo vehicle, based on its construction and design performances, as declared by the manufacturer. This shall be less than or equal to the sum of the maximum axles' (group of axles) capacity.

3.8. "*Gross Train Mass (GTM)*" of a power driven vehicle means the technically permissible maximum mass of the laden vehicle combination, as declared by the manufacturer of the towing vehicle.

3.9. *"State of certified energy"* (SOCE) means the durability performance of the battery at a specific point in the lifetime of the vehicle, determined as a measured or estimated usable battery energy divided by the certified usable battery energy, and expressed as a percentage.

3.10. *"Minimum Performance Requirement" (MPR)* means the minimum durability performance, in terms of SOCE at a specific point in the lifetime of the vehicle, that constitutes compliance with the optional durability provisions of this GTR.

3.11. *"Declared Performance Requirement"* (DPR) means an SOCE value declared by the manufacturer that is greater than that of the corresponding MPR and which then becomes the minimum durability performance that constitutes compliance of that manufacturer with the durability provisions of this GTR.

3.12. *"SOCE monitor"* means an apparatus installed in the vehicle that maintains an estimate of the state of certified energy by means of an algorithm operating on data collected from the vehicle systems.

3.13. *"On-board SOCE"* ($SOCE_{read}$) means an estimate of state of certified energy produced by an SOCE monitor.

3.14. *"Measured SOCE"* ($SOCE_{measured}$) means the state of certified energy as determined by dividing the measured usable battery energy by the certified usable battery energy.

3.15. *"Total propulsion energy"* is the DC energy in kWh supplied to the traction inverter terminals and to auxiliary systems/ accessory loads necessary for basic vehicle operation (for example, braking, steering, lights, heating, ventilation and air conditioning except for Category 1-2 vehicles, hydraulic system for Category 1-2 vehicles according to Annex 5~~)~~ discharging the REESS.

3.16. *"V2X"* means the use of the traction batteries to cover external power and energy demand, such as V2G (Vehicle-to-Grid) for grid stabilisation by utilising traction batteries, V2F (Vehicle-to-Facility) for utilising traction batteries as facility storage for local optimisation or emergency power sources in times of power failure, V2H (Vehicle-to-Home) for utilising traction batteries as residential storage for local optimisation or emergency power sources in times of power failure, and V2L (Vehicle-to-Load, only connected loads are supplied) for use in times of power failure and/or outdoor activity in normal times.

3.17. *"Total energy throughput*" is the total amount of energy in kWh discharged from the REESS, which needs to be provided according to Annex 2.

3.18. *"Pure electric vehicle"* (PEV) means a vehicle equipped with a powertrain containing exclusively electric machines as propulsion energy converters and exclusively rechargeable electric energy storage systems as propulsion energy storage systems.

3.19. *"Off-vehicle charging hybrid electric vehicle"* (OVC-HEV) means a hybrid electric vehicle that can be charged from an external source.

4. Abbreviations

BMS	Battery Management System
DPR	Declared Performance Requirement
FSD	Full Scale Deflection
GTM	Gross Train Mass
GNSS	Global Navigation Satellite System
GVM	Gross Vehicle Mass
HD	Heavy Duty
HD-OVC-HEV	Heavy Duty Off-Vehicle Charging Hybrid Electric Vehicle
HD-PEV	Heavy Duty Pure Electric Vehicle
MPR	Minimum Performance Requirement
OTA	Over the Air
PTO	Power Take-Off
REESS	Rechargeable Electrical Energy Storage System
SOC	State of Charge
SOCE	State of Certified Energy
UBE	Usable Battery Energy
V2F	Vehicle to Facility
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2L	Vehicle to Load
V2X	Vehicle to Grid, to Facility, to Home, to Load

5. Requirements

5.1. State-of Certified Energy (SOCE) monitor

The manufacturer shall install a SOCE monitor that operates for the full lifetime of the vehicle. The SOCE monitor shall maintain an estimate of the state of certified energy (on-board SOCE).

The manufacturer shall determine the algorithms by which on-board SOCE is determined for the vehicles they produce. The manufacturer shall update the on-board SOCE with sufficient frequency as to maintain the necessary degree of accuracy during all normal vehicle operation.

The on-board SOCE shall have a resolution of at least 1 part in 100 and be used for the purposes of verification as the nearest whole number from 0 to 100.

The manufacturer shall make available the most recently determined values of the on-board SOCE via the OBD port and optionally over-the-air (OTA).

For the purposes of consumer information, the manufacturer shall make easily available to the operator of the vehicle the most recently determined value of the SOCE monitor via at least one appropriate method. The resolution and method for the value to be made available shall be determined in agreement with the authorities. For example:

(a) dashboard indicator;

(b) infotainment system;

(c) remote access (such as via mobile-phone applications).

5.2. Battery Performance Requirements

The battery durability requirements of this GTR are defined in terms of Minimum Performance Requirements (MPR*i*), which represent minimum allowable values for SOCE at specific points in the lifetime of the vehicle.

In order to address regional considerations, a Contracting Party may elect to enforce Minimum Performance Requirements (MPR*i*) specified in the tables of the optional Annex 4.

The MPRs may differ depending on the category of the vehicle and type of propulsion.

A SOCE monitor shall be installed on vehicles of categories 1–2 and 2.

A manufacturer may elect to declare a Declared Performance Requirement (DPR*i*) having an SOCE value that is higher than that of the corresponding MPR*i*. The DPR*i* shall then replace the MPR*i* for the purposes of determining compliance by that manufacturer.

If a Contracting Party elects to enforce Minimum Performance Requirements (MPR*i*) from the tables of Annex 4, the manufacturer shall ensure that batteries installed in vehicles comply with the pass/fail rules specified in paragraph 6.4.2. for the MPR*i* (or DPR*i* if applicable).

At the request of the manufacturer and for vehicles designed with additional applications such as V2X, Power take-off (PTO) or non-traction purpose applications, the equivalent virtual distance calculated following the equation below shall be reported by each vehicle, referring to the total energy throughput as the sum of the propulsion energy and additional application discharge energy:

$$\boldsymbol{Virtual\ distance}\ (km) = \text{0dometer km} \times \left(\frac{\text{total energy throughput } [Wh] - total\ propulsion\ energy\ [Wh]}{total\ propulsion\ energy\ [Wh]}\right)$$

In the case in which the total propulsion energy does not include the accessory loads, some typical default values can be added to the propulsion energy, following the recommendations in the Table A5/1 of Annex 5 of this GTR or the regional regulations, with the agreement of the responsible authority.

In the case in which the vehicle configuration includes a transmission mounted PTO, supplying power from the engine to operate equipment unrelated to vehicle traction or auxiliary systems/vehicle accessories necessary for basic vehicle operation (24V/12V-DCDC), on request by the manufacturer and in agreement with the responsible authority it is allowed as an option to subtract the transmission PTO energy from the total propulsion energy. In such cases, appropriate measurement equipment to determine either mechanical, electrical, hydraulic or pneumatic PTO power shall be installed in the vehicle.

The total distance used for confirming compliance with the minimum performance requirements, if applicable, shall consist of the sum of the odometer distance and the virtual distance. The total and the virtual distance shall be recorded and monitored.

6. In-Use Verification

6.1. Definitions of Families

Vehicles having the same characteristics with respect to their evaluation under Part A or Part B below shall be grouped respectively into the Part A or Part B vehicle families for the purpose of compliance verification. Families under Part A shall have the same characteristics with respect to verification of the SOCE monitor. Families under Part B shall have the same characteristics with respect to verification of battery durability.

Families with the same characteristics with respect to compliance verification shall be defined as follows:

6.1.1. For Part A: Verification of the Monitor

Only vehicles that are substantially similar with respect to the following elements may be part of the same monitor family:

(a) Algorithm for estimating on-board SOCE;

(b) Sensor configuration (for sensors used in determination of SOCE estimates);

(c) Characteristics of battery cell which have a non-negligible influence on accuracy of the monitor;

(d) Type of vehicle (HD-PEVs or HD-OVC-HEVs).

At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may deviate from the above criteria for families.

6.1.2. For Part B: Verification of Battery Durability

Only vehicles that are substantially similar with respect to the following elements may be part of the same battery durability family:

(a) Vehicle category (category 1-2 or category 2);

(b) Type and number of electric machines, including net power, construction type (asynchronous/ synchronous, etc.), and any other characteristics having a non-negligible influence on battery durability;

(c) Type of battery (dimensions, type of cell, including format and chemistry, capacity (Ampere-hour), nominal voltage, nominal power;

(d) Battery management system (BMS) (with regards to battery durability monitoring and estimations);

(e) Passive and active thermal management of the battery;

(f) Type of electric energy converter between the electric machine and battery, between the recharge-plug-in and battery, and any other characteristics having a non-negligible influence on battery durability;

(g) Operation strategy of all components influencing battery durability.

At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may deviate from the above criteria for families.

6.1.3. For Part C: Verification of reported virtual distance

Only vehicles that are substantially similar with respect to the following elements may be part of the same virtual distance family:

(a) Algorithm for reported virtual distance;

(b) Sensor configuration (for sensors used in determination of virtual distance);

(c) Characteristics of battery cell which have a non-negligible influence on accuracy of the monitor;

(d) Type of vehicle (HD-PEVs or HD-OVC-HEVs).

At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may deviate from the above criteria for families.

6.2. Information gathering

The following information shall be made available to the authorities by the manufacturer in a format to be agreed between the authorities and the manufacturer: annual report on relevant warranty claims; and annual statistics on repairs for both batteries and other systems that might influence the electric energy consumption of the vehicle.

For Part B, such information shall be made available once a year for each battery durability family for the duration of the period defined in Annex 4 after the last vehicle of this family is sold.

6.3. Part A: Verification of SOCE monitor

6.3.1. Frequency of verifications

The manufacturer shall complete the procedure for in-use verification for Part A with a frequency agreed with the regional authorities, as defined in Annex 4 after the last vehicle of each monitor family is sold and report the results of the verification to the authorities. The authorities may decide to proceed with their own verification of Part A, at a frequency and magnitude based on risk assessment, or request more information from the manufacturers. With the agreement of all Contracting Parties involved, the verification of Part A for vehicles in the same monitor family may be combined between different Contracting Parties. In such cases the relevant Contracting Parties shall be considered as a single authority for the purposes of this verification.

At the option of the Contracting Party, a minimum annual sales volume for a monitor family may be defined, below which verification of monitors is not required. Such families may still be selected to be tested for Part A, at the request of the responsible authorities.

6.3.2. Verification procedure

To verify the SOCE monitor, the value for the usable battery energy shall be measured at the time of the verification and the related value from the monitor shall be collected before the verification test procedure. To support future improvement of the GTR, indicator values shall be collected again after the verification test procedure. Those indicator values read after the verification test procedure shall not be considered in the Part A verification.

The measured SOCE value shall be determined by dividing the measured value for the usable battery energy by the certified value for the usable battery energy, and the result expressed in per cent, in accordance with the procedures defined in Annex 3 of this GTR.

$$SOCE_{measured} = \frac{UBE_{measured}}{UBE_{certified}} * 100$$

In cases where $UBE_{measured}$ is greater than $UBE_{certified}$, $SOCE_{measured}$ shall be set to 100 percent.

The different test procedures for the UBE determination are defined in Annex 3:

Method 1a: battery discharge by driving on a test track using characteristic regional speeds (paragraph 2.1. of Annex 3),

Method 1b: battery discharge by driving on the road (paragraph 2.2. of Annex 3)

Method 2: battery discharge using a bidirectional power supply system (paragraph 2.3. of Annex 3).

As an alternative to these test procedures, the battery may be discharged using a HDV chassis dynamometer over constant speed and transient cycles. (paragraph 2.4. of Annex 3).

6.3.3. Statistical Method for Pass/Fail decision for a sample of vehicles

An adequate number of vehicles (at least 3 and not more than 16) shall be selected from the same monitor family for testing following a vehicle survey (see Annex 1) which contains information designed to ensure that the vehicle has been properly used and maintained according to the specifications of the manufacturer. The following statistics shall be used to take a decision on the accuracy of the monitor.

For evaluating the SOCE monitor normalised values shall be calculated:

$$x_i = SOCE_{read,i} - SOCE_{measured,i}$$

where

$\mathrm{SOCE}_{\mathrm{read,i}}$ is the on-board SOCE read from the vehicle i ; and

$SOCE_{measured,i}$ is the measured SOCE of the vehicle i.

For the total number of N tests and the normalised values of the tested vehicles, $x_1, x_2, \dots x_N$, the average X_{tests} and the standard deviation s shall be determined:

$$X_{tests} = \frac{(x_1 + x_2 + x_3 + \cdots + x_N)}{N}$$

and

$$s = \sqrt{\frac{(x_1 - X_{tests})^2 + (x_2 - X_{tests})^2 + \ldots + (x_N - X_{tests})^2}{N-1}}$$

For each N tests $3 \leq N \leq 16$, one of the three following decisions can be reached, where the factor A shall be set at 5:

(a) Pass the family if $X_{tests} \leq A - \left(t_{P1,N} + t_{P2,N}\right) \cdot s$

(b) Fail the family if $X_{tests} > A + \left(t_{F1,N} - t_{F2}\right) \cdot s$

(c) Take another measurement if:

$$A - \left(t_{P1,N} + t_{P2,N}\right) \cdot s < X_{tests} \leq A + \left(t_{F1,N} - t_{F2}\right) \cdot s$$

where the parameters $t_{P1,N}$, $t_{P2,N}$, $t_{F1,N}$, and t_{F2} are taken from Table 1.

Table 1
Pass/fail decision criteria for the sample size

	PASS		*FAIL*	
Tests (N)	$t_{P1,N}$	$t_{P2,N}$	$t_{F1,N}$	t_{F2}
3	1.686	0.438	1.686	0.438
4	1.125	0.425	1.177	0.438
5	0.850	0.401	0.953	0.438
6	0.673	0.370	0.823	0.438
7	0.544	0.335	0.734	0.438
8	0.443	0.299	0.670	0.438
9	0.361	0.263	0.620	0.438
10	0.292	0.226	0.580	0.438
11	0.232	0.190	0.546	0.438
12	0.178	0.153	0.518	0.438
13	0.129	0.116	0.494	0.438
14	0.083	0.078	0.473	0.438
15	0.040	0.038	0.455	0.438
16	0.000	0.000	0.438	0.438

6.3.4. Corrective measures for the SOCE monitor

A fail decision for the sample means that the monitor fails to report accurately the durability of the system and appropriate action shall be taken by the manufacturer with the agreement of the responsible authority. This may lead to the requirement that the manufacturer repairs or replaces the faulty monitor including the relevant sensors or applies software measures in all affected vehicles in the monitor family.

A pass decision or correction of the non-compliance is required for proceeding with Part B.

6.4. Part B: Verification of Battery Durability

The Part B verification is applicable only in the case when the requirements of Annex 4 are applied.

6.4.1. Frequency of verifications

Data shall be collected yearly by the responsible authorities from a statistically adequate sample of vehicles within the same battery durability family selected randomly from a variety of climate conditions. The decision on the number of vehicles in the sample may be taken by the responsible authority based on risk assessment methodology, but in principle should not be less than 500.

If the number of vehicles in the sample is less than 500, then on the request of the manufacturer and with the agreement of the responsible authority, a maximum of 5 per cent of the values may be excluded from the sample. In such a case, the manufacturer shall provide adequate information to the authority on the reason behind the exclusion for each vehicle.

If the number of vehicles in the sample is equal to or more than 500, then all vehicles shall be included in the sample. The data read shall be those of the SOCE monitor (and other relevant data, such as those defined in Annex 2).

6.4.2. Pass/Fail Criteria for the battery durability family

A battery durability family shall pass if equal to or more than 90 per cent of monitor values read from the vehicle sample are above the MPR*i* or DPR*i*.

A battery durability family shall fail if less than 90 per cent of monitor values read from the vehicle sample are above the MPR*i* or DPR*i*.

6.4.3. Corrective Measures for the Battery Durability Family

In the case of a fail for a battery durability family, corrective measures shall be taken by the manufacturer with the agreement of the responsible authority in order to bring the family or part of the family affected by the issue into compliance.

6.5. Part C: Verification of reported virtual distance

Reserved

6.5.1. Verification procedure

Reserved

6.5.2. Pass or fail of reported virtual distance

Reserved

6.5.3. Corrective measures for reported virtual distance

Reserved

6.6. Process flow charts for Part A and Part B

The flow charts below illustrate the various steps in the verification process of Part A (Figure 1) and Part B (Figure 2).

Figure 1

Flow chart for Part A: Verification of Monitors

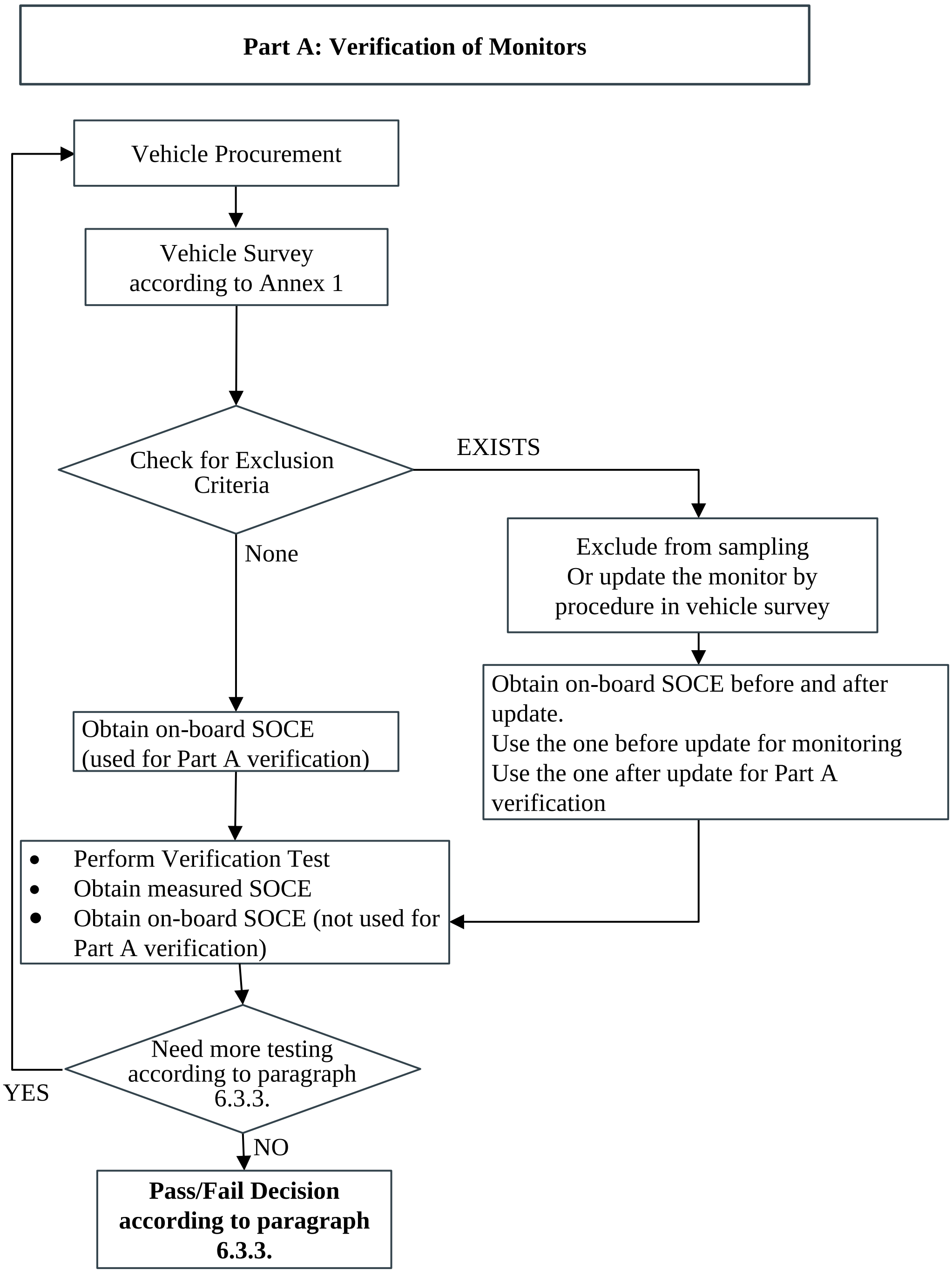
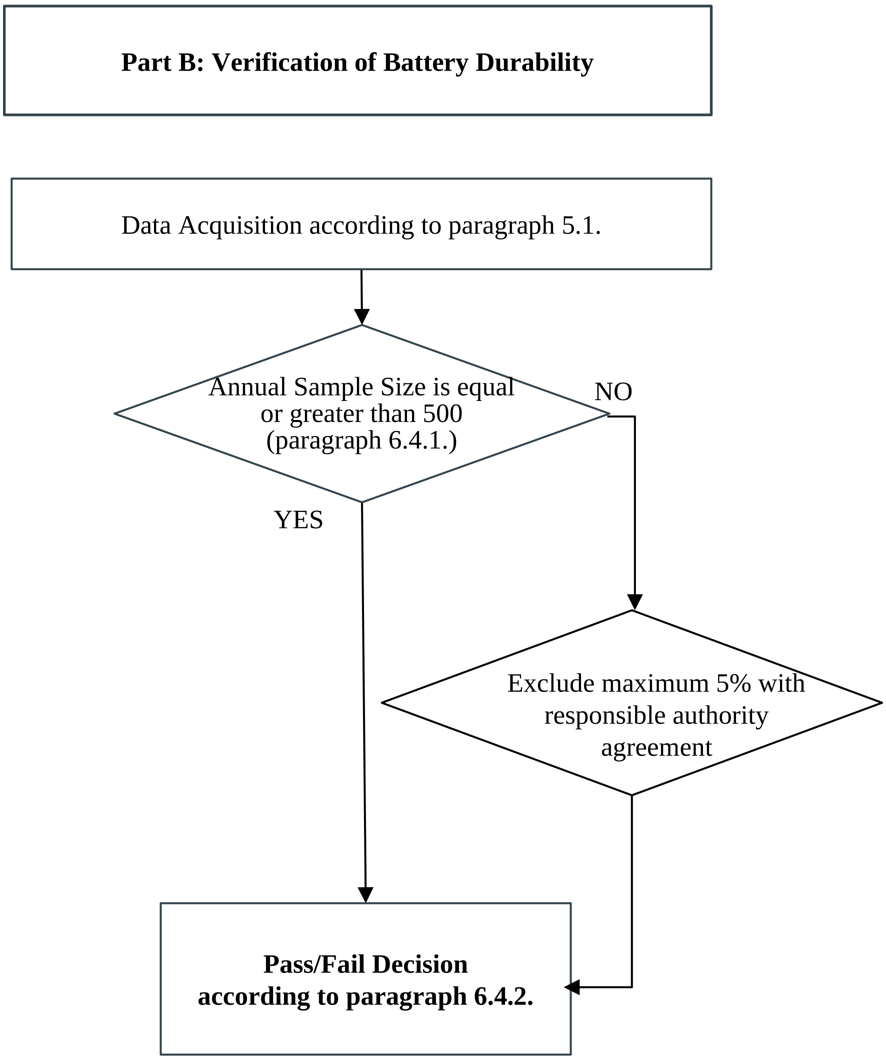


Figure 2
Flow chart for Part B: Verification of Battery Durability



7. Rounding

7.1. When the digit immediately to the right of the last place to be retained is less than 5, that last digit retained shall remain unchanged.

Example:

If a result is 1.2344 kWh but only three places of decimal are to be retained, the final result shall be 1.234 kWh.

7.2. When the digit immediately to the right of the last place to be retained is greater than or equal to 5, that last digit retained shall be increased by 1.

Example:

If a result is 1.2346 kWh but only three places of decimal are to be retained, and because 6 is greater than 5, the final result shall be 1.235 kWh.

Annex 1

Vehicle Survey

The vehicle survey shall be used for all vehicles selected for testing in ‘Part A: Verification of SOCE monitor’, for all the test methods, i.e., Method 1a, Method 1b, Method 2 and Alternative Method of Annex 3. Vehicles that fall under one of the exclusion criteria below shall be eliminated from testing, or otherwise updated according to the procedures described below.

	x = Exclusion Criteria	**x = Checked and reported**	**Confidential**
Date:			**x**
Name of investigator:			**x**
Location of test:			**x**
Country of registration:		**x**	

Vehicle Characteristics	**x = Exclusion Criteria**	**x = Checked and reported**	**Confidential**
Registration plate number:		**x**	**x**
The vehicle must have ***age and distance*** *travelled (defined as the time elapsed after manufacture) below the one required in the optional Annex 4 for the MPR verification*	**x**		
Is the vehicle either HD-PEV or HD-OVC-HEV? If no: the vehicle cannot be selected	**x**		
Date of manufacture (in the case of multistage vehicle several inputs are possible):		**x**	

VIN:		**x**	
Emission class and character or Model Year		**x**	
Country of registration: *The vehicle must be registered in a Contracting Party*	**x**	**x**	
Model:		**x**	
Engine code:		**x**	
Engine volume (l):		**x**	
Engine power (kW):		**x**	
Electric Motor code:		**x**	
Electric Motor power (kW):		**x**	
Electric powertrain type		**x**	
Energy capacity and type of battery		**x**	
Gearbox type (auto/manual):		**x**	
Axle configuration (4x2, 4x4, 6x2, 6x4, 6x6, 8x2,…):		**x**	
Tyre size (front and rear if different):		**x**	

Is the vehicle involved in a recall or service campaign? **If yes: Which one? Have the campaign repairs already been done?** *The repairs must have been done before selecting the vehicle.*	**x**	**x**	

Vehicle Owner Interview
(the owner will only be asked the main questions and shall have no knowledge of the implications of the replies)

Name of the owner (only available to the accredited inspection body or laboratory/technical service)			**x**
Contact (address / telephone) (only available to the accredited inspection body or laboratory/technical service)			**x**

How many owners did the vehicle have?		**x**	
Did the odometer work? *If no, the vehicle cannot be selected.*	**x**		
Was the vehicle used for one of the following?			
As vehicle used in show-room/demonstration purposes?		**x**	
Usage not originally prescribed		**x**	
Has the vehicle carried heavy loads over the specifications of the manufacturer? *If yes, the vehicle cannot be selected.*	**x**		
Have there been major engine, electric motor or vehicle repairs?		**x**	
Have there been unauthorised major engine or vehicle repairs? *If yes, the vehicle cannot be selected.*	**x**		
Was the propulsion battery changed or repaired? *If yes, the vehicle cannot be selected for testing, but information should be collected*	**x**	**x**	
Has there been an unauthorised power increase/tuning? *If yes, the vehicle cannot be selected.*	**x**		
Was any part of the emissions after-treatment system modified? *If yes, the vehicle cannot be selected*	**x**		
What is your estimation of where your vehicle been used more often?			
% motorway		**x**	
% rural		**x**	
% urban		**x**	
Has the vehicle been maintained and used in accordance with the manufacturer's instructions? *If not, the vehicle cannot be selected.*	**x**		
Full service and repair history including any re-works *If the full documentation cannot be provided, the vehicle cannot be selected.*	**x**		
Battery related checks:			
How often did you charge the vehicle when: **% with battery almost at 0 charge** **% with battery half charged** **% with battery almost fully charged**		**x** **x** **x**	
On average how often were fast or ultra-fast*or MegaWatt chargers used in a month, if applicable?**		**x**	

* Ultra-fast charger: up to 600kW (ISO 15118, IEC61851...) ** MegaWatt Charging system: up to 3.75MW (ISO 15118, IEC 62196, …) **What is your estimation of the percentage of time that the vehicle was used in the following ambient temperature ranges:** **Below -7C:** **Between -7C and 35C:** **More than 35C:**		**x** **x** **x**	
Is the vehicle equipped with dynamic charging technology, such as, wireless power transfer, ground-rail, overhead trolley, or with overhead pantograph?		**x**	
If available, on average how often was a dynamic charging technology, such as, wireless power transfer, ground-rail, overhead trolley, overhead pantograph, used to charge the vehicle in a month?		**x**	

Vehicle Examination and Maintenance by the Testing Centre (please use the relevant entries according to the type of vehicle)	**x= Exclusion Criteria**	**x=checked and reported**	**Relevant for EV**
Was the vehicle not charged adequately* for the last month? *If the vehicle was not charged adequately for the last month (as evidenced by values read from the vehicle under point 4, Annex 2) and the tester wishes to use it for testing, then it has to be conditioned by operating the vehicle in a manner that results in discharge of at least 50 per cent of the usable capacity of the battery, followed by a full recharge.* Note: * Adequately in this sense means that the vehicle was not charged in a manner that would lead to an accurate SOCE	**x**		**Y**
Fuel tank level (full / empty) Is the fuel reserve light ON? *If yes, refuel before test.*		**x**	
Are there any warning lights on the instrument panel activated indicating a vehicle or exhaust after-treatment system malfunctioning that cannot be resolved by normal maintenance? (Malfunction Indication Light, Engine Service Light, etc?) *If yes, the vehicle cannot be selected*	**x**		
Is the SCR light on after engine-on? *If yes, the reagent should be filled, or the repair executed before the vehicle is used for testing.*	**x**		
Visual inspection exhaust system Check leaks between exhaust manifold and end of tailpipe. Check and document (with photos) *If there is damage or leaks, the vehicle cannot be tested*	**x**		
Exhaust gas relevant components Check and document (with photos) all emissions relevant components for damage. *If there is damage, the vehicle cannot be tested*	**x**		
Air filter and oil filter Check for contamination and damage. Change if damaged or heavily contaminated or less than 800 km before the next recommended change.		**x**	

Wheels (front & rear) Check whether the wheels are freely moveable or blocked or impeded by the brake. *If not freely moveable, the vehicle cannot be selected.*	**x**		**Y**
Drive belts & cooler cover *In case of damage, the vehicle cannot be tested.*	**x**		
Check fluid levels Check the max. and min. levels (engine oil, cooling liquid) / top up if below minimum		**x**	
Vacuum hoses and electrical wiring Check all for integrity. *In case of damage, the vehicle cannot be tested.*	**x**		**Y**
Injection valves / cabling Check all cables and fuel lines. *In case of damage, the vehicle cannot be tested.*	**x**		**Y**
Ignition cable (gasoline) Check spark plugs, cables, etc. In case of damage, replace them.		**x**	
EGR & Catalyst, Particle Filter Check all cables, wires and sensors. *In case of tampering or damage, the vehicle cannot be selected.*	**x**		
Safety condition Check tyres, vehicle's body, electrical and braking system status are in safe conditions for the test and respect road traffic rules. *If not, the vehicle cannot be selected.*	**x**		**Y**
Semi-trailer Are there electric cables for semi-trailer connection, where required?		**x**	**Y**
Check if less than 800 km away from next scheduled service, if yes, then perform the service.		**x**	**Y**
Powertrain Control Module calibration part number and checksum		**x**	**Y**
OBD diagnosis (before or after the range test) Read Diagnostic Trouble Codes & Print error log		**x**	
OBD Service Mode 09 Query (before or after the range test) Read Service Mode 09. Record the information.		**x**	
OBD mode 7 (before or after the range test) Read Service Mode 07. Record the information		**x**	

Remarks for: Repair / replacement of components / part numbers

Annex 2

Values to be read from vehicles

The manufacturer shall make available the following values to be read visually or via the on-board network.

Mandatory values:

1. On board SOCE value [%]
2. Odometer (i.e. distance driven by the vehicle)[km]
3. Date of manufacture of the vehicle
4. Elapsed time since battery SOC last increased by more than 50 percentage points [days]
5. Average battery temperature while propulsion system is active; during charging; and (if equipped) during non-usage of the vehicle (i.e. non-propulsion system active, non-charging)
6. Total energy throughput [kWh]

Values required if manufacturer applies virtual distance option:

7. Total propulsion energy [kWh]
8. Total distance (sum of the distance driven as reported by the odometer and the virtual distance) [km],
9. Virtual distance [km],

Annex 3

Test procedures for the UBE determination and performance parameters

1. General

For the calculation of the $SOCE_{measured}$, according to paragraph 6.3.2. of this GTR, the measured and certified values of usable battery energy (UBE) for HD-PEVs and HD-OVC-HEVs are required:

- $UBE_{measured}$ and $UBE_{certified}$

This annex describes in paragraph 2. the procedures for determining these parameters and gives guidance on the measurements that need to be carried out.

1.1. Vehicle selection

1.1.1. Vehicle selection during certification

The vehicle selection during certification shall be carried out according to regional regulations and with the agreement of the responsible authority.

1.1.2. Vehicle selection during Part A verification

The vehicle selected during Part A verification shall be randomly selected. In the case in which the number of tests is less than the number of Part B families, then more than one vehicle selection is not allowed from the same Part B family. In the case in which the number of tests is equal to or greater than the number of Part B families, then at least one vehicle shall be selected from each Part B family.

1.2. Measurement requirements

Measurement devices shall be of certified accuracy, as shown in Table A3/1, traceable to an approved regional or international standard.

All the items in Table A3/1, unless specified otherwise in the table, shall be measured and recorded at a frequency of 20 Hz.

The item 'room/ambient temperature' shall be at least recorded as single measurement activity at start of the vehicle battery testing and after end of the vehicle battery testing in all the test procedures as described in paragraph 2. of this annex.

Table A3/1
Measurement items and required accuracy

Item	*Units*	*Accuracy*	*Remarks*
Electrical voltage	V	±0.3 % FSD or ±1 % of reading	Whichever is greater. Resolution 0.1 V.
Electrical current	A	±0.3 % FSD or ±1 % of reading	Whichever is greater. Resolution 0.1 A
Room/ambient temperature	K	±1 °C, with a measurement frequency of at least 0.033 Hz	
Time	s	± 10 ms; min. precision and resolution: 10 ms	

Item	*Units*	*Accuracy*	*Remarks*
Vehicle speed	km/h	The total trip distance shall deviate by no more than 4 % from the reference distance	GNSS or Sensor or ECU

2. Test procedures

Table A3/2 summarises the different test procedures for the UBE determination: Method 1a, Method 1b and Method 2.

The test method using a HDV chassis dynamometer is an alternative method.

The same test method shall be applied at certification to the SOCE monitor family concerned and during in-service testing Part A verification, if applicable and in accordance with regional provisions, unless there is an agreement between the regional authority and the manufacturer.

Table A3/2
Testing methods for UBE determination

Testing methods for UBE determination			
	Method 1a	**Method 1b**	**Method 2**
Description	Discharge by driving on a test track using characteristic regional speeds with tolerances And then charge	Discharge by driving on the road using average speeds And then charge	Discharging using a bidirectional power supply system And then charge
Alternative Method	Discharge using constant and transient cycles test method by using a HDV chassis dynamometer And then charge		

2.1. Method 1a: Discharge by driving on a test track using characteristic regional speeds

In Method 1a the battery shall be depleted by driving the vehicle on a test track as specified in this paragraph.

2.1.1. General test requirements

The vehicle shall be driven on a test track at standard constant average speeds with a tolerance as specified in paragraph 2.1.2.7.

The manufacturer shall guarantee that all the traction batteries installed on the vehicle are engaged during the test to determine the certified and measured Usable Battery Energy (UBE).

The test track road surface shall be representative of current urban and highway road surfaces, according to regional regulations.

2.1.1.1. Determine vehicle speed

Vehicle speed shall be determined by at least one of the following methods:

(a) A Global Navigation Satellite System (GNSS):

If vehicle speed is determined by a GNSS, the total trip distance shall be checked by calculating and comparing the total trip distance with reference measurements obtained from either a sensor, the validated ECU or, alternatively, from a digital road network or topographic map. It is mandatory to correct GNSS data for obvious errors, e.g., by applying a dead reckoning sensor, prior to the consistency check. The original and uncorrected data file shall be retained and any corrected data shall be marked. The corrected data shall not exceed an uninterrupted time period of 120 s or a total of 300 s. The total trip distance as calculated from the corrected GNSS data shall deviate by no more than 4 per cent from the reference. If the GNSS data do not meet these requirements and no other reliable speed source is available, the test results shall be voided

(b) A sensor (e.g., optical or micro-wave sensor):

If vehicle speed is determined by a sensor, the speed measurements shall comply with the accuracy requirements of ±1.0km/h absolute, or alternatively, the total trip distance determined by the sensor shall be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the sensor shall deviate by no more than 4 per cent from the reference distance.

(c) The ECU:

If vehicle speed is determined by the ECU, the total trip distance as determined by the EC can be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the ECU shall deviate by no more than 4 per cent from the reference.

Vehicle speed determined by the GNSS is considered the preferred option.

2.1.1.2. Reserved

2.1.1.3. Reserved

2.1.1.4. Soak and charge area

The temperature of the soak and charge area, if applicable, shall be maintained at 25 °C ±5 °C.

2.1.1.5. Required information

The manufacturer shall provide the responsible authority with the information required to conduct the test procedure as follows.

The manufacturer shall specify if a pure electric testing operation mode shall be set at the vehicle level for the purpose of performing the test of HD-OVC-HEVs.

The manufacturer shall provide the responsible authority with a list of the deactivated devices and justification for the deactivation.

The testing operation mode shall be approved by the responsible authority and the use of a testing operation mode shall be recorded.

The vehicle's testing operation mode shall not activate, modulate, delay or deactivate the operation of any part that affects the battery energy throughput under the test conditions except for the internal battery heating-cooling system and the eventual eco mode automatically activated at the end of the depleting phase. The manufacturer shall provide evidence to the responsible authority.

2.1.1.6. Required measurements

The test vehicle shall be instrumented with measurement devices for measuring the necessary input values for the UBE calculation (voltage and electrical current). The external equipment shall be powered by an external power supply. The discharge and charge energy shall be measured at the battery to avoid combined battery-inverter efficiency and energy losses. Instrumentation for this purpose shall be based on manufacturer specifications and demonstrated to the responsible authority.

As an alternative to the use of voltage and current measurement devices, use of on-board measurement data is permissible if the accuracy and frequency of these data is demonstrated to the responsible authority to meet the minimum requirements for accuracy and frequency described in paragraph 1.2. of this annex.

The on-board measurement data of the voltage and current can be used during the in-service testing only when the accuracy and frequency of on-board measurement data is confirmed during the certification. Safe inspection points shall be made available for the direct measurement verification.

2.1.2. Test sequence

2.1.2.1. General

The test shall be carried out in accordance with paragraphs 2.1.2.4. to 2.1.2.8. of this annex, (see Figure A3/1 and Figure A3/4). The test shall be void if the break-off criterion is not reached or the battery temperature is outside the normal operating range specified by the manufacturer.

2.1.2.1.1. Breaks for the driver are permitted as prescribed in Table A3/3, but they shall be verified with responsible authorities so as not to violate local legal rules. The maximum break times are set so that the battery conditioning is maintained.

Having more than one driver is permitted, however in order to maintain the conditioning of the batteries the changeover time between drivers shall not be more than that allowed for driver breaks, as specified in Table A3/3.

The minimum and maximum average temperature of the battery (all of the REESS) during the driver break shall have a difference of less than 14°C. If this condition is not met the test shall be repeated.

Table A3/3
Breaks for the driver

Driving time (h)	*Maximum total break (min)*
every each 1h	10
More than 4h	Shall be based on the manufacturer’s recommendation or regional authority

Note: During a break, the powertrain shall be switched off.

2.1.2.1.2. The following operational metrics shall be monitored and recorded throughout the test in order to support the verification of the conditioning of the battery, if needed:

(a) battery temperature (minimum, maximum, as indicated by the temperature of the battery cells, modules, or pack, as available);

(b) battery state of charge (SOC) (from BMS and dashboard);

(c) battery conditioning on/off, as available.

The manufacturer shall specify the normal operating range for the battery temperature .

2.1.2.2. Preparation of vehicle

The vehicle shall be presented in good technical condition.

In the case of certification, the vehicle shall be run-in in accordance with the manufacturer’s recommendations.

HD-PEVs and HD-OVC-HEVs shall have been run-in at least 300 km or one full charge distance, whichever is longer.

In the case of in-service conformity check, the vehicle shall be subject to the acceptance check criteria defined in Annex 1 of this GTR.

2.1.2.3. Preparation of measurement devices

The measurement devices shall be installed at suitable and safe position(s) within the vehicle. The manufacturer shall recommend the measurement points with the approval of the responsible authority and with appropriate technical justification.

2.1.2.4. Initial setting of the battery

Prior to or during vehicle soak (paragraphs 2.1.2.5. and 2.1.2.6. of this annex), the battery shall be charged/discharged to an initial state of charge (SOC), as displayed on the monitor of the vehicle, less than or equal to 10 per cent. At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may specify a different initial SOC of the battery.

The battery shall be charged/discharged to the initial SOC in accordance with the procedure specified by the manufacturer.

2.1.2.5. Vehicle pre-conditioning

The battery of the vehicle shall be discharged, left stabilised for no less than 30 minutes and no more than 1 hour and then fully charged at a power less than or equal to the manufacturer's recommendation for normal charging before starting the test as specified in Figure A3/1.

The manufacturer may recommend a longer stabilisation time if necessary to ensure stabilisation of the high voltage battery.

This first battery discharge, referred to as pre-conditioning, shall be performed according to manufacturer's recommendation or given speed within the range of the characteristic regional speeds and payload without requirements on the ambient temperature.

The manufacturer shall guarantee that the battery is as fully depleted as possible using the discharge test procedure.

During the discharge of the battery, the operational metrics (see paragraph 2.1.2.1.2. of this annex) shall be recorded, if required.

2.1.2.6. Vehicle soak and charge

The soak and charge is performed in the soak area or test room if available.

If the soak and charge is performed in a soak area or test room the soak area temperature during soak shall be as specified in paragraph 2.1.1.4. of this annex.

Recording the energy consumption for all the soak and charge duration is required.

External devices that control battery temperature, different from charging stations, are not allowed.

The external equipment such as the charging station shall be powered by an external power supply.

Measurement devices installed within the vehicle shall be warmed up as appropriate.

The measurement devices shall start collecting data.

The battery shall be fully charged at a power less than or equal to the manufacturer's recommendation for normal charging.

Record the charge current and voltage and the elapsed time required to reach fully charged battery status.

The vehicle shall be soaked and charged for a minimum of 6 hours and a maximum of 36 hours to ensure temperature stabilisation of the high voltage battery.

The manufacturer may recommend a different minimum time for the soak and charge in agreement with the responsible authority.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

Fully charged battery status shall be reached. If the selected power charging does not allow the fully charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges.

The temperature of the battery shall be checked before starting the test.

Thermal equilibration is reached if in the preceding 1 hour the deviations of the temperature of the battery are within a 7 °C range. If this condition is not met the soak and charge shall be repeated.

If the soak and charge is performed in a soak area, the vehicle shall not receive unjustified exposure to temperatures other than 25 °C ±5 °C. If unavoidable, the time of exposure shall be limited to a maximum of 10 minutes for each exposure.

It is allowed to monitor the operating metrics and perform additional conditioning as necessary in order to maintain the operating metrics within the normal operating ranges.

2.1.2.7. Method 1a test

The actual test run shall start within a period of 1 hour after the disconnection of the vehicle from the charging station, otherwise the preconditioning and charge shall be repeated.

The test shall be carried out on a test track using the regional characteristic speeds and payload per Gross Vehicle Mass (GVM) and Gross Train Mass (GTM) in agreement with the responsible authorities. The vehicle mass including the payload and trailer if applicable shall not exceed 90 percent of GVM or GTM. .

The same regional characteristic vehicle speed used for certification may be used if applicable, and in accordance with regional provisions, unless there is an agreement between the regional authority and the manufacturer.

The battery shall be discharged preferably using a constant speed within the range of the characteristic regional speeds up to a battery state of charge (SOC), as reported by the vehicle, less than or equal to 10 per cent. In agreement with the responsible authority and based on technical evidence the battery may be discharged to a higher battery state of charge (SOC) in the first part of the depleting test.

In the remaining part of the depleting test, the battery shall be discharged with a target constant speed and a payload per Gross Vehicle Mass (GVM) and Gross Train Mass (GTM) in agreement with the responsible authorities with a speed tolerance of ± 7km/h according to the specifications of paragraph 2.1.1.1. of this annex.

In the remaining part of the depleting test the minimum speed shall be targeted at no less than 30 km/h.

The same target constant speed shall be used during certification and in-service testing, unless there is an agreement between the regional authority and the manufacturer.

During the test, the speed may be controlled manually or by cruise control system if available.

The acceleration and deceleration during vehicle speed change shall be smooth and it is recommended to be accomplished within the range ±1 km/h/sec.

It is allowed to complete the last part of the test-driving outside the test track, but inside the test track facility.

The end of discharge criterion is reached when the break-off criterion is met.

The equivalence with the certification test method and break-off criterion shall be demonstrated to the responsible authority.

In the case of HD-PEVs, the break-off criterion is reached when the vehicle exceeds the driving speed tolerance or experiences a driving power cut for 4 consecutive seconds or more.

In the case of HD-OVC-HEVs the break-off criterion is reached when in the last part of the test over a distance Δkm equivalent to 5 per cent of the total available energy of the battery, the $|\Delta E_{REESS,\Delta km}|/\Delta km$ is equal to or less than 3 per cent of the cumulative UBE/(total distance travelled - Δkm) (energy consumption before the last Δkm)

$$\frac{\Delta E_{REESS,\Delta km}}{\Delta km} \leq 3\% \ \frac{UBE_{cumulative}}{total\ distance - \Delta km}$$

where:

Δkm	distance in the last part of the test equivalent to 5 per cent of the total available energy of the battery
$\Delta E_{REESS,\Delta km}$	is the measured electric energy change of the battery, over the distance Δkm, defined as $\sum_{i=1}^{n} \Delta E_{REESS,i,\Delta km}$, Wh
$\Delta E_{REESS,i,\Delta km}$	is the measured electric energy change of battery i, over the distance Δkm, Wh;
i	is the index number of the considered battery;
n	is the total number of batteries;

and:

$$\Delta E_{REESS,i,\Delta km} = \frac{1}{3600} \times \int_{t_{0,\Delta km}}^{t_{end,\Delta km}} U(t)_{REESS,i} \times I(t)_{REESS,i}\ dt$$

where:

$U(t)_{REESS,i}$	is the voltage of battery i, V;
$I(t)_{REESS,i}$	is the electric current of battery i, A;
$t_{0,\Delta km}$	is the starting time of the driving of the Δkm portion of the test, s;
$t_{end,\Delta km}$	is the end time of the driving of the Δkm portion of the test, s;
$\frac{1}{3600}$	is the conversion factor from Ws to Wh;
$UBE_{cumulative}$	is the usable battery energy (UBE) ,Wh, calculated as $\sum_{i=1}^{n} \Delta E_{REESS,i,total\ distance - \Delta km}$ defined as

$$\Delta E_{REESS,i,total\ distance - \Delta km} = \frac{1}{3600} \times \int_{t_0}^{t_{0,\Delta km}} U(t)_{REESS,i} \times I(t)_{REESS,i}\ dt$$

where

t_0	is the time at the beginning of the discharge test, s.

The UBE is calculated over the total distance travelled, including the distance Δkm.

The manufacturer shall provide evidence to the responsible authority after the test that the break-off requirement is fulfilled.

The UBE is the total discharged energy calculated as described in paragraph 3. of this annex.

The vehicle shall be connected to a charging station within 120 minutes after coming to a standstill, if required.

The battery shall be fully charged, if required, at a power less than or equal to the manufacturer's recommendation for normal charging.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

If the selected power charging does not allow the full charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges.

In the case that UBE_{charge} is required, the total charged energy is calculated as described in paragraph 3. of this annex.

The Method 1a test is performed on new vehicles within a family, if the measurement of the UBE is applied at certification, to determine the $UBE_{certified}$.

The Method 1a test is performed on aged vehicles within a family to determine the $UBE_{measured}$.

The $SOCE_{measured}$ is derived according to paragraph 6.3.2. of this GTR.

2.1.2.8. End of Method 1a test

At the end of the Method 1a test, the measured values and the operational metrics (see paragraph 2.1.2.1.2. of this annex) shall be recorded.

After the measurements are complete, the vehicle and measurement devices shall be stopped.

2.2. Method 1b: Discharge by driving on the road

In Method 1b the battery shall be depleted by driving the vehicle on the road as specified in this paragraph.

2.2.1. General test requirements

The vehicle shall be driven on the road with speeds as specified in paragraph 2.2.2.7.

The manufacturer shall guarantee that all the traction batteries installed on the vehicle are engaged during the test to determine the certified and measured Usable Battery Energy (UBE).

The road surface shall have a texture and composition representative of current urban and highway road surfaces, according to regional regulations.

2.2.1.1. Determine vehicle speed

Vehicle speed shall be determined by at least one of the following methods:

(a) A Global Navigation Satellite System (GNSS):

If vehicle speed is determined by a GNSS, the total trip distance shall be checked by calculating and comparing the total trip distance with reference measurements obtained from either a sensor, the validated ECU or, alternatively, from a digital road network or topographic map.

It is mandatory to correct GNSS data for obvious errors, e.g., by applying a dead reckoning sensor, prior to the consistency check. The original and uncorrected data file shall be retained and any corrected data shall be marked. The corrected data shall not exceed an uninterrupted time period of 120 s or a total of 300 s. The total trip distance as calculated from the corrected GNSS data shall deviate by no more than 4 per cent from the reference. If the GNSS data do not meet these requirements and no other reliable speed source is available, the test results shall be voided

(b) A sensor (e.g., optical or micro-wave sensor):

If vehicle speed is determined by a sensor, the speed measurements shall comply with the accuracy requirements of ±1.0 km/h absolute, or alternatively, the total trip distance determined by the sensor shall be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the sensor shall deviate by no more than 4 per cent from the reference distance.

(c) The ECU:

If vehicle speed is determined by the ECU, the total trip distance as determined by the EC can be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the ECU shall deviate by no more than 4 per cent from the reference.

Vehicle speed determined by the GNSS is considered the preferred option.

2.2.1.2. Reserved

2.2.1.3. Reserved

2.2.1.4. Soak and charge area

The temperature of the soak and charge area, if applicable, shall be maintained at 25 °C ±5 °C.

2.2.1.5. Required information

The manufacturer shall provide the responsible authority with the information required to conduct the test procedure as follows.

The manufacturer shall specify if a pure electric testing operation mode shall be set at the vehicle level for the purpose of performing the test of HD-OVC-HEVs.

The manufacturer shall provide the responsible authority with a list of the deactivated devices and justification for the deactivation.

The testing operation mode shall be approved by the responsible authority and the use of a testing operation mode shall be recorded.

The vehicle's testing operation mode shall not activate, modulate, delay or deactivate the operation of any part that affects the battery energy throughput under the test conditions except for the internal battery heating-cooling system and the eventual eco mode automatically activated at the end of the depleting phase. The manufacturer shall provide evidence to the responsible authority.

2.2.1.6. Required measurements

The test vehicle shall be instrumented with measurement devices for measuring the necessary input values for the UBE calculation (voltage and electrical current). The external equipment shall be powered by an external power supply. The discharge and charge energy shall be measured at the battery to avoid combined battery-inverter efficiency and energy losses. Instrumentation for this purpose shall be based on manufacturer specifications and demonstrated to the responsible authority.

As an alternative to the use of voltage and current measurement devices, use of on-board measurement data is permissible if the accuracy and frequency of these data is demonstrated to the responsible authority to meet the minimum requirements for accuracy and frequency described in paragraph 1.2. of this annex.

The on-board measurement data of the voltage and current can be used during the in-service testing only when the accuracy and frequency of on-board measurement data is confirmed during the certification. Safe inspection points shall be made available for the direct measurement verification.

2.2.2. Test sequence

2.2.2.1. General

The test shall be carried out in accordance with paragraphs 2.2.2.4. to 2.2.2.8. of this annex, (see Figure A3/2 and Figure A3/4). The test shall be void if the break-off criterion is not reached or the battery temperature is outside the normal operating range specified by the manufacturer.

2.2.2.1.1. Breaks for the driver are permitted as prescribed in Table A3/4, but they shall be verified with responsible authorities so as not to violate local legal rules. The maximum break times are set so that the battery conditioning is maintained.

Having more than one driver is permitted, however in order to maintain the conditioning of the batteries the changeover time between drivers shall not be more than that allowed for driver breaks, as specified in Table A3/4.

The minimum and maximum average temperature of the battery (all of the REESS) during the driver break shall have a difference of less than 14°C. . If this condition is not met the test shall be repeated.

Table A3/4
Breaks for the driver

Driving time (h)	*Maximum total break (min)*
every each 1h	10
More than 4h	Shall be based on the manufacturer’s recommendation or regional authority

Note: During a break, the powertrain shall be switched off.

2.2.2.1.2. The following operational metrics shall be monitored and recorded throughout the test in order to support the verification of the conditioning of the battery, if needed:

(a) battery temperature (minimum, maximum, as indicated by the temperature of the battery cells, modules, or pack, as available);

(b) battery state of charge (SOC) (from BMS and dashboard);

(c) battery conditioning on/off, as available.

The manufacturer shall specify the normal operating range for the battery temperature.

2.2.2.2. Preparation of vehicle

The vehicle shall be presented in good technical condition.

In the case of certification, the vehicle shall be run-in in accordance with the manufacturer’s recommendations.

HD-PEVs and HD-OVC-HEVs shall have been run-in at least 300 km or one full charge distance, whichever is longer.

In the case of in-service conformity check, the vehicle shall be subject to the acceptance check criteria defined in Annex 1 of this GTR.

2.2.2.3. Preparation of measurement devices

The measurement devices shall be installed at suitable and safe position(s) within the vehicle. The manufacturer shall recommend the measurement points with the approval of the responsible authority and with appropriate technical justification.

2.2.2.4. Initial setting of the battery

Prior to or during vehicle soak (paragraphs 2.2.2.5. and 2.2.2.6. of this annex), the battery shall be charged/discharged to an initial state of charge (SOC), as displayed on the monitor of the vehicle, less than or equal to 10 per cent. At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may specify a different initial SOC of the battery.

The battery shall be charged/discharged to the initial SOC in accordance with the procedure specified by the manufacturer.

2.2.2.5. Vehicle pre-conditioning

The battery of the vehicle shall be discharged, left stabilised for no less than 30 minutes and no more than 1 hour and then fully charged at a power less than or equal to the manufacturer’s recommendation for normal charging before starting the test as specified in Figure A3/2.

The manufacturer may recommend a longer stabilisation time if necessary to ensure stabilisation of the high voltage battery.

This first battery discharge, referred to as pre-conditioning, shall be performed according to manufacturer's recommendation or given speed within the range of the characteristic regional speeds and payload without requirements on the ambient temperature.

The manufacturer shall guarantee that the battery is as fully depleted as possible using the discharge test procedure.

During the discharge of the battery, the operational metrics (see paragraph 2.2.2.1.2. of this annex) shall be recorded, if required.

2.2.2.6. Vehicle soak and charge

The soak and charge is performed in the soak area or test room if available.

If the soak and charge is performed in a soak area or test room the soak area temperature during soak shall be as specified in paragraph 2.2.1.4. of this annex.

Recording the energy consumption for all the soak and charge duration is required.

External devices that control battery temperature, different from charging stations, are not allowed.

The external equipment such as the charging station shall be powered by an external power supply.

Measurement devices installed within the vehicle shall be warmed up as appropriate.

The measurement devices shall start collecting data.

The battery shall be fully charged at a power less than or equal to the manufacturer’s recommendation for normal charging.

Record the charge current and voltage and the elapsed time required to reach the fully charged battery status.

The vehicle shall be soaked and charged for a minimum of 6 hours and a maximum of 36 hours to ensure temperature stabilisation of the high voltage battery.

The manufacturer may recommend a different minimum time for the soak and charge in agreement with the responsible authority.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

Fully charged battery status shall be reached. If the selected power/c-rate charging does not allow the fully charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges.

The temperature of the battery shall be checked before starting the test.

Thermal equilibration is reached if in the preceding 1 hour the deviations of the temperature of the battery are within a 7 °C range. If this condition is not met the soak and charge shall be repeated.

If the soak and charge is performed in a soak area, the vehicle shall not receive unjustified exposure to temperatures other than 25 °C ±5 °C. If unavoidable, the time of exposure shall be limited to a maximum of 10minutes for each exposure.

It is allowed to monitor the operating metrics and perform additional conditioning as necessary in order to maintain the operating metrics within the normal operating ranges.

2.2.2.7. Method 1b test

The actual test run shall start within a period of 1 hour after the disconnection of the vehicle from the charging station, otherwise the preconditioning and charge shall be repeated.

The test shall be carried out on road using the regional characteristic speeds and payload per Gross Vehicle Mass (GVM) and Gross Train Mass (GTM) in agreement with the responsible authorities. The vehicle mass including the payload and trailer if applicable shall not exceed 90 percent of GVM or GTM.

The same route may be used at certification and Part A verification in accordance with regional authority, if applicable.

The same regional characteristic vehicle speed used for certification may be used if applicable and in accordance with regional provisions, unless there is an agreement between the regional authority and the manufacturer.

During the test, the speed may be controlled manually or by cruise control system if available.

The acceleration and deceleration during vehicle speed change shall be as smooth as possible in relation to traffic conditions and safety of driving and it is recommended to be accomplished within the range ±1 km/h/sec if applicable. The proportional cumulative positive altitude gain over the entire trip shall be less than 1,200m / 100km and be determined according to regional regulations, for example referring to UN Regulation No. 168.

The battery shall be discharged up to a minimum battery state of charge level in agreement with the responsible authority and safety rules.

The minimum speed in the remaining part of the depleting test shall be targeted at no less than 30 km/h

A safe place to perform the test shall be agreed with the responsible/relevant authority.

It is allowed to start and end the test at the test facilities to comply with the road safety requirements.

It is allowed to use static battery discharging systems in the last part of the test to complete the discharge if agreed with the responsible authority. The discharge power of the system should be representative of the characteristic driving speed. The battery power as measured from the battery shall not be less than 10 kW. The break off criterion is reached when the discharging power experiences a drop of 10 per cent of the target discharge power for 4 seconds.

In the case these testing provisions are not achievable, a different test method may be applied with the agreement between the manufacturer and the responsible authority. The end of discharge criterion is reached when the break-off criterion is met.

The equivalence with the certification test method and break-off criterion shall be demonstrated to the responsible authority.

In the case of HD-PEVs, the break-off criterion is reached when the vehicle exceeds the driving speed tolerance or experiences a driving power cut for 4 consecutive seconds or more.

In the case of HD-OVC-HEVs the break-off criterion is reached when in the last part of the test over a distance Δkm equivalent to 5 per cent of the total available energy of the battery, the $|\Delta E_{REESS,\Delta km}|/\Delta km$ is equal to or less than 3 per cent of the cumulative UBE/(total distance travelled - Δkm) (energy consumption before the last Δkm).

$$\frac{\Delta E_{REESS,\Delta km}}{\Delta km} \leq 3\% \frac{UBE_{cumulative}}{total\ distance - \Delta km}$$

where:

Δkm	distance in the last part of the test equivalent to 5per cent of the total available energy of the battery
$\Delta E_{REESS,\Delta km}$	is the measured electric energy change of the battery, over the distance Δkm, defined as $\sum_{i=1}^{n} \Delta E_{REESS,i,\Delta km}$, Wh
$\Delta E_{REESS,i,\Delta km}$	is the measured electric energy change of battery i, over the distance Δkm, Wh;
i	is the index number of the considered battery;
n	is the total number of batteries;

and:

$$\Delta E_{REESS,i,\Delta km} = \frac{1}{3600} \times \int_{t_{0,\Delta km}}^{t_{end,\Delta km}} U(t)_{REESS,i} \times I(t)_{REESS,i}\, dt$$

where:

$U(t)_{REESS,i}$	is the voltage of battery i, V;
$I(t)_{REESS,i}$	is the electric current of battery i, A;
$t_{0,\Delta km}$	is the starting time of the driving of the Δkm portion of the test, s;
$t_{end,\Delta km}$	is the end time of the driving of the Δkm portion of the test, s;
$\frac{1}{3600}$	is the conversion factor from Ws to Wh;
$UBE_{cumulative}$	is the usable battery energy (UBE) ,Wh, calculated as $\sum_{i=1}^{n} \Delta E_{REESS,i,total\ distance-\Delta km}$ defined as

$$\Delta E_{\mathrm{REESS,i},total\ distance-\ \Delta km} = \frac{1}{3600} \times \int_{t_0}^{t_{0,\Delta km}} U(t)_{\mathrm{REESS,i}} \times I(t)_{\mathrm{REESS,i}}\ dt$$

where

t_0 is the time at the beginning of the discharge test, s.

The UBE is calculated over the total distance travelled, including the distance Δkm.

The manufacturer shall provide evidence to the responsible authority after the test that the break-off requirement is fulfilled.

The UBE is the total discharged energy calculated as described in paragraph 3 of this annex.

The vehicle shall be connected to a charging station within 120 minutes after coming to a standstill, if required.

The battery shall be fully charged, if required, at a power less than or equal to the manufacturer's recommendation for normal charging.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

If the selected power charging does not allow the fully charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges.

In the case that UBE_{charge} is required, the total charged energy is calculated as described in paragraph 3. of this annex.

The Method 1b test is performed on new vehicles within a family, if the measurement of the UBE is applied at certification, to determine the $UBE_{certified}$.

The Method 1b test is performed on aged vehicles within a family to determine the $UBE_{measured}$.

The $SOCE_{measured}$ is derived according to paragraph 6.3.2. of this GTR.

2.2.2.8. End of Method 1b test

At the end of the Method 1b test, the measured values and the operational metrics (see paragraph 2.2.2.1.2. of this annex) shall be recorded.

After the measurements are complete, the vehicle and measurement devices shall be stopped.

2.3. Method 2: Discharge using a bidirectional power supply system

In Method 2 the battery shall be depleted with a bidirectional power supply unit as specified in this paragraph.

2.3.1. General test requirements

The manufacturers shall guarantee that all the traction batteries installed on the vehicle are engaged during the test to determine the certified and measured Usable Battery Energy (UBE) and that they perform within the same operating limits with regard to power as in the driving mode.

2.3.1.1. Test room

The test room shall have a temperature set point of 25 °C and shall not deviate by more than ±5 °C during the test.

2.3.1.2. Cooling fan

A cooling fan shall be active if required to perform the tests as described in paragraph 2.3.2.5. to 2.3.2.8., according to bidirectional power supply test.

2.3.1.3. Bidirectional power supply system

A bidirectional power supply is a power converter that can convert DC and AC power bi-directionally to any power system.

The bidirectional power supply system shall be able to operate at least at a constant power operating mode and shall comply with the specific requirements reported in Table A3/5.

Table A3/5

Specifications of bidirectional power supply system

Item	**Specification**
Altitude	Functioning properly at lower or equal to 700 meters above sea level
Ambient temperature	Functioning properly at greater than or equal to 273.15 K (0 °C) and less than or equal to 308.15 K (35 °C)
Ambient humidity	Functioning properly at greater than or equal to 30% RH and less than or equal to 80% RH (no condensation)
Input power	Follow the instruction of the product (shall comply with power unit specification and/or requirement of each region)
Discharge power	Maximum 150 kW
Powering / Regenerating efficiency	Greater than 80% @ maximum rated
Operating mode	Constant Power (also consider the transient power profile* to duplicate the real-world driving pattern)
Response time (10% to 90%)	Less than or equal to 25ms (greater than or equal to 40Hz)
* Charge⇔Discharge change time	Less than or equal to 50ms @ 90% of setting
Stability (static load fluctuation)	Within ±0.5% of maximum rated
Accuracy	Within ±1.50% of maximum rated ±8.0% of the reading, whichever is smaller
Output fluctuation（Ripple）	Within ±0.5% rms
DC Charging Connector	Shall comply with the specific requirement

2.3.1.4. Soak and charge area

The temperature of the soak area shall be maintained at 25 °C ±5 °C.

2.3.1.5. Required information

The manufacturer shall provide the responsible authority with the information required to conduct the test procedure as follows.

The manufacturer shall specify if a bidirectional operation mode shall be set at vehicle level for performing the test, and shall prove that the operating window for two-way discharge is identical to that for driving.

The manufacturer shall provide the responsible authority with a list of the deactivated devices and justification for the deactivation.

The bidirectional charge operation mode-shall be approved by the responsible authority and the use of a bidirectional charge operation mode shall be recorded.

The vehicle's bidirectional charge operation mode shall not activate, modulate, delay or deactivate the operation of any part that affects the battery energy throughput under the test conditions except for the internal battery heating-cooling system and the eventual eco mode automatically activated at the end of the depleting phase. The manufacturer shall provide evidence to the responsible authority.

2.3.1.6. Required measurements

The test vehicle shall be instrumented with measurement devices for measuring the necessary input values for the UBE calculation (voltage and electrical current). The discharge and charge energy shall be measured at the battery to avoid combined battery-inverter efficiency and energy losses. Instrumentation for this purpose shall be based on manufacturer specifications and demonstrated to the responsible authority.

As an alternative to the use of voltage and current measurement devices, use of on-board measurement data is permissible if the accuracy and frequency of these data is demonstrated to the responsible authority to meet the minimum requirements for accuracy and frequency described in paragraph 1.2. of this annex.

The on-board measurement data of the voltage and current can be used during the in-service testing only when the accuracy and frequency of on-board measurement data is confirmed during the certification. Safe inspection points shall be made available for the direct measurement verification.

2.3.2. Test sequence

2.3.2.1. General

The test shall be carried out in accordance with paragraphs 2.3.2.4. to 2.3.2.8. of this annex, (see Figure A3/3 and Figure A3/4). The test shall be void if the break-off criterion is not reached or the battery temperature is outside the normal operating range specified by the manufacturer.

2.3.2.1.1. The following operational metrics shall be monitored and recorded throughout the test in order to support the verification of the conditioning of the battery, if needed:

(a) battery temperature (minimum, maximum, as indicated by the temperature of the battery cells, modules, or pack, as available);

(b) battery state of charge (SOC) (from BMS and dashboard);

(c) battery conditioning on/off, as available.

The manufacturer shall specify the normal operating range for the battery temperature

2.3.2.2. Preparation of vehicle

The vehicle shall be presented in good technical condition.

In the case of certification, the vehicle shall be run-in in accordance with the manufacturer's recommendations.

HD-PEVs and HD-OVC-HEVs shall have been run-in at least 300 km or one full charge distance, whichever is longer.

In the case of in-service conformity check, the vehicle shall be subject to the acceptance check criteria defined in Annex 1 of this GTR.

2.3.2.3. Preparation of measurement devices

The measurement devices shall be installed at suitable and safe position(s) within the vehicle. The manufacturer shall recommend the measurement points with the approval of the responsible authority and with appropriate technical justification.

2.3.2.4. Initial setting of the battery

Prior to or during vehicle soak (paragraphs 2.3.2.5. and 2.3.2.6. of this annex), the battery shall be charged/discharged to an initial state of charge (SOC), as displayed on the monitor of the vehicle, less than or equal to 10 per cent. At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may specify a different initial SOC of the battery.

The battery shall be charged/discharged to the initial SOC in accordance with the procedure specified by the manufacturer.

2.3.2.5. Vehicle and bidirectional power supply system installation and pre-conditioning

The battery of the vehicle shall be discharged, left stabilised for no less than 30 minutes and no more than 1 hour and then fully charged at a power less than or equal to the manufacturer's recommendation for normal charging before starting the test as specified in Figure A3/3.

The manufacturer may recommend a longer stabilisation time if necessary to ensure stabilisation of the high voltage battery.

The vehicle and the bidirectional power supply system shall be installed for the preconditioning if the first discharge of the battery is performed with a bidirectional system.

The bidirectional power supply system shall be conditioned in accordance with the manufacturer's recommendations, as appropriate, so that the internal electrical systems may be stabilised. Auxiliary devices of the vehicle shall be switched off or deactivated during bidirectional charge.

If necessary to operate properly the bidirectional power supply system, the vehicle's bidirectional charge operation mode shall be activated by using the manufacturer's instruction.

This first battery discharge, referred to as pre-conditioning, shall be performed according to manufacturer's recommendation or given speed within the range of the characteristic regional speeds or power range derived from the regional characteristic speed and payload without requirements on the ambient temperature.

The manufacturer shall guarantee that the battery is as fully depleted as possible using the discharge test procedure.

During the discharge of the battery, the operational metrics (see paragraph 2.3.2.1.1. of this annex) shall be recorded, if required.

2.3.2.6. Vehicle soak and charge

The soak and charge is performed in the soak area or test room if available.

The battery shall be recharged with the bidirectional power supply system or a charging station.

If the soak and charge is performed in a soak area or test room the soak area temperature during soak shall be as specified in paragraph 2.3.1.4. of this annex.

Recording the energy consumption for all the soak and charge duration is required.

External devices that control battery temperature, different from charging stations, are not allowed.

The external equipment such as the charging station or the bidirectional power supply system shall be powered by an external power supply.

Measurement devices installed within the vehicle shall be warmed up as appropriate.

The measurement devices shall start collecting data.

The battery shall be fully charged at a power less than or equal to the manufacturer's recommendation for normal charging, by the bidirectional power supply system or a charging station.

Record the charge current and voltage and the elapsed time required to reach the fully charged battery status.

The vehicle shall be soaked and charged for a minimum of 6 hours and a maximum of 36 hours to ensure temperature stabilisation of the high voltage battery.

The manufacturer may recommend a different minimum time for the soak and charge in agreement with the responsible authority.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

Fully charged battery status shall be reached. If the battery is recharged with a charging station and the selected power charging does not allow the fully charged status of the battery to be reached due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without waiting time between the two charges.

The temperature of the battery shall be checked before starting the test.

Thermal equilibration is reached if in the preceding 1 hour the deviations of the temperature of the battery are within a 7 °C range. If this condition is not met the soak and charge shall be repeated.

If the soak and charge is performed in a soak area, the vehicle shall not receive unjustified exposure to temperatures other than 25 °C ±5 °C. If unavoidable, the time of exposure shall be limited to a maximum of 10minutes for each exposure.

It is allowed to monitor the operating metrics and perform additional conditioning as necessary in order to maintain the operating metrics within the normal operating ranges.

2.3.2.7. Method 2 test

The actual test run shall start within a period of 1 hour after the disconnection of the vehicle from the charging station, otherwise the preconditioning and charge shall be repeated.

If the same instrument is used both for charging and discharging the battery of the vehicle, the actual test run shall start within a period of 1 hour after the setting of the bidirectional power supply system in the discharging mode, with or without the disconnection of the system according to the operational instruction of the system.

The test shall be carried out using a power range derived from the regional characteristic speed and payload per Gross Vehicle Mass (GVM) and Gross Train Mass (GTM) in agreement with the responsible authorities. The vehicle mass including the payload and trailer if applicable shall not exceed 90percent of GVM or GTM.

The battery shall be discharged preferably using a power derived from a constant speed within the range of the characteristic regional speeds up to a battery state of charge (SOC), as reported by the vehicle, less than or equal to 10 per cent. In agreement with the responsible authority and based on technical evidence the battery may be discharged to a higher battery state of charge

(SOC) in the first part of the depleting test. In the remaining part of the depleting test the battery shall be discharged with a constant power derived from the constant speed and a payload per Gross Vehicle Mass (GVM) and Gross Train Mass (GTM) in agreement with the responsible authorities with a speed tolerance of ± 7km/h according to specification of paragraph 2.1.1.1. of this annex.

In the remaining part of the depleting test the discharged power shall correspond to a minimum speed targeted at no less than 30 km/h.

The same power/regional characteristic vehicle speed used for certification shall be used during certification and in-service testing if applicable and in accordance with regional provisions, unless there is an agreement between the regional authority and the manufacturer.

The end of discharge criterion is reached when the break-off criterion is met.

The equivalence with the certification test method and break-off criterion shall be demonstrated to the responsible authority.

The break off criterion is reached when the discharging power experiences a drop of 10 per cent of the target discharge power for 4 seconds.

The UBE is the total discharged energy calculated as described in paragraph 3. of this annex.

The vehicle shall be connected to the bidirectional power supply system or a charging station within 120 minutes after the break-off criterion is met, if required.

The battery shall be fully charged, if required, at a power less than or equal to the manufacturer's recommendation for normal charging, by the bidirectional power supply system or a charging station.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

If the selected power charging does not allow the fully charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges if the charge is with a charging station.

In the case that UBE_{charge} is required, the total charged energy is calculated as described in paragraph 3. of this annex.

The Method 2 test is performed on new vehicles within a family, if the measurement of the UBE is applied at certification, to determine the $UBE_{certified}$.

The Method 2 test is performed on aged vehicles within a family to determine the $UBE_{measured}$.

The $SOCE_{measured}$ is derived according to paragraph 6.3.2. of this GTR.

For HD-OVC-HEVs the internal combustion engine shall not operate during the duration of the test.

2.3.2.8. End of the Method 2 test

At the end of the Method 2 test, the measured values and the operational metrics (see paragraph 2.3.2.1.1. of this annex) shall be recorded.

After the measurements are complete, the vehicle and measurement devices shall be stopped.

Figure A3/1
Test sequence Method 1a

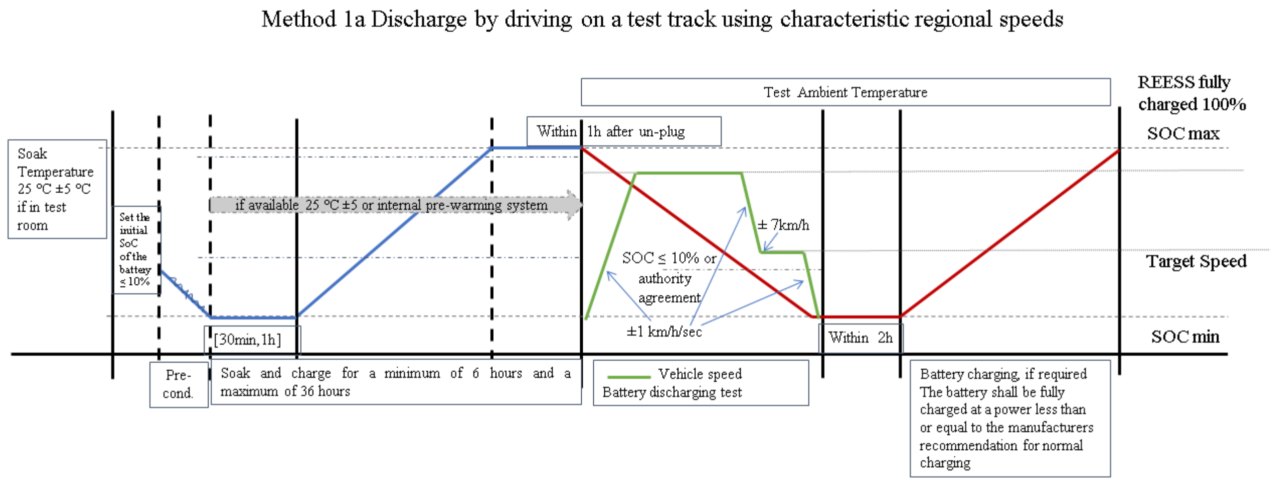


Figure A3/2
Test sequence Method 1b

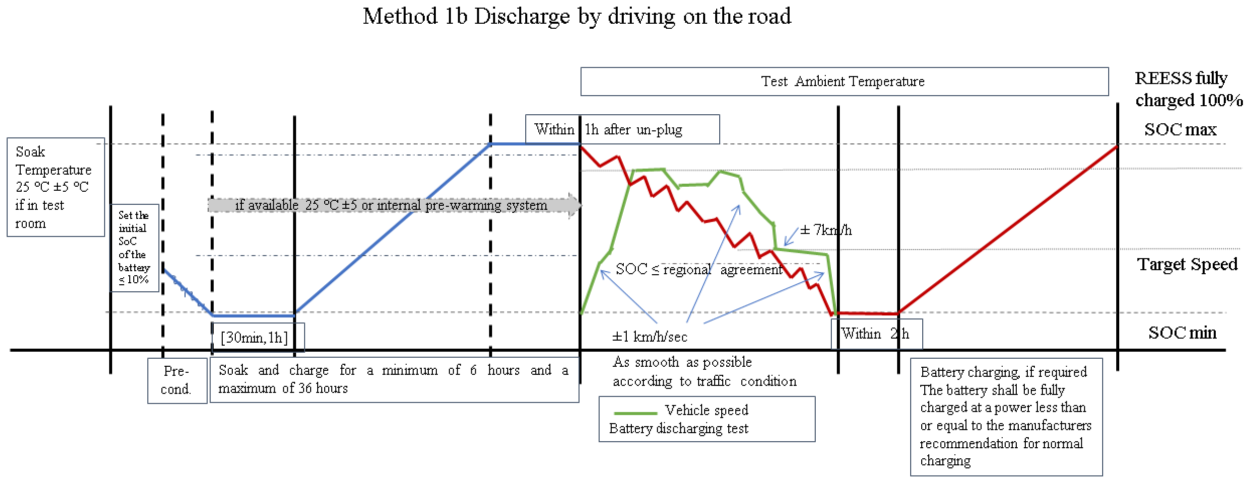


Figure A3/3
Test sequence Method 2

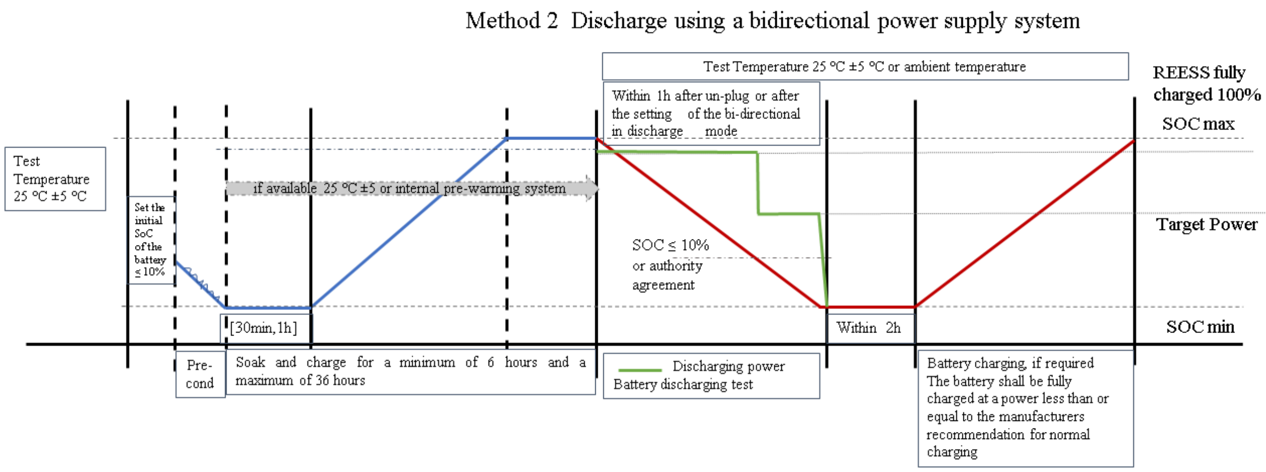
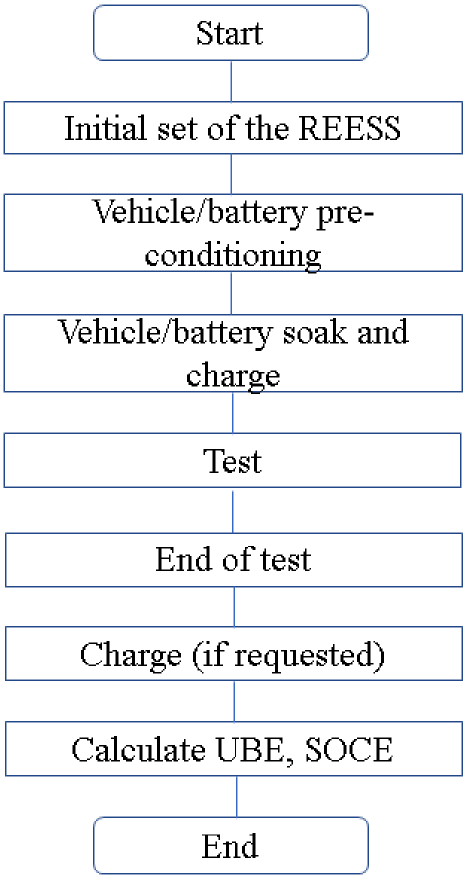


Figure A3/4
Test sequence



2.4. Alternative Method: Discharge using constant and transient cycles test method by using a HDV chassis dynamometer

In the Alternative Method the battery shall be depleted by a cycles test method by driving the vehicle on a HDV chassis dynamometer after pre-conditioning as specified in this paragraph.

2.4.1. General test requirements

This method allows both constant speed test and transient condition test on HD chassis dynamometer.

The manufacturer shall guarantee that all the traction batteries installed on the vehicle are engaged during the test to determine the certified and measured Usable Battery Energy (UBE).

The road load dyno setting, the measurement points together with the test cycle must be identical at certification and during in-service testing Part A verification if the Alternative Method is applied for the vehicle family concerned.

A section of constant speed driving is allowed to stabilise the SOC of the battery during the depleting test.

2.4.1.1. Dynamometer

2.4.1.1.1. Dynamometer road load coefficient setting

During the test, the resistance coefficient obtained from the coasting test or the recommended resistance value shall be used for the chassis dynamometer setting conditions. The recommended value shall be determined in agreement with the responsible authorities.

The chassis dynamometer setting and test shall be carried out according to the regional regulations, for example, referring to the Title 40 of the US Code of Federal Regulation, to the China stage 3 and 4 vehicle tests for fuel consumption determination, to the vehicle data as described in Regulation (EU) 2017/2400, or to other regional requirements.

2.4.1.1.2. Coasting resistance measurement

Coasting resistance measurement shall follow regional regulations.

2.4.1.1.3. Coasting resistance calculation

The coasting resistance calculation shall follow regional regulations.

2.4.1.1.4. Chassis dynamometer settings

Chassis dynamometer settings shall follow regional regulations.

During the test, the driver should be able to accurately control the driving speed and driving time of the vehicle through the driver assistance device. The driver assistance device shall display curve tracking in real time. The deviation between the vehicle driving speed and the target speed of the driving condition shall meet the deviation requirements.

2.4.1.1.5. The chassis dynamometer shall meet the structural and functional requirements as specified in the regional regulations.

2.4.1.1.6. The accuracy of the chassis dynamometer shall meet the requirements of regional regulations.

The chassis dynamometer roller(s) shall be clean, dry and free from foreign material that might cause tyre slippage.

2.4.1.2. Test room

The test room shall have a temperature set point of 25°C and shall not deviate by more than ±5 ºC during the test.

2.4.1.3. Cooling fan

When testing with a chassis dynamometer in the Alternative Method, the fan shall synchronise with the speed of the vehicle and follow the regional regulations in relation to the minimum requirements for the fan outlet and the maximum deviation from air velocity related to the driving velocity.

2.4.1.4. Soak and charge area

The temperature of the soak area shall be maintained at 25 °C ±5°C.

2.4.1.5. Required information

The manufacturer shall provide the responsible authority with the information required to conduct the test procedure as follows.

The manufacturer shall specify if a testing operation mode shall be set at vehicle level for performing the test.

The manufacturer shall provide the responsible authority with a list of the deactivated devices and justification for the deactivation.

The testing operation mode shall be approved by the responsible authority and the use of a testing operation mode shall be recorded.

The vehicle's testing operation mode shall not activate, modulate, delay or deactivate the operation of any part that affects the battery energy throughput under the test conditions except for the internal battery heating-cooling system and the eventual eco mode automatically activated at the end of the depleting phase. The manufacturer shall provide evidence to the responsible authority.

2.4.1.6. Required measurements

The test vehicle shall be instrumented with measurement devices for measuring the necessary input values for the UBE calculation (voltage and electrical current). The external equipment shall be powered by an external power supply. The discharge and charge energy shall be measured at the battery to avoid combined battery-inverter efficiency and energy losses. Instrumentation for this purpose shall be based on manufacturer specifications and demonstrated to the responsible authority.

As an alternative to use of voltage and current measurement devices, use of on-board measurement data is permissible if the accuracy and frequency of these data is demonstrated to the responsible authority to meet the minimum requirements for accuracy and frequency described in paragraph 1.2. of this annex.

The on-board measurement data of the voltage and current can be used during the in-service testing only when the accuracy and frequency of on-board measurement data is confirmed during the certification. Safe inspection points shall be made available for the direct measurement verification.

2.4.2. Test sequence

2.4.2.1. General

The test shall be carried out in accordance with paragraphs 2.4.2.4. to 2.4.2.11. of this annex, (see Figure A3/8 and Figure A3/9). The test shall be void if the break-off criterion is not reached or the battery temperature is outside the normal operating range specified by the manufacturer.

2.4.2.1.1. Breaks for the driver are permitted according to the regional regulations if available. If no regulations for HDV dynamometer testing are in place, breaks for the driver are permitted as prescribed below for the transient speed test or the shortened test and in Table A3/6a or A3/6b for the constant speed test.

For the transient speed test, unless otherwise specified, the vehicle is allowed to stop once every 4 test cycles, the time should not exceed 10 minutes. During the stop the vehicle shall be in the "OFF" state, the test fan shall be turned-off, the brake pedal shall be released, and the battery cannot be charged using an external power source.

In the case that the test is performed using the shortened test method the breaks for the driver and/or operator are permitted only in the constant speed segments, as prescribed in Table A3/6a in relation to the driven distance or Table A3/6b in relation to the driving time.

For the constant speed test, unless otherwise specified, the vehicle is allowed to stop as prescribed in Table A3/6a in relation to the driven distance or Table A3/6b in relation to the driving time.

The minimum and maximum average temperature of the battery (all of the REESS) during the driver's break shall have a difference of less than 14°C. If this condition is not met the test shall be repeated.

Table A3/6a
Breaks for the driver based on distance: for constant speed test

Distance driven in constant speed (km)	*Maximum total break (min)*
Up to 100	10
Up to 150	20
Up to 200	30
Up to 300	60
More than 300	Shall be based on the manufacturer's recommendation

Note: During a break, the powertrain shall be switched off.

Table A3/6b
Breaks for the driver based on time: for constant speed test

Driving time (h)	*Maximum total break (min)*
every each 1h	10
More than 4h	Shall be based on the manufacturer's recommendation or regional authority

Note: During a break, the powertrain shall be switched off.

2.4.2.1.2. The following operational metrics shall be monitored and recorded throughout the test in order to support the verification of the conditioning of the battery, if needed:

(a) battery temperature (minimum, maximum, as indicated by the temperature of the battery cells, modules, or pack, as available);

(b) battery state of charge (SOC) (from BMS and dashboard);

(c) battery conditioning on/off, as available.

The manufacturer shall specify the normal operating range for the battery temperature.

2.4.2.2. Preparation of vehicle

The vehicle shall be presented in good technical condition and shall be run-in in accordance with the manufacturer's recommendations.

HD-PEVs and HD-OVC-HEVs shall have been run-in at least 300 km or one full charge distance, whichever is longer.

In the case of in-service conformity check, the vehicle shall be subject to the acceptance check criteria defined in Annex 1 of this GTR.

2.4.2.3. Preparation of measurement devices

The measurement devices shall be installed at suitable and safe position(s) within the vehicle. The manufacturer shall recommend the measurement points with the approval of the responsible authority and with appropriate technical justification.

2.4.2.4. Initial setting of the battery

Prior to or during vehicle soak (paragraphs 2.4.2.5. and 2.4.2.6. of this annex), the battery shall be charged/discharged to an initial state of charge (SOC), as displayed on the monitor of the vehicle, less than or equal to 10 per cent. At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may specify a different initial SOC of the battery.

The battery shall be charged/discharged to the initial SOC in accordance with the procedure specified by the manufacturer.

2.4.2.5. Vehicle installation and pre-conditioning

The vehicle and the charging station shall be installed for the preconditioning, if the battery discharge will be performed by driving in a test room.

The battery of the vehicle shall be discharged, left stabilised for no less than 30 minutes and no more than 1 hour and then fully charged at a power less than or equal to the manufacturer's recommendation for normal charging before starting the test as specified in Figure A3/9.

The manufacturer may recommend a longer stabilisation time if necessary to ensure stabilisation of the high voltage battery.

This first battery discharge, referred to as pre-conditioning, shall be performed according to manufacturer's recommendation or given speed within the range of the characteristic regional speeds and payload, without requirements on the ambient temperature.

The manufacturer shall guarantee that the battery is as fully depleted as possible using the discharge test procedure.

During the discharge of the battery, the operational metrics (see paragraph 2.4.2.1.2. of this annex) shall be recorded if required.

2.4.2.6. Vehicle soak and charge

The soak and charge is performed in the soak area or test room if available.

If the soak and charge is performed in a soak area or test room the soak area temperature during soak shall be as specified in paragraph 2.4.1.4. of this annex.

Recording the energy consumption for all the soak and charge duration is required.

If the soak and charge is not performed in a soak area, external devices that control battery temperature, different from charging stations, are not allowed.

The external equipment such as the charging station shall be powered by an external power supply.

Measurement devices installed within the vehicle shall be warmed up as appropriate.

The measurement devices shall start collecting data.

The battery shall be fully charged at a power less than or equal to the manufacturer's recommendation for normal charging.

Record the charge current and voltage and the elapsed time required to reach the fully charged battery status.

The vehicle shall be soaked and charged for a minimum of 6 hours and a maximum of 36 hours to ensure temperature stabilisation of the high voltage battery.

The manufacturer may recommend a different minimum time for the soak and charge in agreement with the responsible authority.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

Fully charged battery status shall be reached. If the selected power charging does not allow the full charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges.

The temperature of the battery shall be checked before starting the test.

Thermal equilibration is reached if in the preceding 1 hour the deviations of the temperature of the battery are within a 7 °C range. If this condition is not met the soak and charge shall be repeated.

If the soak and charge is performed in a soak area, the vehicle shall not receive unjustified exposure to temperatures other than 25 °C ±5 °C If unavoidable, the time of exposure shall be limited to a maximum of 10 minutes for each exposure.

It is allowed to monitor the operating metrics and perform additional conditioning as necessary in order to maintain the operating metrics within the normal operating ranges.

2.4.2.7. Discharge test cycle

The Contracting Party shall determine the combination of the test cycle according to the regional regulations.

2.4.2.8. Test method for HD-PEVs

2.4.2.8.1. The constant velocity method test

The velocity and test cycle and payload shall be determined in agreement with the responsible authorities.

The constant driving speed shall be related to the vehicle category and characteristic regional speeds. The vehicle mass including the payload and trailer if applicable shall not exceed 90 percent of GVM or GTM. During the test, the speed may be controlled manually or by cruise control system if available. The speed deviation shall be controlled in the range of ± 3 km/h.

2.4.2.8.2. The transient cycle method test

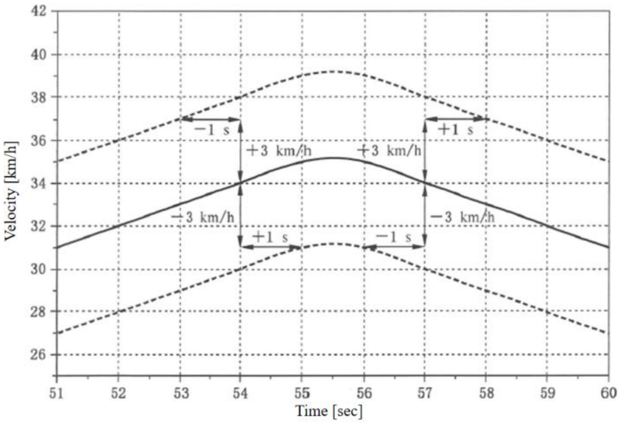
The cycle and payload shall be determined in agreement with the local authorities and according to the regional regulations. The vehicle mass including the payload and trailer if applicable shall not exceed 90 percent of GVM or GTM.

As an example, this could be by referring to the Title 40 of the US Code of Federal Regulation, to the China stage 3 and 4 vehicle tests for fuel consumption determination, to Regulation (EU) 2017/2400, or to other regional requirements.

Different test cycles shall be used according to the vehicle type. The tolerance on the speed, time and the total deviation time of each cycle are determined according to regional regulations.

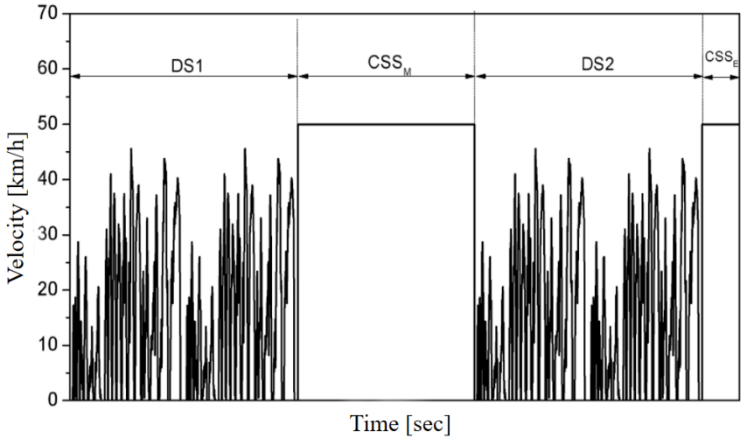
For example, the tolerance of each point of the speed may be ±3km/h, of the time may be ±1s, and the total deviation time of each cycle may not exceed 15s, as shown in Figure A3/5.

Figure A3/5
Example, reference curve and tolerance



2.4.2.8.3. Shortened test method

Figure A3/6
Shortened test method



The test cycle for the shortened test method is shown in Figure A3/6. The test condition consists of two dynamic test cycle segments (DS1 and DS2) and two constant speed segments (Constant Speed Segment Middle (CSS_M) and Constant Speed Segment End (CSS_E)). The constant speed section can be carried out at a higher speed to discharge the battery faster and reduce the test time. The constant speed is selected in accordance with the vehicle category and characteristic regional speeds and regional regulations. The vehicle mass including the payload and trailer if applicable shall not exceed 90 percent of GVM or GTM.

The same regional characteristic vehicle speed used for certification may be used if applicable, and in accordance with regional provisions, unless there is an agreement between the regional authority and the manufacturer.

At the request of the manufacturer and with approval of the responsible authority, a higher constant speed in the constant speed segments may be selected.

The transient cycle (DS1 and DS2) and the two constant velocity segments and the length of the constant speed segments shall be defined in agreement with the responsible authority and regional regulations.

2.4.2.8.4. Test termination for HD-PEVs

The end of discharge criterion is reached when the break-off criterion is met.

The equivalence with the certification test method and break-off criterion shall be demonstrated to the responsible authority.

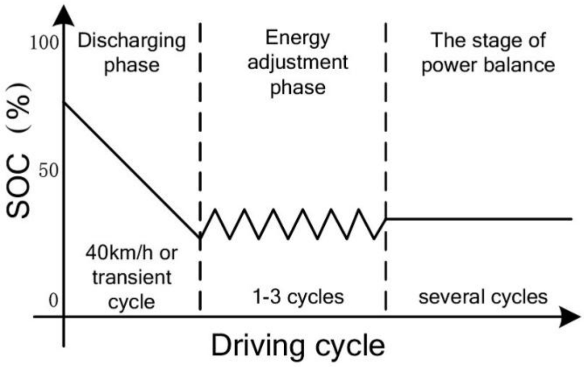
The break-off criterion is reached when the vehicle exceeds the driving speed tolerance for 4 consecutive seconds or more. The accelerator control shall be deactivated and the vehicle shall be braked to standstill within 60 seconds after the break-off is reached.

The manufacturer shall provide evidence to the responsible authority after the test that this requirement is fulfilled.

2.4.2.9. Test method for HD-OVC-HEVs

Figure A3/7

Schematic diagram of state of charge (SOC) variation of heavy-duty hybrid electric vehicle



2.4.2.9.1. The HD-OVC-HEV has three operation stages: discharging phase; energy adjustment phase; and the stage of electric power balance, as depicted in Figure A3/7. The UBE testing procedure shall be in phase 1 and phase 2.

The test cycle and payload shall be determined in agreement with the responsible authorities and according to the regional regulations. The vehicle mass including the payload and trailer if applicable shall not exceed 90 percent of GVM or GTM.

2.4.2.9.2. Test termination for HD-OVC-HEVs

The end of discharge criterion is reached when the break-off criterion is met.

The equivalence with the certification test method and break-off criterion shall be demonstrated to the responsible authority.

The break-off criterion is reached, for the constant velocity method test and for the transient cycle method test, when in the last part of the test over a distance Δkm equivalent to 5 per cent of the total available energy of the battery, the $|\Delta E_{REESS,\Delta km}|/\Delta km$ is equal to or less than 3 per cent of the cumulative UBE/(total distance travelled - Δkm) (energy consumption before the last Δkm).

$$\frac{\Delta E_{REESS,\Delta km}}{\Delta km} \leq 3\% \ \frac{UBE_{cumulative}}{total\ distance - \Delta km}$$

where:

Δkm	distance in the last part of the test equivalent to 5 per cent of the total available energy of the battery
$\Delta E_{REESS,\Delta km}$	is the measured electric energy change of the battery, over the distance Δkm, defined as $\sum_{i=1}^{n} \Delta E_{REESS,i,\Delta km}$, Wh

$\Delta E_{REESS,i,\Delta km}$ is the measured electric energy change of battery i, over the distance Δkm, Wh;

i is the index number of the considered battery;

n is the total number of batteries;

and:

$$\Delta E_{REESS,i,\Delta km} = \frac{1}{3600} \times \int_{t_{0,\Delta km}}^{t_{end,\Delta km}} U(t)_{REESS,i} \times I(t)_{REESS,i}\, dt$$

where:

$U(t)_{REESS,i}$ is the voltage of battery i, V;

$I(t)_{REESS,i}$ is the electric current of battery i, A;

$t_{0,\Delta km}$ is the starting time of the driving of the Δkm portion of the test, s;

$t_{end,\Delta km}$ is the end time of the driving of the Δkm portion of the test, s;

$\frac{1}{3600}$ is the conversion factor from Ws to Wh;

$UBE_{cumulative}$ is the usable battery energy (UBE) ,Wh, calculated as $\sum_{i=1}^{n} \Delta E_{REESS,i,total\ distance-\Delta km}$ defined as

$$\Delta E_{REESS,i,total\ distance-\Delta km} = \frac{1}{3600} \times \int_{t_0}^{t_{0,\Delta km}} U(t)_{REESS,i} \times I(t)_{REESS,i}\, dt$$

where

t_0 is the time at the beginning of the discharge test, s.

The UBE is calculated over the total distance travelled, including the distance Δkm.

For the transient cycle method test, according to regional regulation a Contracting Party may elect to enforce that the break-off criterion is reached when $REEC_i$, as calculated using the following equation, is less than 5 per cent.

$$REEC_i = \frac{\left|\Delta E_{REESS,i}\right|}{E_{cycle} \times \frac{1}{3600}}$$

where:

$REEC_i$ is the relative electric energy change of the applicable test cycle considered i of the charge-depleting test;

$\Delta E_{REESS,i}$ is the change of electric energy of all REESSs for the considered charge-depleting test cycle i calculated according to paragraph 3. of this annex, Wh;

E_{cycle} is the total cycle energy demand E in Ws, and shall be calculated by summing E_i over the corresponding cycle time between t_{start} and t_{end} according to regional regulations and the following equation:

$$E = \sum_{t_{start}}^{t_{end}} E_i$$

i is the index number for the considered applicable WLTP test cycle;

$\frac{1}{3600}$ is a conversion factor to Wh for the cycle energy demand.

t_{start}	is the time at which the applicable test cycle or phase starts, s;
t_{end}	is the time at which the applicable test cycle or phase ends, s;
E_i	is the energy demand during time period (i-1) to (i), Ws, calculated according to regional regulations.

The manufacturer shall provide evidence to the responsible authority after the test that this requirement is fulfilled.

2.4.2.10. For both HD-PEVs and HD-OVC-HEVs the UBE is the total discharged energy calculated as described in paragraph 3. of this annex.

The vehicle shall be connected to a charging station within 120 minutes after coming to a standstill, if required.

The battery shall be fully charged, if required, at a power less than or equal to the manufacturer's recommendation for normal charging.

The end of charge criterion is reached when a fully charged battery is detected by the on-board or external instruments.

If the selected power charging does not allow the fully charged status of the battery to be reached automatically due to battery protection systems, it is allowed to complete the charging by applying a slower charging method, unplugging and then plugging in again the vehicle if needed, either with or without a waiting time between the two charges.

In the case that UBE_{charge} is required, the total charged energy is calculated as described in paragraph 3. of this annex.

The Alternative Method is performed on new vehicles within a family, if the measurement of the UBE is applied at certification, to determine the $UBE_{certified}$.

The Alternative Method is performed on aged vehicles within a family, if applicable, to determine the $UBE_{measured}$.

The $SOCE_{measured}$ is derived according to paragraph 6.3.2. of this GTR.

2.4.2.11. End of Alternative Test Method

At the end of the Alternative Method test, the measured values and the operational metrics (see paragraph 2.4.2.1.2. of this annex) shall be recorded.

After the measurements are complete, the vehicle and measurement devices shall be stopped.

Figure A3/8
Test sequence Alternative Method

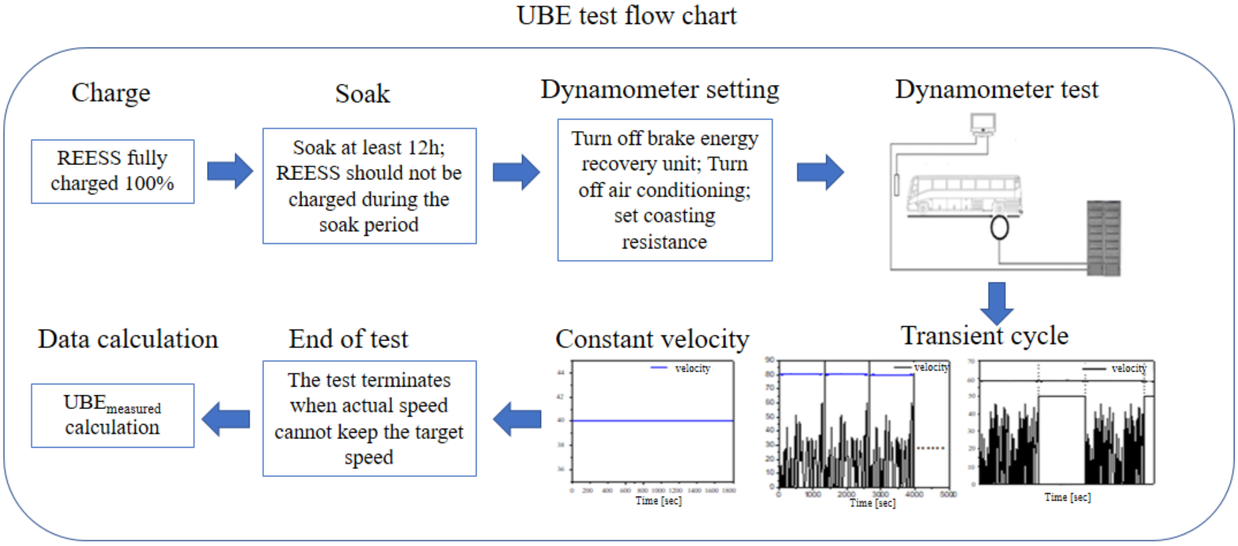
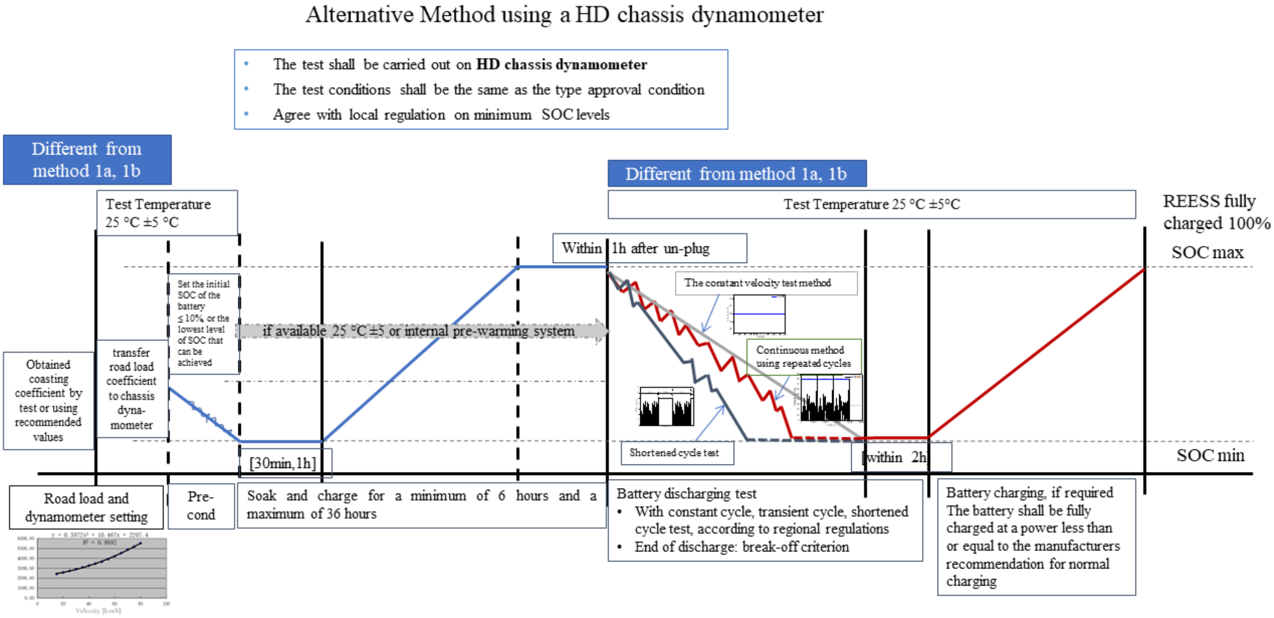


Figure A3/9
Test sequence Alternative Method using HD chassis dynamometer



3. Performance parameters

3.1. Measured and certified UBE values

3.1.1. Method 1a, Method 1b and Method 2 for HD-PEVs, Method 2 for HD-OVC-HEVs and Alternative Method for HD-PEVs

Parameters	Explanation
$UBE_{certified}$	$UBE_{certified}$ is the usable battery energy (UBE) of the vehicle at the point of certification.
$UBE_{measured}$	$UBE_{measured}$ is the usable battery energy (UBE) of the vehicle determined at Part A verification by the test procedure
	The required input parameter UBE is calculated as follows: $$\mathrm{UBE} = \sum_{i=1}^{n} \Delta E_{REESS,i}$$ where: $\Delta E_{REESS,i}$ is the measured electric energy change of battery i, Wh; i is the index number of the considered battery; n is the total number of batteries; and: $$\Delta E_{REESS,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,i} \times I(t)_{REESS,i}\, dt$$ where: $U(t)_{REESS,i}$ is the voltage of battery i, V; $I(t)_{REESS,i}$ is the electric current of battery i, A; t_0 is the time at the beginning of the discharge test, s; t_{end} is the time at the end of the discharge test (break-off criterion), s; $\frac{1}{3600}$ is the conversion factor from Ws to Wh.
No rounding shall be applied on $UBE_{measured}$. $UBE_{certified}$ shall be rounded according to paragraph 7 of this GTR: - To the nearest whole number if the unit is Wh - To three significant numbers if the unit is kWh	

3.1.2. Method 1a, Method 1b and Alternative Method for HD-OVC-HEVs

<table>
<tr><th>Parameters</th><th>Explanation</th></tr>
<tr><td>$UBE_{certified}$</td><td>$UBE_{certified}$ is the usable battery energy (UBE) of the vehicle at the point of certification.</td></tr>
<tr><td>$UBE_{measured}$</td><td>$UBE_{measured}$ is the usable battery energy (UBE) of the vehicle determined at Part A verification by the test procedure</td></tr>
<tr><td></td><td>The required input parameter UBE is calculated as follows:

$$UBE = \sum_{i=1}^{n} \Delta E_{REESS,i}$$

where:
$\Delta E_{REESS,i}$ is the measured electric energy change of battery i, Wh;
i is the index number of the considered battery;
n is the total number of batteries;
and:

$$\Delta E_{REESS,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,i} \times I(t)_{REESS,i}\, dt$$

where:
$U(t)_{REESS,i}$ is the voltage of battery i, V;
$I(t)_{REESS,i}$ is the electric current of battery i, A;
t_0 is the time at the beginning of the charge-depleting test, s;
t_{end} is the time at the end of the stage of power balance of the charge-depleting test where break-off criterion was reached for the first time, s;
$\frac{1}{3600}$ is the conversion factor from Ws to Wh.</td></tr>
<tr><td colspan="2">No rounding shall be applied on $UBE_{measured}$.
$UBE_{certified}$ shall be rounded according to paragraph 7 of this GTR:
- To the nearest whole number if the unit is Wh
- To three significant numbers if the unit is kWh</td></tr>
</table>

3.1.3. UBE_{charge}

<table>
<tr><th>Parameters</th><th>Explanation</th></tr>
<tr><td>UBE_{charge}</td><td>The required input parameter UBE_{charge} is calculated as follows:
$$UBE_{charge} = \sum_{i=1}^{n} \Delta E_{REESS,i}$$
where:
$\Delta E_{REESS,i}$ is the measured electric energy change of battery i, Wh;
i is the index number of the considered battery;
n is the total number of batteries;
and:
$$\Delta E_{REESS,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,i} \times I(t)_{REESS,i}\, dt$$
where:
$U(t)_{REESS,i}$ is the voltage of battery i, V;
$I(t)_{REESS,i}$ is the electric current of battery i, A;
t_0 is the time at the beginning of the charge test, s;
t_{end} is the time at the end of the charge test, s;
$\frac{1}{3600}$ is the conversion factor from Ws to Wh.</td></tr>
<tr><td colspan="2">No rounding shall be applied on UBE_{charge}.</td></tr>
</table>

Annex 4

Battery Energy based (SOCE) minimum performance requirements (optional annex)

This optional annex includes the Minimum Performance Requirements (MPR), which a Contracting Party may elect to enforce for conforming to the requirements of this GTR (see paragraph 5.2. of this GTR).

The energy-throughput, the total amount of energy in kWh discharged from the battery, will be monitored during phase 1 of this GTR in view of a future revision of the lifetime thresholds (years, km, kWh) for confirming the compliance with the minimum performance requirements.

Table A4/1
Battery Energy based (SOCE) MPR for Category 2 vehicles not exceeding 16 tonnes

	*Battery energy based MPR for **Category 2 vehicles not exceeding 16 tonnes***	*HD-OVC-HEV*	*HD-PEV*
Metric	From start of life to years or km, whichever comes first		
A	6 yr, 150 000 km	70%	70%
B	8 yr, 300 000 km	70%	70%
C	8 yr, 400 000 km	70%	70%
D	10 yr, 375 000 km	65%	65%

Table A4/2
Battery Energy based (SOCE) MPR for Category 2 vehicles exceeding 16 tonnes

	*Battery energy based MPR for **Category 2 vehicles exceeding 16 tonnes***	*HD-OVC-HEV*	*HD-PEV*
Metric	From start of life to years or km, whichever comes first		
E	6 yr, 150 000 km	70%	70%
F	8 yr, 600 000 km	70%	70%
G	12 yr, 700 000 km	55%	55%
H	15 yr, 875 000 km	50%	50%

Table A4/3

Battery Energy based (SOCE) MPR for Category 1-2 vehicle not exceeding 5 tonnes

	*Battery energy based MPR for **Category 1-2 vehicle not exceeding 5 tonnes***	*HD-OVC-HEV*	*HD-PEV*
Metric	From start of life to years or km, whichever comes first		
A	6 yr, 150 000 km	70%	70%
B	8 yr, 160 000 km	65%	65%
C	8 yr, 300 000 km	70%	70%
D	10 yr, 200 000 km	60%	60%

Table A4/4

Battery Energy based (SOCE) MPR for Category 1-2 vehicle exceeding 5 tonnes but not exceeding 7.5 tonnes

	*Battery energy based MPR for **Category 1-2 vehicle exceeding 5 tonnes but not exceeding 7.5 tonnes***	*HD-OVC-HEV*	*HD-PEV*
Metric	From start of life to years or km, whichever comes first		
E	6 yr, 150 000 km	70%	70%
F	8 yr, 300 000 km	65%	65%
G	8 yr, 500 000 km	70%	70%
H	10 yr, 375 000 km	60%	60%

Table A4/5

Battery Energy based (SOCE) MPR for Category 1-2 vehicle exceeding 7.5 tonnes

	*Battery energy based MPR for **Category 1-2 vehicle exceeding 7.5 tonnes***	*HD-OVC-HEV*	*HD-PEV*
Metric	From start of life to years or km, whichever comes first		
I	6 yr, 150 000km	70%	70%
J	8 yr, 600 000 km	70%	70%
K	12 yr, 700 000km	50%	50%
P	15 yr, 875 000km	45%	45%

Annex 5

Power to operate the vehicle auxiliary systems/accessory loads

In the case in which the total propulsion energy does not include the accessory loads, some typical default values can be added to the total propulsion energy, following the recommendations in the table below or those in regional regulations, with the agreement of the responsible authority. On the request of the manufacturer and in agreement with the responsible authority it is also allowed as an option to measure the accessory loads.

Table A5/1
Vehicle auxiliary systems/accessory loads typical default power values

Vehicle Category	Power (W)
Category 2, <16 tonnes with hydraulic or electric brake system	900
Category 2, <16 tonnes with pneumatic brake system	1,600
Category 2, >16 tonnes	2,300
Category 1-2, <5 tonnes	[Reserved]
Category 1-2, <7.5 tonnes	[Reserved]
Category 1-2, >7.5 tonnes	[Reserved]