Heavy-duty industry adaptation of gtr22 on in-vehicle battery durability

EVE IWG - Session 63

-online-

July 18th, 2023

POSITION ON VIRTUAL MILEAGE

Based on real-world data, we request EVE IWG to rethink the virtual mileage proposal and to consider energy throughput as additional lifetime requirement.

- e-HDVs GTR: V2X, PTO, …

$$\boldsymbol{Virtual\ km(V2X+PTO+\cdots)} = Odometer\ km \times \left(\frac{total\ discharge\ energy\ during\ V2X+PTO+\cdots\ [Wh]}{total\ discharge\ energy\ while\ driving\ [Wh]}\right)$$

$$\text{Total distance km} = \text{Odometer km} + \text{virtual km}$$

- Requires two counters: Total discharge energy while driving or total discharge energy during V2X+ PTO+.., etc.
- Counts all energy usage i.e., while parked and extreme use cases
- ***As per GTR 22 the total distance used for confirming the compliance with the minimum performance requirements will consist of the <u>sum of the distance driven and the virtual distance</u>****. The total percentage of the virtual distance shall be recorded and monitored.*

Considering the unique configurations and/or functionalities of HD vehicles:

1) **Based on expert discussions and real-world data, it is not feasible to differentiate all the seperate electric vehicle-internal energy flows**
2) **OICA prefers to apply the whole battery energy/capacity throughput instead of mileage for MPR criteria.**

POSITION ON VIRTUAL MILEAGE

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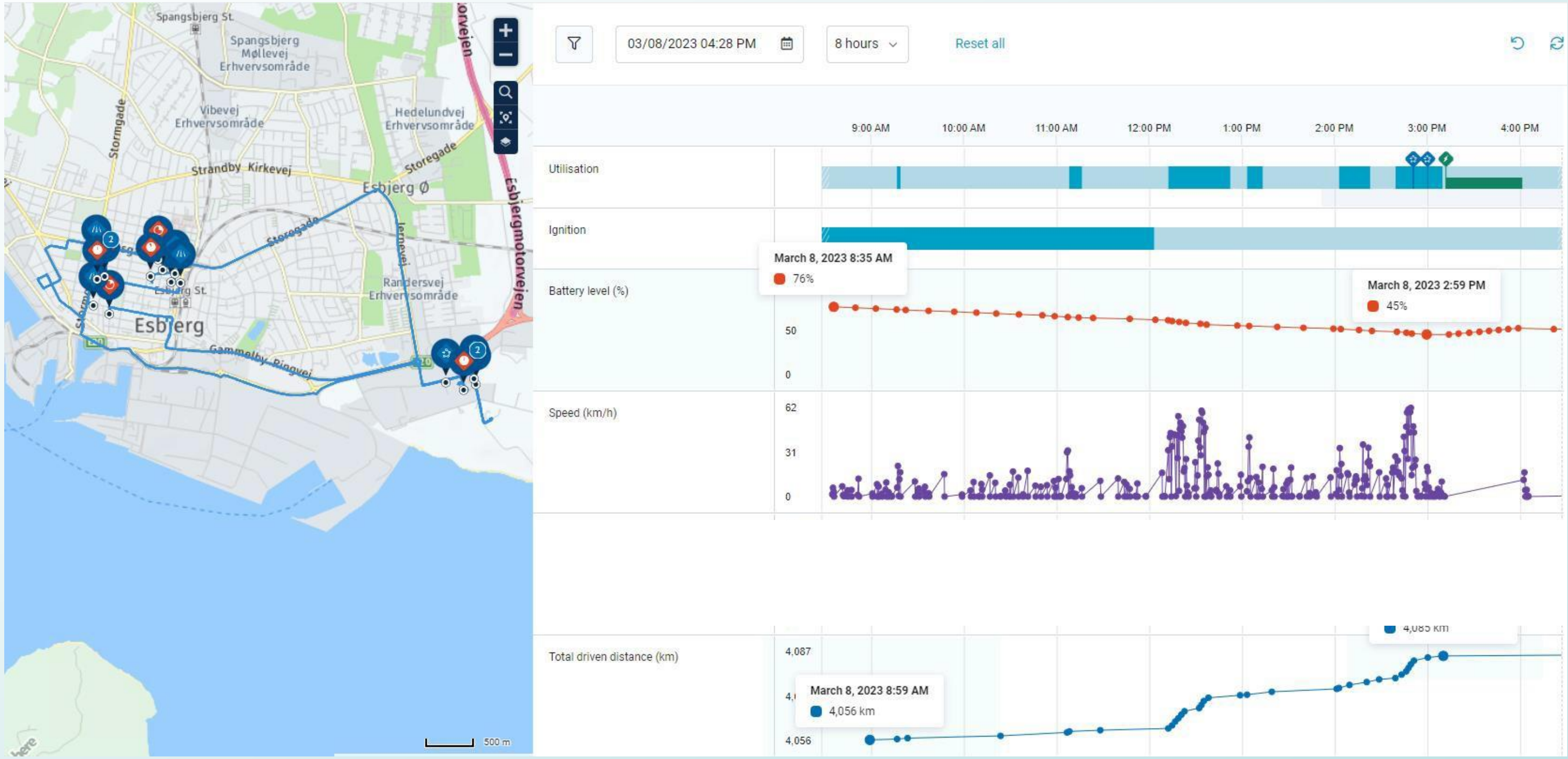
EXAMPLE: EV MUNICIPAL UTILITY

<u>Vehicle:</u>

- **Electric HDV**
- **4x2 rigid, 32t**
- **Municipal utility**
- **Full electric Powertrian (Battery: 300 kWh, Engine: 300 kW Pcont)**



Take aways

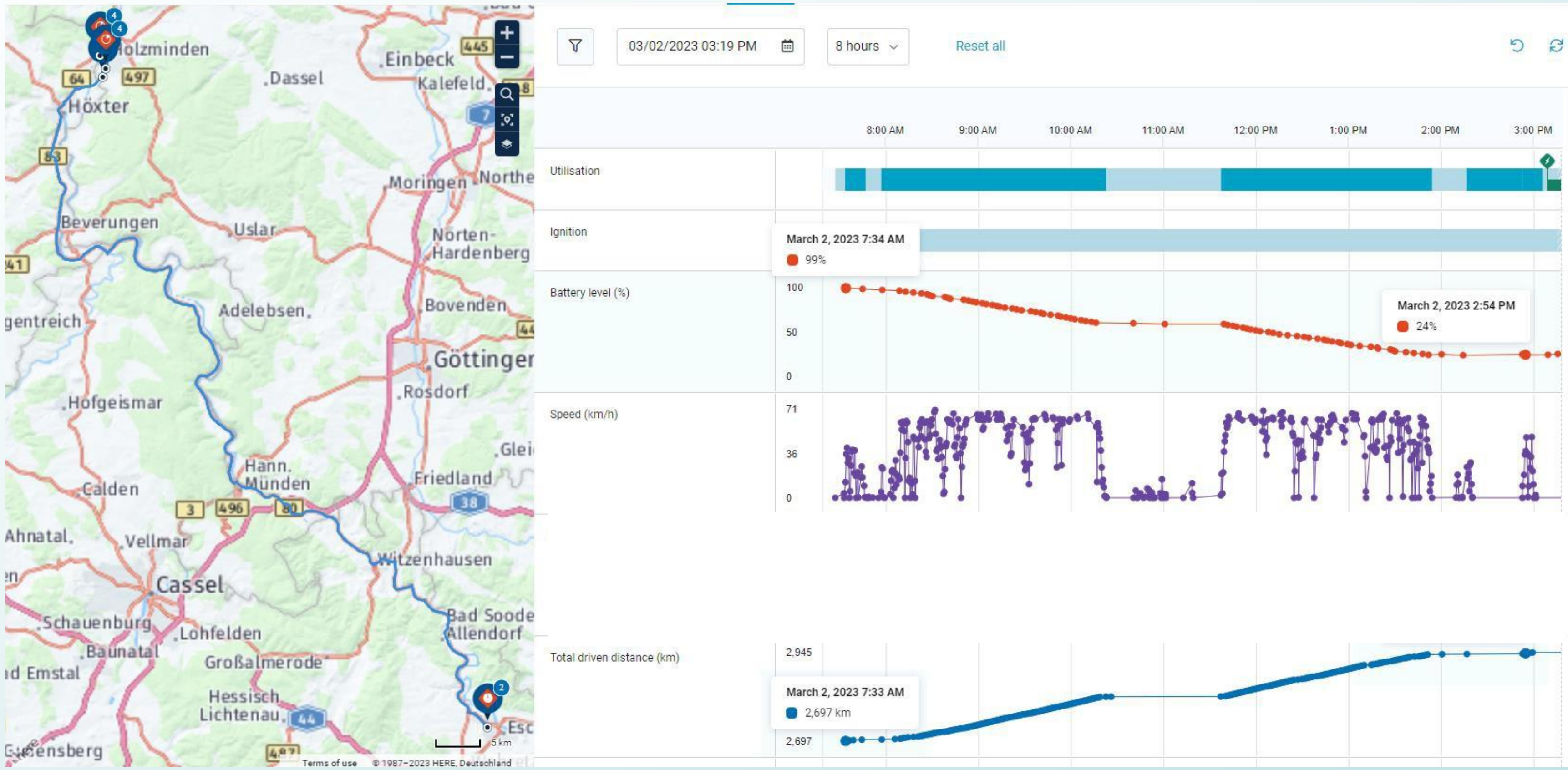
- Mileage: **29km**
- Vaverage: **15 km/h**
- Duration: **4,5h**
- DoD: **31% (76%-45%)**

- Specific DoD: **3kWh/km**

EXAMPLE: EV LONG-HAUL & REGIONAL DELIVERY

Vehicle:

- **Electric HDV**
- **4x2 rigid, 40t**
- **Long-Haul & Regional Delivery**
- **Full electric Powertrian (Battery: 300 kWh, Engine: 400 kW Pcont**)



Take aways

- Mileage: **245km**
- Vaverage: **65 km/h**
- Duration: **5,5h**
- DoD: **75% (99%-24%)**

- Specific DoD: **1kWh/km**

EXAMPLE: DIESEL MUNICIPAL UTILITY & LONG-HAUL

Vehicle:
- Diesel HDV
- 4x2 rigid, 32t
- Municipal utility
- 78h PTO operation @709km
- 3 PTOs in total installed
- FC: 171 l/100km

Verbrauchswerte	
Gesamtverbrauch **1.218,4 l**	Fahrverbrauch **339,9 l**
ø Gesamtverbrauch **171,80 l/100km**	ø Fahrverbrauch **47,93 l/100km**
Einsatzmerkmale	
Fahrstrecke **709,2 km**	ø Gewicht **31 t**
Anteil > 85 km/h an Fahrstrecke **0,0 % (0,0 km)**	Betriebsbremsweg/Fahrstrecke **4,7 % (33,5 km)**
Fahrzeit **22:35:47 (hh:mm:ss)**	Standzeit laufender Motor **78:25:48 (hh:mm:ss)**
1. Nebenabtrieb **74:17:04 (hh:mm:ss)**	2. Nebenabtrieb **00:00:00 (hh:mm:ss)**

Vehicle:
- Diesel HDV
- 4x2 tractor, 40t
- Long-Haul
- No PTO operation
- No PTOs in total installed
- FC: 24,5 l/100km

Verbrauchswerte	
Gesamtverbrauch **2.675,4 l**	Fahrverbrauch **2.650,6 l**
ø Gesamtverbrauch **24,54 l/100km**	ø Fahrverbrauch **24,32 l/100km**
Einsatzmerkmale	
Fahrstrecke **10.900,7 km**	ø Gewicht **21 t**
Anteil > 85 km/h an Fahrstrecke **24,9 % (2.718,6 km)**	Betriebsbremsweg/Fahrstrecke **1,2 % (133,6 km)**
Fahrzeit **155:55:35 (hh:mm:ss)**	Standzeit laufender Motor **16:12:27 (hh:mm:ss)**
1. Nebenabtrieb **00:00:00 (hh:mm:ss)**	2. Nebenabtrieb **00:00:00 (hh:mm:ss)**

Take aways

- Mileage: **709km vs. 10900 km**
- PTO: **78h vs. 0h**
- FC: **171 l/100km vs. 24.5 l/100km**
- Duration: **96hrs vs. 155hrs**
- Time specific PTO operation: **81% vs. 0%**

POSITION ON VIRTUAL MILEAGE

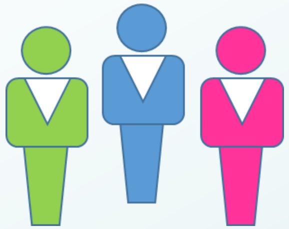
Considering the unique configurations and/or functionalities of HD vehicles:

1) **Based on expert discussions and real-world data, it is not feasible to differentiate all the seperate electric vehicle-internal energy flows**

2) **OICA prefers to apply the whole battery energy/capacity throughput instead of mileage for MPR criteria.**

BEST SOLUTION COUNTS AND NOT ONE FITS ALL

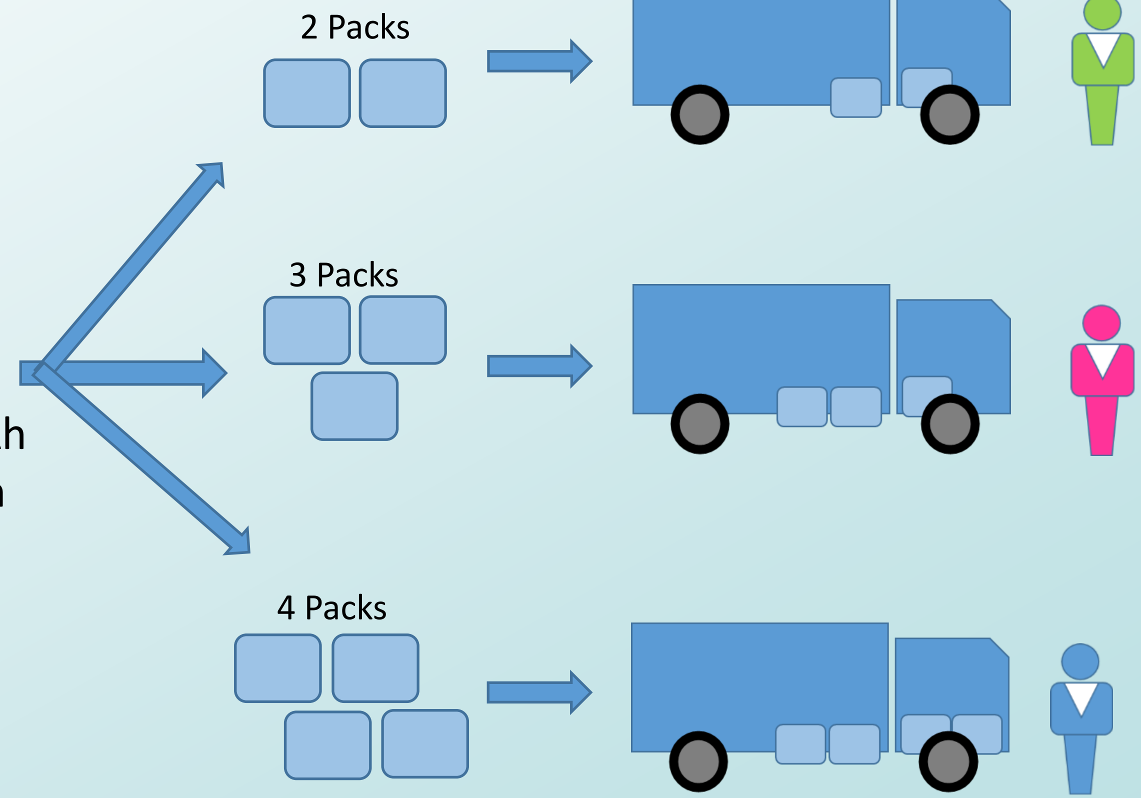
Customer interests:



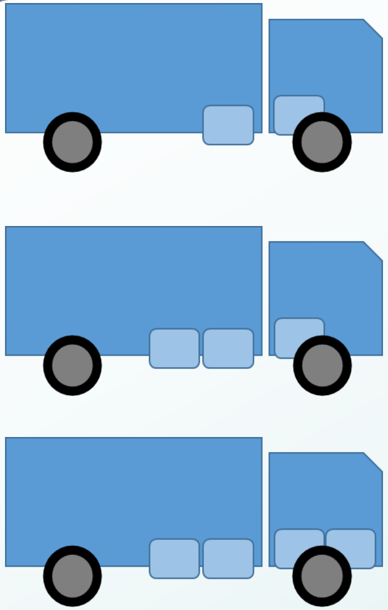
- Daily range
- Payload
- Product cost

Batterie Pack:
Nominal Voltage: 670 V
Nominal Capacity: 130 Ah
Nominal Energy: 87 kWh

Modular multi-pack configuration



RANGE IS NOT A VALID LIFETIME CRITERIA FOR IN VEHICLE BATTERIES



Range criteria: 700.000 km

Assumption: Energy consumption of the vehicle 1 kWh/km (flat test track, no hills!)

Total energy consumption of the vehicle 700.000 kWh

Energy provided **per Pack**:

2 Pack conf.:
700.000kWh/2 = 350 MWh

3 Pack conf.:
700.000kWh/3 = 233 MWh

4 Pack conf.:
700.000kWh/4 = 175 MWh

Battery Pack:
Nominal Voltage: 670 V
Nominal Capacity: 130 Ah
Nominal Energy: 87 kWh

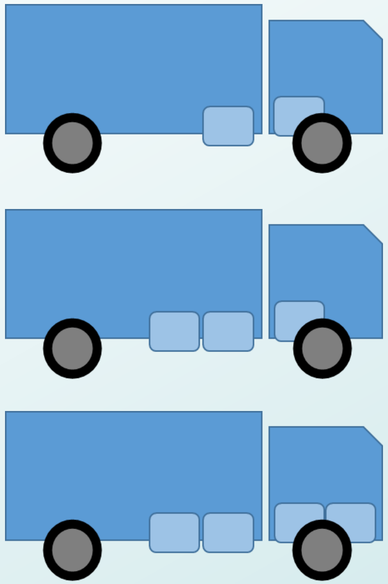
Vehicle range based counter index for in vehicle battery durability **leads to different durability criteria** for **identical battery packs**. This would lead to a decreasing number of customer options and would favor cost intensive vehicle configurations.
Energy throughput based on installed Battery energy expressed by **Full cycle equivalent** FCE is an appropriate criteria.

NUMBER OF FULL CHARGING CYCLES IS A VALID LIFETIME CRITERIA FOR BATTERIES

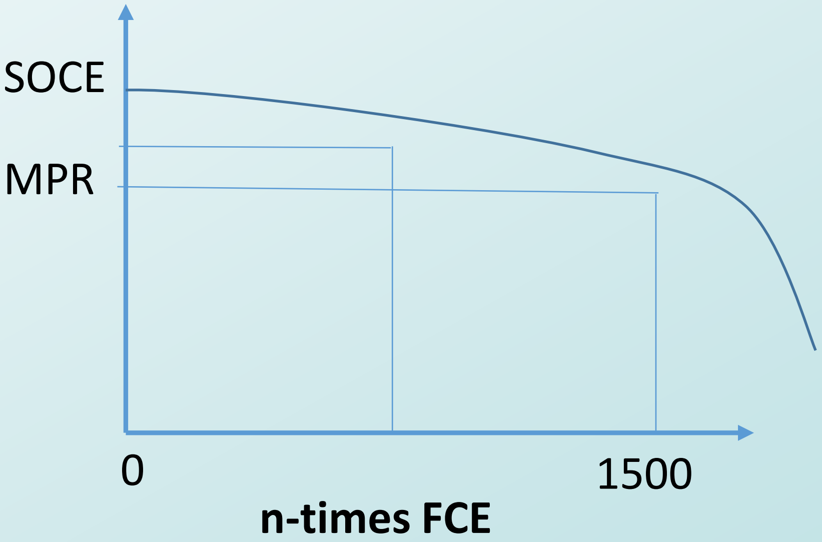
Batterie Pack:
Nominal Voltage: 670 V
Nominal Capacity: 130 Ah
Nominal Energy: 87 kWh

Parameters are clearly visible on the battery label

Lifetime criteria:
n-times Full Charging cycles
(e.g. 1500 cycles => 130 MWh)



On system or vehicle level:
n-times FCE (full cycle equivalent)



Number of full cycle equivalent n FCE is representing a lifetime criteria that takes the individual installed battery capacity or energy of the vehicle into account. For multi pack configurations, the lifetime requirement stays the same for each individual pack.

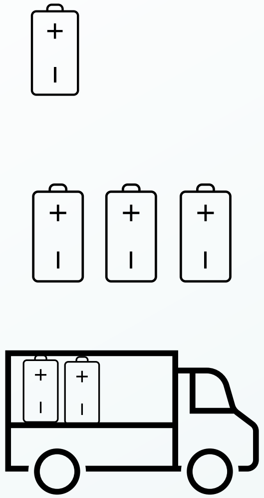
GENERAL CONCEPT

FUNDAMENTAL CHANGES COMPARED TO GTR N.22

- **The durability parameter is based on energy or capacity**
  - The durability parameter is based on UBE, but can be measured on UBC, where discharge measurement is not possible
    - Capacity can be measured directly.
    - Capacity could in a better way include all system variants for HDV – pack to multipack systems
    - Capacity can be measured directly where measuring of energy is more complex when considering system design and configuration
  - The internal certified current sensor of the REES shall be taken for the measurement.
    - No influence of PTOs → simple measurement → (in that case: no external device with additional inaccuracies/ need for calibration)
    - Accuracy has to be proven by a certification/ reference measurement
- **Measurements based on charge or discharge events**
  - E.g.: UBE measurement based on discharge and/or charge event, UBC measurement based upon on charge event.
  - Simple measurement reduces failures
  - Less influencing factors compared to a driving based generic cycle
  - **Technology neutrality is important! A Bidi forced regulation will exclude vehicles without that technical functionality from scope!**
- **It *is* required to use the same test method for certification test and in-service test**
  - In-vehicle test for certification test and in-service test needed to ensure comparability of results!
  - influencing factors on test bench and in driving cycle very different
  - In-vehicle test for customer-oriented/ practical results

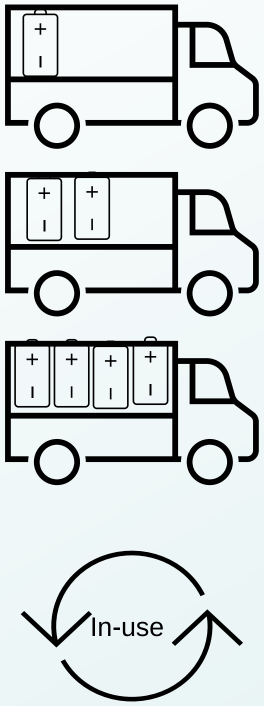
TEST PROCEDURE

Certification test



$\text{UBC/E}_{\text{certified}}$
Sensor
Counter

In-service verification test



$\text{UBC/E}_{\text{measured}}$

High variation of battery and battery systems for the HDV industry

- Same test method for certification test and in-service test to ensure comparability of results but adapted to the configuration
- HDV solution is modular and scalable which also needs to be reflected in the test method
- Upper and lower charge and discharge limits according to detailed technical description of manufacturer

TEST PROCEDURE DISCHARGE & CHARGE

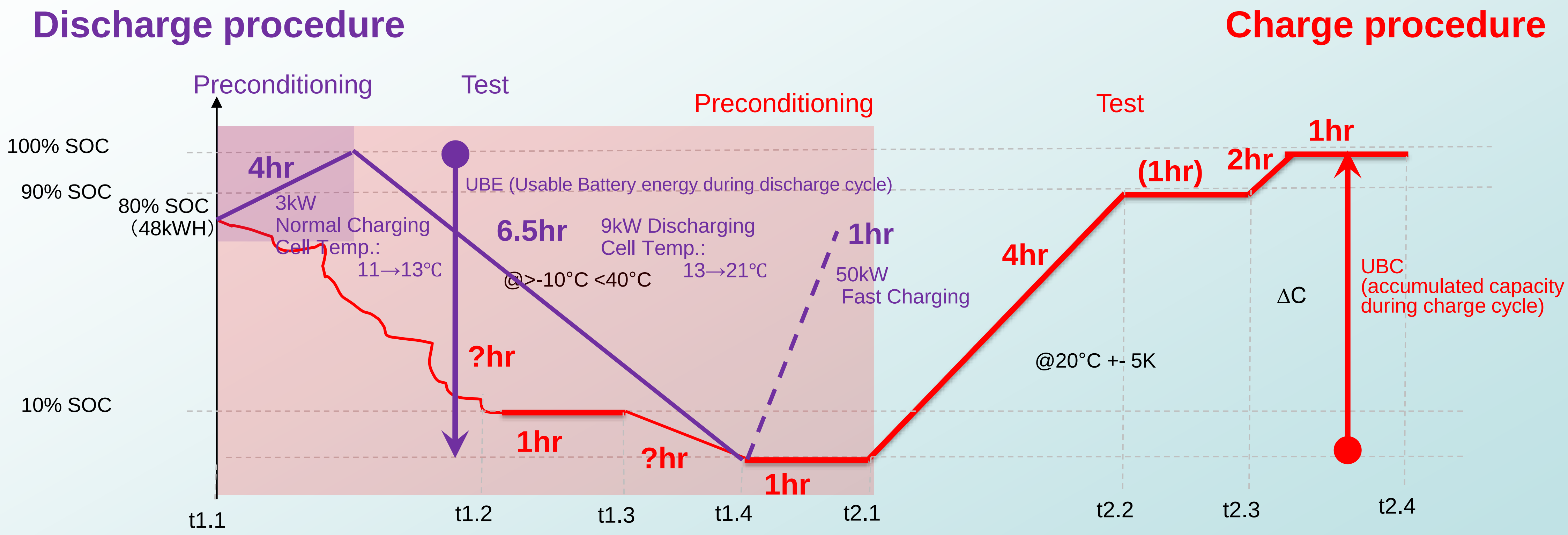
We are convinced that GTR22b shall give authorities and OEMs the **choice between two different procedures** (independend from vehicle weight or type):

- Charging as reference
- Discharging as reference

<u>Based on:</u>

- testing infrastructure and
- market specific boundary conditions

TEST PROCEDURE DISCHARGE & CHARGE



Test duration Discharge with 60 kWh: 4hr+6,5hr = ~11hr
Test duration Charge with 600 kWh: 4,5hr+1hr+8hr = ~13hr

COMPARING **SINGLE CELL VS. PACK VS. IN-VEHICLE DISCHARGE AND CHARGE** RESULTS, **EFFICIENCIES** ARE **ALMOST SAME**

Cell

Cell no. (SOH - EOL)	BOL [%]
1	99.91
2	99.9
3	99.89
4	99.89
5	99.9
6	99.85
7	99.79
8	99.88
9	99.76

Energy Efficienc
Energy **(Wh)**

BOL [%]	EOL [
96.56	
96.55	
96.51	
96.52	
96.47	
96.45	
96.39	
96.49	
96.22	

$\eta_{Coulomb}$ = 99,8 %
η_{Energy} = 96,5 %

Pack

	19.10.2022 discharge C/3 rate	19.10.2022 charge C/3 rate
SW	51223203	51223203
C_HV_Kenn [Ah]	273,13	272,16
E_HV_Kenn [kWh]	108,85	111,70
C_corr_SOC → 1,006		273,82
E_corr_SOC		112,37
BMS_SOC_min [%]	0,24	0,24
BMS_SOC_max [%]	99,44	98,85
I_HV_mid60s [A]	93,99	-93,98
BMS_I_HV_mid60s [A]	-94,16	94,25
Deviation I_HV BMS_I_HV [%]	-0,18	-0,29
SOC_min_DT_4_A1 [%]	0,97	0,97
SOC_min_DT_4_A2 [%]	0,97	0,99
SOC_max_DT_4_A1 [%]	99,20	98,94
SOC_max_DT_4_A2 [%]	99,42	99,13
C_HV_Kenn_Extrap_DT_4_A1 [Ah]	139,21	139,25
C_HV_Kenn_Extrap_DT_4_A2 [Ah]	139,07	139,17
SOH_min_OCV_DT_4_A1 [%]	98,73	98,76
SOH_min_OCV_DT_4_A2 [%]	98,63	98,70

$\eta_{Coulomb}$ = 99,8 %
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Vehicle

	EV 32t Long run In-Vehicle discharge		EV 32t Long run charge	
	07.12.22	**09.12.22**	**07.12.22**	**09.12.22**
C_HV [Ah]	773,12	763,1	776,17	755,49
C_HV_Bat [Ah]	257,71	254,37	258,72	251,83
BMS_SOC_min [%]	4,87	6,62	4,87	6,62
BMS_SOC_max [%]	97,045	97,05	97,01	96,74
E_HV [kWh]	307,21	303,75	320,2	314,84
E_HV_Bat [kWh]	102,40	101,25	106,73	104,95

Duration: 5h discharge, 30 min break, 5h charge @C/5 → ~11h

$\eta_{Coulomb}$ = 99,6 %
η_{Energy} = 96,0 %

Increasing measurement inaccuracy

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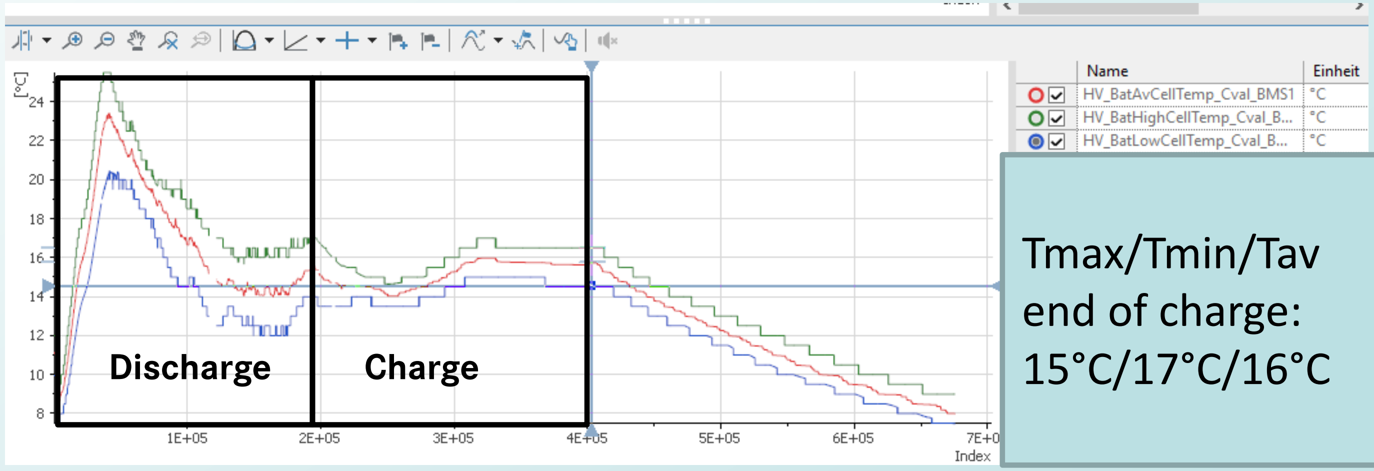
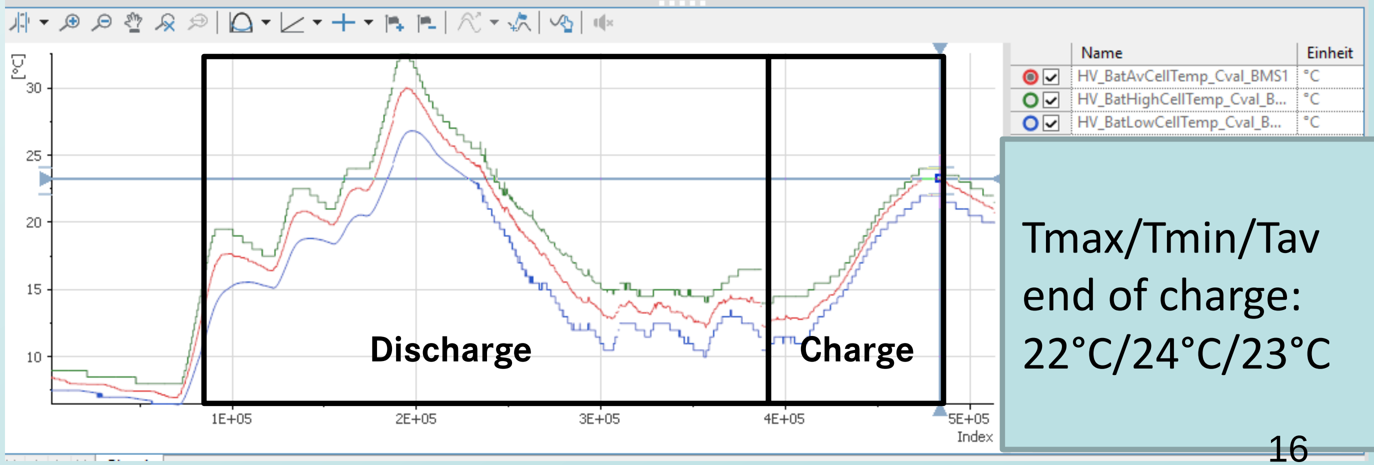
Increasing measurement inaccuracy

07.12.22, Tamb = 5°C, Idischarge,max=600A, Icharge=200A



Tmax/Tmin/Tav end of charge: 15°C/17°C/16°C

09.12.22 , Tamb = 5°C, Idischarge,max=600A, Icharge=400A

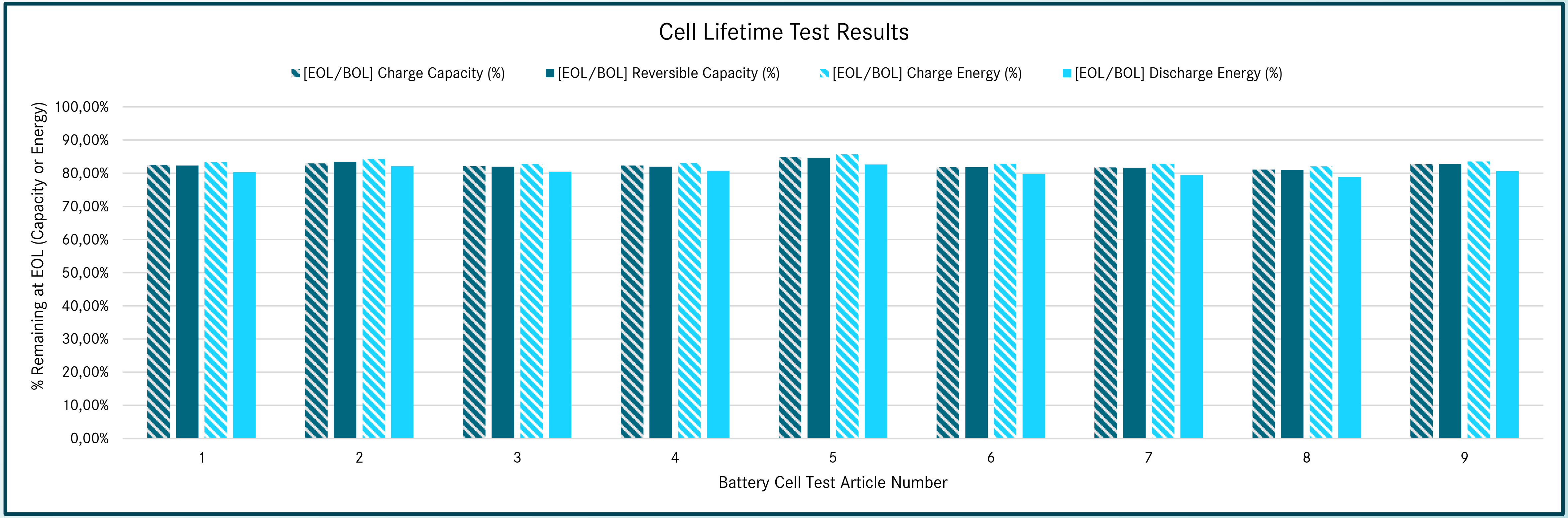


Tmax/Tmin/Tav end of charge: 22°C/24°C/23°C

CHARGE/DISCHARGE CAPACITY AND ENERGY TEST RESULTS CELL LIFETIME AT 80% SOH @PACK WITH MULTIPLE REPETITIONS SHOWS HIGH COMPARIBILITY

Test conditions:

- **Single component ex-vehicle test**
- Discharge rate (constant) – C/3
- Charge rate (constant) – [1] EOL making CCCV*: 1.2C → 0.87C → 0.33C → CV to 0.05
  - [2] Capacity test: C/3 → 0.05C CC-CV
- ~80% SOH
- Start/end criteria for charge/discharge: 2.8V – 4.2V. Test end at 80%SOH



OBSERVATION – CAPACITY DURING CHARGING IS A MUST

Observations based on first promising measurement results. Not all OEMs delivered data. Still under research.

→ Basically, the issue of capacity and charging phase must be considered together. In addition, the aging of the capacity during charging is based on first measurement results very reliable at reflecting the aging of the energy content during discharging.

→ We do not evaluate absolute values, but relatively between capacity BoL and capacity EoL. **This relative aging of the capacity is very comparable to the relative aging of the energy content**.

→ Thus, when using the capacity, on the one hand you make only a very small error and on the other hand you have the advantages of a very simple and reproducible process, less influence from measurement errors. These advantages easily outweigh the small error (e.g. << 1%) you make.

Statements based on first promising measurement results. Not all OEMs delivered data. Still under research.

1) The capacity is the same in the charging and discharging phase (e.g. Coloumb efficiency approximately 100%)
2) **The capacity is more reproducibly measurable, since only the current sensor with very high accuracy (e.g. error << 1%) is used.**
3) **The capacity can be measured easily and reproducibly as well as technology neutral during the charging process at the charging station. Easy to replicate by third-party organizations or even by customers. Which leads to given transparency and possible validation at all time.**
4) The cell measurements show that at the end of life (SOH = 80%), the deviation between relative aging, energy content, discharge and relative aging capacity is about 1.5%. For mid of life (for new generations of cells) the error will probably be decrease to < 1%.
5) The measurement of the energy content during discharge is subject to much more influences (in particular, discharge rate load in the cycle). For this, a discharge procedure would have to be defined very precisely in order to drive it on the road (e.g. PEMS), Chassis Dyno, on-board equipment (auxiliaries like fan) or BiDi.