HDV GTR achievements and discussion
EVE IWG 74th session

Tokyo, September 18th

-hybrid-

3 general comments

1) As a matter of principle, we understand the urgency of finishing the HDV GTR battery durability Phase 1 drafting in time, thus OICA would like to support any editing of [**] Square brackets. E.g. in a dedicated break-out session.

2) However, as detailed discussions on the Alternative Method (C/D test) have not been completed OICA is convinced that C/D must be discussed in Phase 2.

3) Monitoring of Energy throughput is common sense as we understand. An energy throughput MPR shall be monitored and adopted based on the monitoring results.

Pilot Phase – **what did we do?**

<u>Guidelines agreed to have in common:</u>

- 1a or 1b or 2 based on v17-update text
- Tests to be done at OEMs premises
- No other OEM will participate at other pilot phase tests
- Technical Service or authority is witnessing the tests as applicable in the short notice
- Details as:
  - road gradient, break-off criteria, pass/fail tolerance, repeatability, reproducability,
  - Accuracy requirements, frequncy requirements
  - Testing devices, battery construction/geometry impact on testing devices/locations
- Participation during tests:
  - 1-3 days
  - Whole day
  - Part day
  - Result evaluation
- External verification of voltage and current: OEMs try to organize measurement clamps (preferrably HIOKI as mutual industry standard)
  - At least break-out boxes will be used

Pilot Phase Tests: **promising but challenging**

Required measurement accuracy

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.

The items atmospheric pressure and room or ambient ~~(or on-road)~~ 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 3. of this Annex.

[Table A3/1

Measurement items and required accuracy

- Accuracy requirements come from GTR15 and GTR21, which are both valid **ONLY for external measurement devices**
- Sensors accuracy will not be as good as external measurement devices
- A second table to define sensor accuracy is needed when on-board sensors are used
- **The option for external-measuring devices and on-board sensors should be decided by the respective regional approval authorities. If the deference is allowed by them at the type approval test, the manufacturer may use the value of the on-board sensor instead of the external-measuring device in type approval test, CoP, and ISC**

22

Pilot Phase results DTAG

(assessed by technical service)

Test procedure

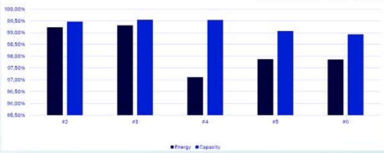
Method 1b

Variation of procedure and highlighting problems

Test results

Comparison Discharge / Capacity - Energy

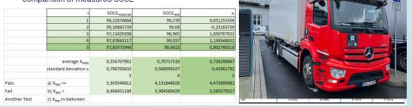
- Standard deviation SOCE: 0,9722%
- Standard deviation SOCC: 0,2926%



Test results

Evaluation of statistical method

- Any combination of the previous 5 test of eActros 300 lead to a pass criteria after 3 tests
- Good performance of onboard SOCE algorithm in comparison of measured SOCE



Test vehicle:

- eActros 6x2 Rigid
- GCW: 37 t
- Rated power: 400 kW
- Installed ESS energy/capacity: 336kWh/846Ah (3 packs)

Test Method 1b:

- flat / hilly (within 1200m/100km)

Main conclusions:

- real driving tests with selected end of test criteria are possible
- adjustments in draft GTR are required
  - Brake-off criteria,
  - acceleration… see report of technical service
- low payload and large batteries lead to very long test duration
- more heavy load/route/driving mode → higher c-rate → less discharge capacity/energy
- Accuracy of SOC estimator influences result
- important to reproduce SOC at start of test
- capacity differs less compared to energy
- higher deviations possible (lower/higher vehicle weight, more hilly route, different vehicle, different drivers)

VOLVO

- FM 6x2 Tag Rigid
- GCW: 32 t
- Rated power: 312 kW
- Installed ESS energy/capacity: 360kWh/540Ah (4 packs)

Test method: 1a

- 2.5 hours of driving at 80 km/h followed by about 50 minutes of driving at 40 km/h

Main conclusions:

- The SoC estimator is critical. Especially at low SoC when SoC estimation will impact the break-off criteria and measured UBE
- Running to 0% SoC may be impractical; even on a test track
- Internal sensors gave accurate results compared to high accuracy measurement equipment
- Installing external sensors is complex and time-consuming
- Measurements sampling at 20 Hz gave no additional accuracy compared to 1 Hz

Very promising results with some issue to work on!

But: everything with huge planning effort in advance, own tracks, no customer vehicles, every equipment available!

Pilot Phase Summary

Main goals:

Show accuracy of SOCE prediction

Demonstrate test procedure feasibility

- On-board sensors reliable
- Ultra-low SoC break-off criteria impractical to reproduce or meet
- Differences between UBE and UBC due to load profiles (route, mass, acceleration, deceleration, recuperation)

Definitions & Abbreviations

E-HDV tests: **we have to close the gaps**

e-HDVs tests: drafting text open questions

Open points of the draft HDV GTR:

- Rational section [for October]
- 'small-volume manufacturer', special purpose, off-road and all-wheel-drive vehicles, ..., explanation moved to the rational section
- Revision of the definitions in the draft GTR: to check REESS, Battery,…
  - *"Not off-vehicle charging hybrid electric vehicle "* (NOVC-HEV) … in the definition section because mentioned in the rational section
  - PTO-operation definition
- Test track and on-road surface paragraphs description
- Vehicle Speed (2.1.1.1.1.)
- Pure electric operational mode

Comments

- Rational should be ready <u>before</u> regulation drafting which shows that HDV ZEV experience is still at a very low level
- Exemptions to be shifted to cps individual decision supported
- For OICA most importantly the link and differentiation between REESS and Battery shall be clarified. Proposal: keep battery in the text and relate it to REESS
- PTO-operation [see R49, rev.07: 2.1.56. without engine-reference]: *"Power take-off **operation**" means any **energy** output for the purpose~~s~~ of powering auxiliary. (taking vehicle and V2X auxiliar into account; reference to traction battery necessary?)*

Example: Re-definition of PTO and add ePTO

Definitions 2.51. of UN-R49-07 defines "PTO unit", but since PEV/OVC-HEV has the following PTOs, So new definitions of PTO and ePTO are required. (see below 3.17 and 3.**)

2.51. "*Power take-off unit*" means an engine driven output device for the purposes of powering auxiliary, vehicle mounted, equipment;

OICA propose that **PTO** be defined as case 1)
OICA porpose that ePTO be defined as Case 2) and 3)
Or PTO and ePTO as defined by 4)

1) Power is taken from the gearbox connected to the drive motor set by the OEM, and used as an external power source. = Gearbox PTO → PTO
2) A dedicated motor set by the OEM drives a hydraulic pump, etc., and serves as an external power source. = Mechanical PTO → ePTO
3) Power is supplied to the equipment set by the body manufacturer to drive the installed equipment. = Electrical PTO → ePTO

Or

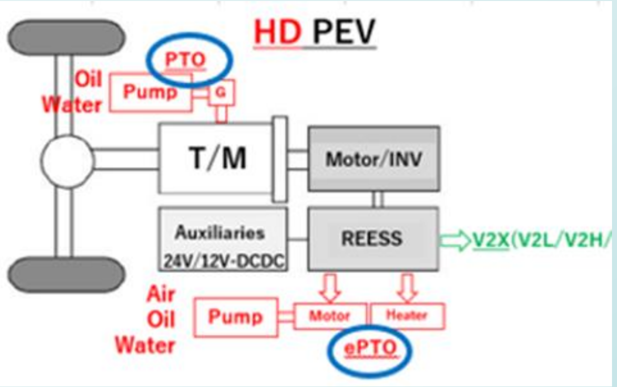
4) Any e- or PTO means an internal combustion engine-, gearbox- or electric-machine-driven output device for the purpose of powering auxiliary, vehicle & trailer mounted, equipment.

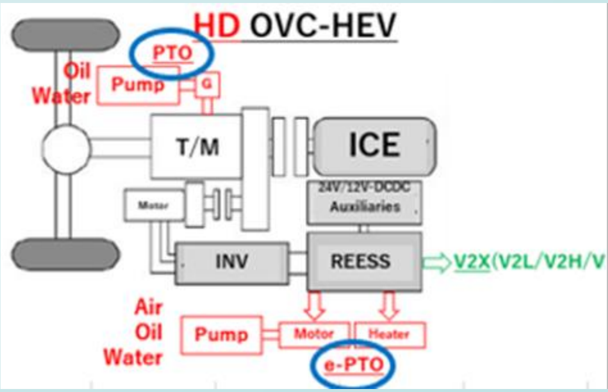
Example: Re-definition of PTO and add ePTO

Definitions 2.51. of UN-R49-07 defines "PTO unit", but since PEV/OVC-HEV has the following PTOs,
So new definitions of PTO and ePTO are required. (see below 3.17 and 3.**)

2.51. "*Power take-off unit*" means an engine driven output device for the purposes of powering auxiliary, vehicle mounted, equipment;

3.17.	*Power take-off (PTO)* means supplying power from the engine (ICE, motor) to operate auxiliaries equipment unrelated to vehicle traction or normal vehicle auxiliaries(24V/12V-DCDC), such as oil pumps, water pumps (for concrete mixers, garbage trucks, fire trucks etc.).
3.**.	*Electrical Power take-off (ePTO)* means a directly REESS that provides substantial auxiliary power for purposes unrelated to vehicle propulsion or normal vehicle accessories (Heater, 24V/12V-DCDC) such as air pump, oil pump, water pump (fpr Cargo Thermal Control trucks, Refrigerator trucks, Cabin heater and air-conditioning etc…)





MLR & MPR

Optional MPR tables is **a feasible proposal**!

MPR for HDV GTR

If CP wants to introduce the MPR (regulatory value) within the HDV GTR, OICA proposes that it should be used as a provisional value until the monitoring is completed and that there will be an opportunity to reconsider grouping (based on HDV types and use-cases) after the monitoring is completed.

Table 1
Battery Energy based (SOCE) MPR for N2, N3<16t

Vehicle age/km/MWh for **N2,N3<16t**	*HD-OVC-HEV*	*HD-PEV*
From start of life to [x] years or [xxx]km or [xxx]kWh, whichever comes first	[xx] per cent	[xx] per cent

Table 2
Battery Energy based (SOCE) MPR for N3>16t

Vehicle age/km/MWh for **N3>16t_Grp 3**	*HD-OVC-HEV*	*HD-PEV*
From start of life to [x] years or [xxx]km or [xxx] MWh, whichever comes first	[xx] per cent	[xx] per cent

Table 3
Battery Energy based (SOCE) MPR for M2

Vehicle age/km/MWh for ***M2***	*HD-OVC-HEV*	*HD-PEV*
From start of life to [x] years or [xxx]km or [xxx]kWh, whichever comes first	[xx] per cent	[xx] per cent

Table 4
Battery Energy based (SOCE) MPR for M3<7.5t

Vehicle age/km/MWh for **M3<7.5t**	*HD-*	
From start of life to [x] years or [xxx]km or [xxx]kWh, whichever comes first	[xx] per cent	[xx] per cent

Table 5
Battery Energy based (SOCE) MPR for M3>7.5t

Vehicle age/km/MWh for **M3>7.5t**	*HD-OVC-HEV*	*HD-PEV*
From start of life to [x] years or [xxx]km or [xxx]kWh, whichever comes first	[xx] per cent	[xx] per cent

Conclusion

For HDV industry, use-case and vehicle type dependent MPR are key for fair treatment and to meet feasible customer needs. Oversized MPRs may lead to oversized batteries just to fulfill the law, to the drawback of customers due to increased vehicle weights, less payload etc. (we will not comment prizing due to competitional law)

Dedicated comment on vehicles <16t

As with GTR22, we calculated the Energy Throughput which is the MPR index for 5 years and 8 years.

[Table 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*
From start of life to years or km, whichever comes first and kWh in monitoring [and additional lifetime]		
5 yr or 125 000 km or Energy throughput [*****] kWh	75%	75%
6 yr, 150 000 km	70%	70%
8 yr or 200 000 km or Energy throughput [*****] kWh	~~65~~ 60%	~~65~~ 60%
8 yr, 300 000 km		
8 yr, 400 000 km		
10 yr, 300 000 km		
10 yr, 375 000 km		
15 yr, 250 000 km		

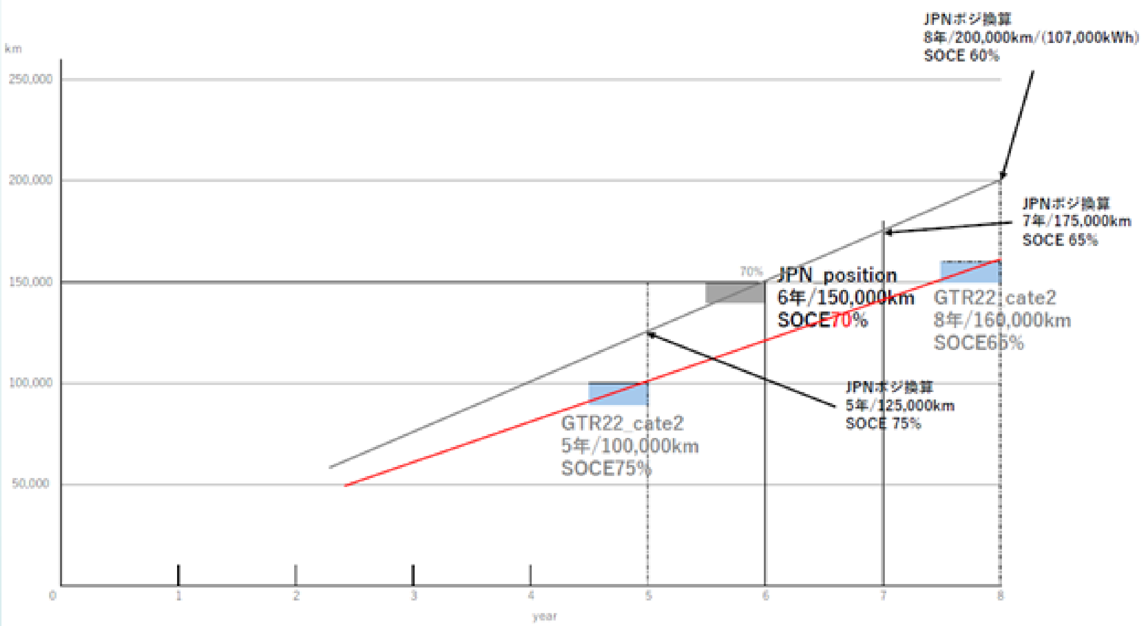


Table 3
Battery Energy based (SOCE) MPR for Category 1-2 vehicle not exceeding 5 tonnes

Battery energy based MPR for C[...] not exceeding 5 tonnes
From start of life to years or km [...] first and kWh in monitoring [an[...]
5 yr or 150 000 km or Energy [...] kWh
6 ys, 150 000 km
8 yr or 240 000 km or Energy [...] kWh
8 ys, 160 000 km
8 ys, 300 000 km
10 ys, 200 000 km

Table 4
Battery Energy based (SOCE) MPR for Cat[...] exceeding 5 tonnes but not exceeding 7.5 ton[...]

*Battery energy based MPR for **Category 1-2 veh[...] exceeding 5 tonnes but not exceeding 7.5 tonnes***
From start of life to years or km, whichever come[...] first and kWh in monitoring [and additional lifeti[...]
5 yr or 150 000 km or Energy throughput [****[...] kWh
6 ys, 150 000 km
8 yr or 240 000 km or Energy throughput [****[...] kWh
8 ys, 300 000 km
8 ys, 500 000 km
10 ys, 375 000 km
15 ys, 240 000 km

Table 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*
From start of life to years or km, whichever comes first and kWh in monitoring [and additional lifetime]		
5 yr or 150 000 km or Energy throughput [*****] kWh	75%~~70%~~	75% ~~70%~~
6 ys, 150 000 km	70%	70%
8 yr or 240 000 km or Energy throughput [*****] kWh	65%	65%
8 ys, 600 000 km		
10 ys, 300 000 km		
10 ys, 700 000km		
12 ys, 700 000km		
15 ys, 875 000km		

Virtual Distance & Energy Throughput

ENERGY THROUGHPUT DEFINES THE ZEV TRUCK – **VIRTUAL MILEAGE FEASIBLE BASED ON PROPULSION**!

- Challenges with virtual distance on LDV formula:
  - PTO energy during driving is not properly accounted
  - Separate between energy for propulsion and energy for other purposes (PTO, V2X, etc.)
  - VD formula valid for LDV is not representative for HDV
  - Verification of the virtual distance is challenging for HDVs
- **Energy throughput is the preferred measure in addition to mileage and age for battery deterioration**
  - Energy throughput should be monitored and set in phase 2
- Virtual distance may be evaluated during the monitoring phase and decided in phase 2

HDBD-VIRTUAL DISTANCE PROPOSAL COULD BE KEY.

Workaraound LDV:

- For LDV, VD was introduced in phase 1, verification procedure was introduced in phase 2
- Therefore, it is important to consider the possibility for verification

With this formula we see a very feasible solution for VD:

$$\textit{Virtual distance}\ (km) = \text{Odometer km} \times \left(\frac{\text{total discharge energy}\ [Wh] - \textit{total propulsion energy}\ [Wh]}{\textit{total propulsion energy}\ [Wh]}\right)$$

Additionally:

- The current verification procedure is adapted from LDV but needs more elaboration for HDV
- In order to verify virtual distance, both total discharge energy and total propulsion energy need to be verified
- Total discharge energy = Energy throughput
- Total propulsion energy needs to be agreed and defined. In the case of LDV, energy consumption is a certified value from WLTP

Energy Throughput Alternative proposal: addition to Part B or “Part C-2”

- In-use Verification
  6.4 Part B; Verification of Battery Durability
  At first, evaluate MPR simply based on age and mileage (= odometer)
  even if PTO or ePTO is installed.
  If it passes, the evaluation ends.
  If it fails, move to ***Part B step2 or Part C-2*** to investigate and evaluate the impact of ***V2X, PTO and ePTO.***

  6.X ***Part B step2 or Part C-2***;
  Re-evaluate families that failed Part B using energy throughput.
  Because there are various types and usage methods of PTO and ePTO,
  energy consumption may not be simply converted to mileage (virtual distance).
  Therefore, it will be evaluated using energy throughput compared with energy throughput percentiles of the samples.

  OICA would like to propose the details by the next EVE Meeting.
  We are summarizing this proposal in OICA.

Pass/Fail criteria

TOLERANCE AND PASS/FAIL CRITERIA FOR BOTH PART A AND PART B

- The current statistical method was developed for LDV which was established on field data and was based on the assumption of homogeneity in the customer usage

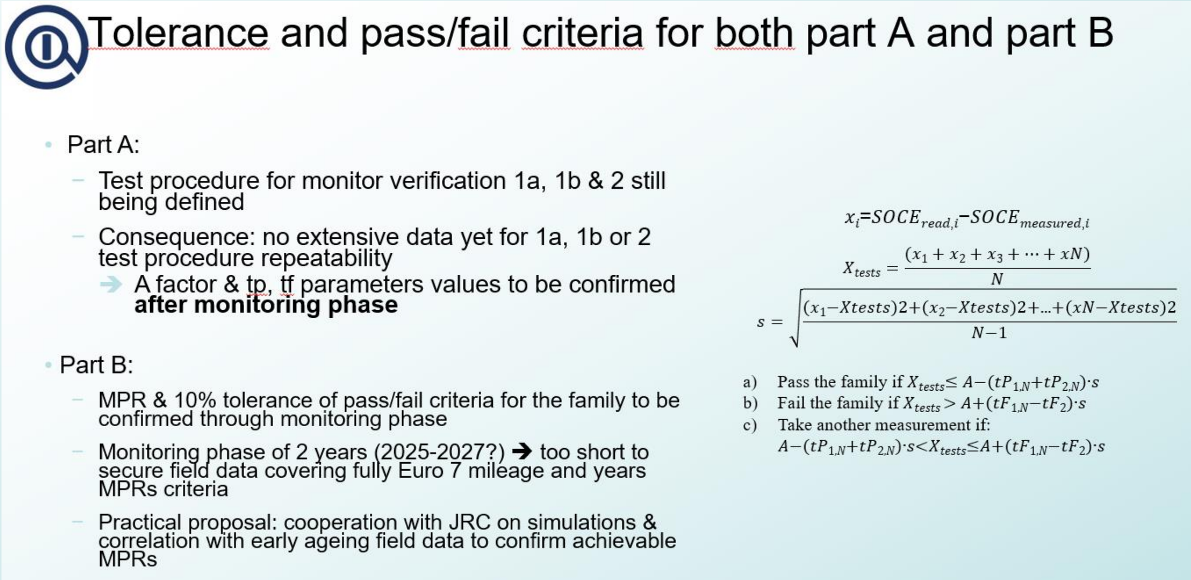
- It was intensively discussed at EVE46, EVE48 and EVE 49 etc. with simulation and statistics for LDV, EVE-46-16e, EVE-48-02e, EVE-48-03, EVE-49-03e.pdf

- It is highly appreciated to have a **dedicated meeting with JRC and interested stakeholders** to discuss and investigate the applicability of the same statistical method for HDV, most likely adaptions need to be made.

VEHICLE TEST SAMPLE SIZE

- Each vehicle is a tailor-made work tool for a customer. Applying the same strategy for vehicle test sample size (3-16) as light-duty/passenger vehicles would create an enormous testing burden for all HDV manufacturers and should be avoided.

- We would like to see the impact of sample size on the current statistical approach from JRC simulation and discuss the applicability of the method and parameters.



Tolerance and pass/fail criteria for both part A and part B

- Part A:
  - Test procedure for monitor verification 1a, 1b & 2 still being defined
  - Consequence: no extensive data yet for 1a, 1b or 2 test procedure repeatability
    - ➔ A factor & tp, tf parameters values to be confirmed **after monitoring phase**
- Part B:
  - MPR & 10% tolerance of pass/fail criteria for the family to be confirmed through monitoring phase
  - Monitoring phase of 2 years (2025-2027?) ➔ too short to secure field data covering fully Euro 7 mileage and years MPRs criteria
  - Practical proposal: cooperation with JRC on simulations & correlation with early ageing field data to confirm achievable MPRs

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

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

$$s = \sqrt{\frac{(x_1 - Xtests)2 + (x_2 - Xtests)2 + \ldots + (xN - Xtests)2}{N-1}}$$

a) Pass the family if $X_{tests} \leq A - (tP_{1,N} + tP_{2,N}) \cdot s$

b) Fail the family if $X_{tests} > A + (tF_{1,N} - tF_2) \cdot s$

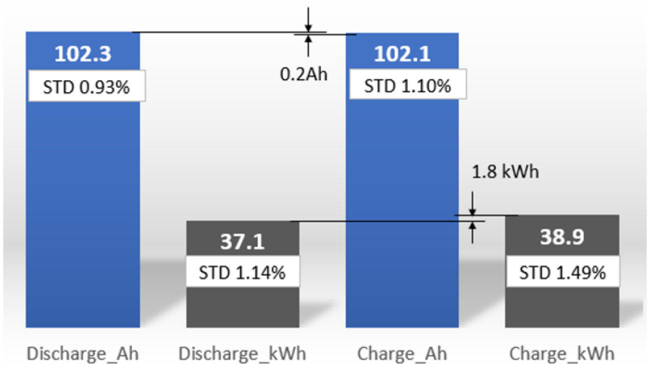
c) Take another measurement if:
$A - (tP_{1,N} + tP_{2,N}) \cdot s < X_{tests} \leq A + (tF_{1,N} - tF_2) \cdot s$

UBC vs. UBE. OICA compromise proposal: keep UBC in parallel for monitoring

Results(2) Comparison UBE vs. UBC

> RTE test results of discharging up to On-Board discharge and charging with DC/AC for each method.
> Compare average UBE(kWh) and UBC(Ah)

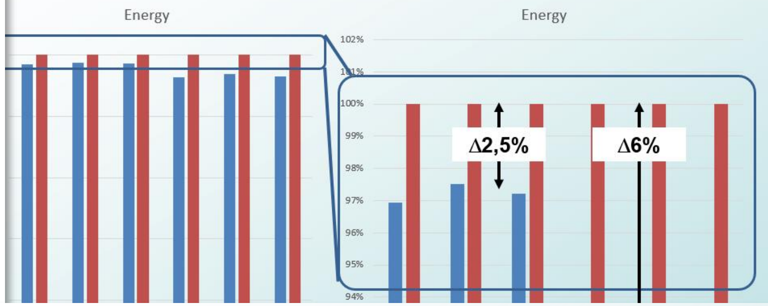
n=8 Tests Ave.Ah/kWh__Discharge/Charge



Draft

<Result>
> UBE(kWh) ; Due to internal resistance, discharge is Δ1.8kWh compared to charging.
The variation is 1.14-1.49% which is much larger than UBC due to voltage multiplication.
> UBC(Ah) ; Measured using DC charging and AC charging, The values are almost same,
the difference is Δ0.2Ah. Variation are 0.93 - 1.10 %.

Results energy



Tolerances:
Discharge: ~6%
Charge: ~3%

test Nr.	route	charge
1	flat 10,5t	fast
2	flat 10,5t	fast
3	flat 10,5t	mobile
4	hilly 39t	fast
5	hilly 39t	mobile
6*	hilly 39t	fast
7**	hilly 39t	mobile

* Driving mode „Range"
** charging aborted

RESULTS

- Results from closed test track & for discharge part of test procedure
- Measured variation in energy max 1.04% among tests

Test Case	Test 1	Test 2	Test 3
Preconditioning	Slow Charge from 32% SOC	Slow Charge from 37% SOC	Slow charge from 40% SOC
Measured Variation UBE (UBE: $\int(U * I)\,dt$)	1,04%	0%*	0,71%
Measured Variation UBC (UBC: $\int(I)\,dt$)	1,34%	0%*	0,84%

* reference to calculate variation among tests

- Average Cell Temperature is ~25 °C

Discharge Cycle – Avg cell temperature over 6 BP		
Avg Max Cell Temperature	Avg Min Cell Temperature	Avg Cell Temperature
25,82	24,65	25,39

Conclusion

- Capacity is the same in the charging and discharging phase (e.g. Coulomb efficiency approximately 100%)
- Capacity is more reproducibly measurable, since only the current sensor with very high accuracy (e.g. error << 1%) is used.
- 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.

Items for Phase 2

- Chassis dyno method
- Pass/Fail criteria review
- MLR (minimum lifetime requirement – km, age, energy throughput) and MPR (SOCE requirement) definition