Heavy-duty industry adaptation of GTR22 on in-vehicle battery durability

EVE IWG - Session 66

-online-

December 06th, 2023

Aligned OICA Positions on HD Battery Durability core building blocks

OICA Positions on HD Battery Durability GTR22b

update

<u>Capacity vs. Energy</u>

- Capacity (→ reasons: reproducibility, accuracy ; based on different OEM test results; ~1% deviation)

update

<u>Charge vs. Discharge</u>

- Given Capacity as metric, charge or discharge should be acknowledged and selectable within Methods 1(a-b) and 2 (~1% deviation) based on OEM real testing data
- Type approval test or in-service Part A are performed using the same method (charge or discharge)

<u>Energy Throughput as appropriate Lifetime Requirement</u>

- Energy Throughput will include additional driving and stand still auxiliary energy consumption (incl. V2X) and give a rather complete picture of the battery health compared to age and mileage. Energy throughput will be counted on full-cycle-equivalents.
- Mileage not reasonable anymore when taking energy throughput into account
- Energy throughput metering shall be verified during certification run

update

OICA Positions on HD Battery Durability GTR22b

Test Procedures reference & Part A

update

- Only two*: Method 1 (on-road) and Method 2 (Bidi)
- 1: to be performed on-road, the routes may include both public and private tracks. Same boundary conditions apply to all testing methods. Target speed(s) as function over time and c-rates to be aligned.
- 2: BiDi
- *if applicable 1 or 2 can also be conducted at chassis-dyno test, complying to same requierements
- As a matter of principle, family criteria (f) of point 6.1.1. (PART A) should be reduced to type of batteries incl. Battery configuration (see also Part B)

Verification of current and voltage signals during Part A

- On-board only (OBD), see GTR21 point 6.1.2 (→ reason: on-board accuracy could also be verified by e.g. 3 following measurements of the same vehicle within a certain time)
- Qualification process: to be agreed upon with type approval authorities
- To be qualified on a representative family member

update

Cut-off criterion and full-charge criterion

- Based on OEM vehicle specifications or
- determined by BMS, similar to the BMS determining Full-Charge

AFTER 12 MONTH, EVALUATION AND TESTING, OICA WOULD LIKE TO EXPRESS THE FOLLOWING CORE POSITIONS

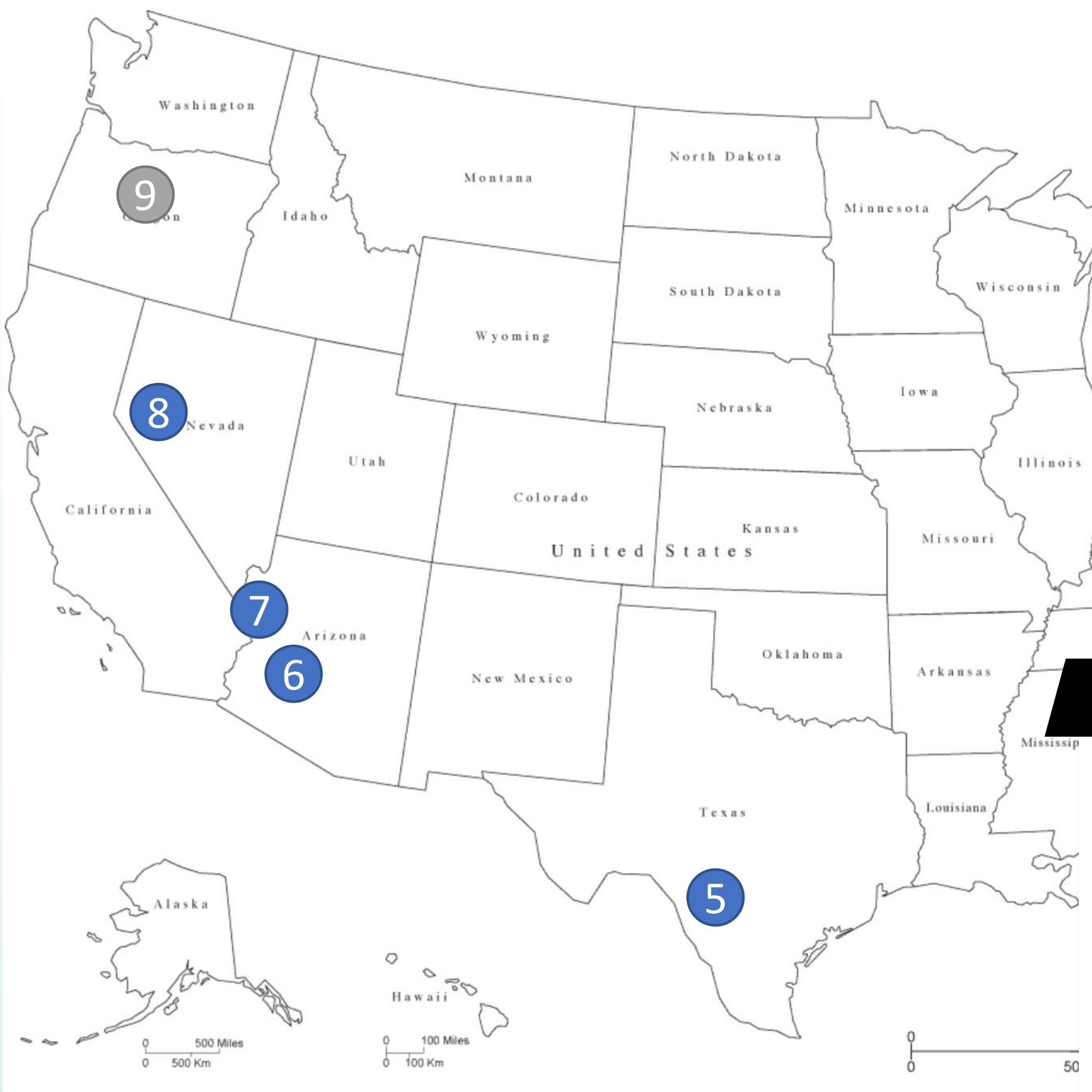
update

Methods for Checking Battery Durability Monitor for HDV					
	HDV with no bidirectional charging				HDV with bidirectional charging
	Method 1		Method 1c	Method 1d	Method 2
					
Description	charge/discharge procedures are allowed per OEM recommendation; this method requires constant speeds for discharge or constant c-rates for charge.	charge procedure only; C-rate could vary depending on OEM recommendation	Discharge with on-board systems and charge	Standard charging Discharging by any method (not measured)	charge/discharge procedures are allowed per OEM recommendation; this method requires constant c-rate speeds for discharge.
Metric	**UBC**	**UBC**	**UBE**	**UBC**	**UBC**

update

Test Tracks for HDV Testing in US

update



Test Tracks for HDV Testing in US

- Transportation Research Center (East Liberty, OH)
- American Center for Mobility (Ypsilanti, MI)
- Michigan Technical Resource Park (Ottawa Lake, MI)
- **Navistar** Proving Grounds (New Carlisle, IN)
- **Continental** Tire Uvalde Proving Grounds (Uvalde, TX)
- Arizona Mobility Test Center Powered by **Intertek** (Wittmann, AZ)
- **Stellantis** Arizona Proving Ground (Yucca, Arizona)
- Nevada Automotive Test Center (Silver Springs, NV)
- **Daimler Truck** Proving Grounds (Madras, OR)

Comments

- List based on **publicly available knowledge** about these test facilities.
- Other facilities exist to accommodate HDV, but **some do not have tracks large enough for continuous high speed.**
- Some **facilities belong to OEMs**, which may **limit other OEMs' ability** to utilize the facility.
- **Facilities are not reasonably accessible** throughout US, which **limits practicality of Method 1a** in some portions of US.

Other **private facilities may exist** with limited info available.

【Proposal】JAMA Position (draft)
Test results & conclusions
Discharge/Charge _ UBE/UBC
@23℃ C/D
for HDV Battery Deterioration

JAMA Battery Deterioration MTG

5th Dec. 2023

Test Pattern

Conducting RTE tests for discharging and charging by method in a chassis dynamo room managed by 23 deg.C , and measured the following items.

> UBE[kWh] and UBC[Ah]
> Test time
> Cell temperature transition

Method	n		Date	Discharge Capa. Ah PW8001	Discharge Energy kWh PW8001	Discharge Duration SEC	Discharge Cell/Temp.Max Δ℃	Discharge Cell/Temp.Max ST->End	Discharge warning HV Stop Cut-off	Charge Type PWR	Charge Capa. Ah PW8001	Charge Energy kWh PW8001	Charge Duration SEC	Charge Cell/Temp.Max Δ℃	Charge Cell/Temp.Max ST->End
1a	1	Const. Speed	14-Nov							DC48					
		On-Board Discharge							●	AC3					
	2	Const. Speed	17-Nov							AC3					
		On-Board Discharge							●						
	3	Const. Speed	21-Nov							DC100					
		On-Board Discharge							●	AC3					
1b	1	JE05 mode	13-Nov							DC48					
		On-Board Discharge							●	AC3					
1c	1	On-Board Discharge	16-Nov						●	DC48					
										AC3					
	2	On-Board Discharge	20-Nov						●	AC3					
	3	On-Board Discharge	22-Nov						●	DC100					
										AC3					
2	1	Bidi Charger	9-Nov							AC3					
	2	Bidi Charger	15-Nov							AC3					
	3	Bidi Charger	24-Nov							DC100					
		On-Board Discharge							●	AC3					

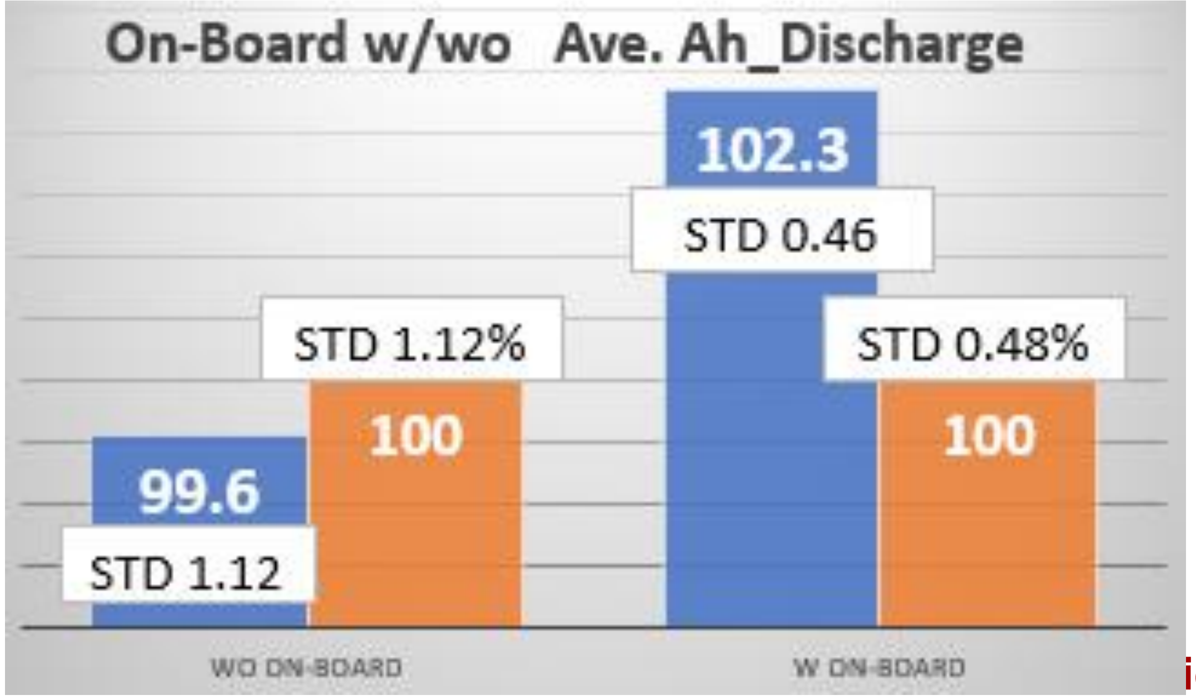
Detailed data values are not disclosed as they are the company information.

Method 1a is constant speed running on C/D

Results(1) Break-off criterion

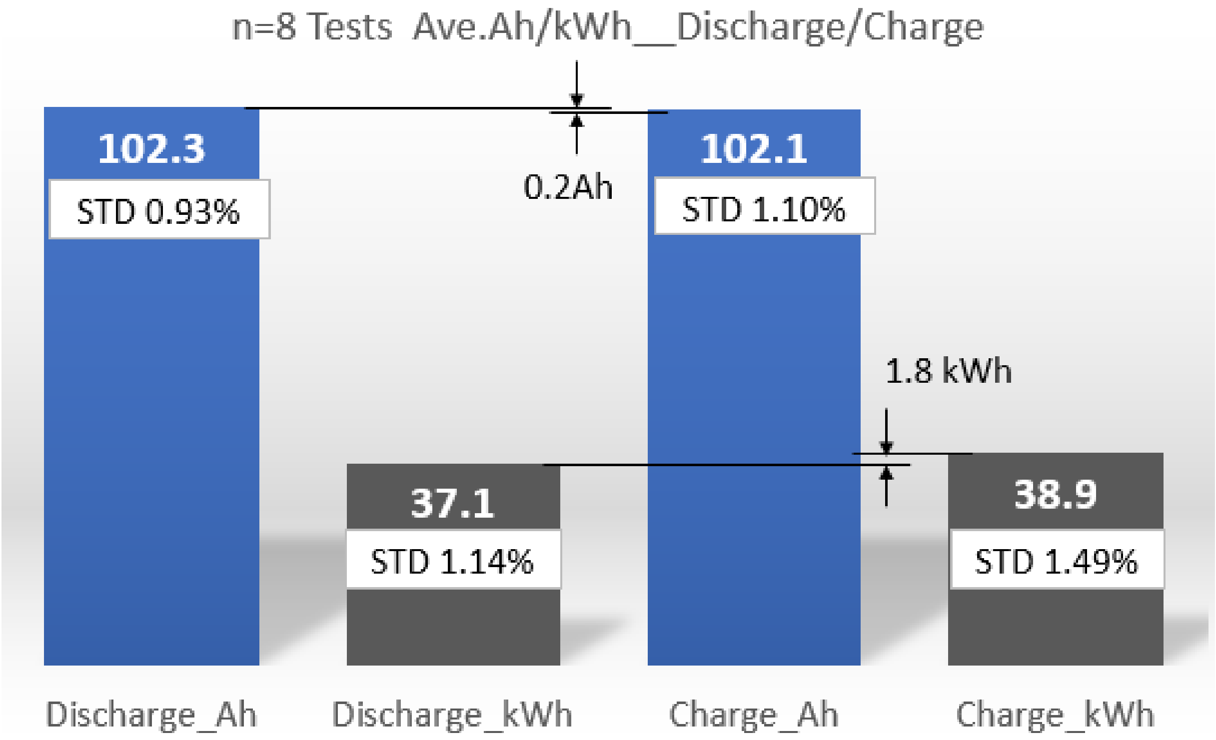
> In order to consider accurate power shortage determination,
check for variations in measured values wiith and without the On-Board discharge which activates the high-voltage discharge stop warning lamp.
> Since the absolute value of discharge amount is different with and without On-Board, both are converted to "100"and compared.
> Without ; Method 1a; -2km/h after deviation for 4 seconds until stop. And then IGN-off.
Method 2 ; Until the vehicle stopes discharging. And then IGN-off.
> With ; On-Board discharge that consumes power by electric auxiliary equipment, high voltage discharge stop warning lamp on. And then IGN-off.

<Result>
> By implementing On-board discharge, the variation was reduced from 1.12% to 0.48%



Results(2) Comparison UBE vs. UBC

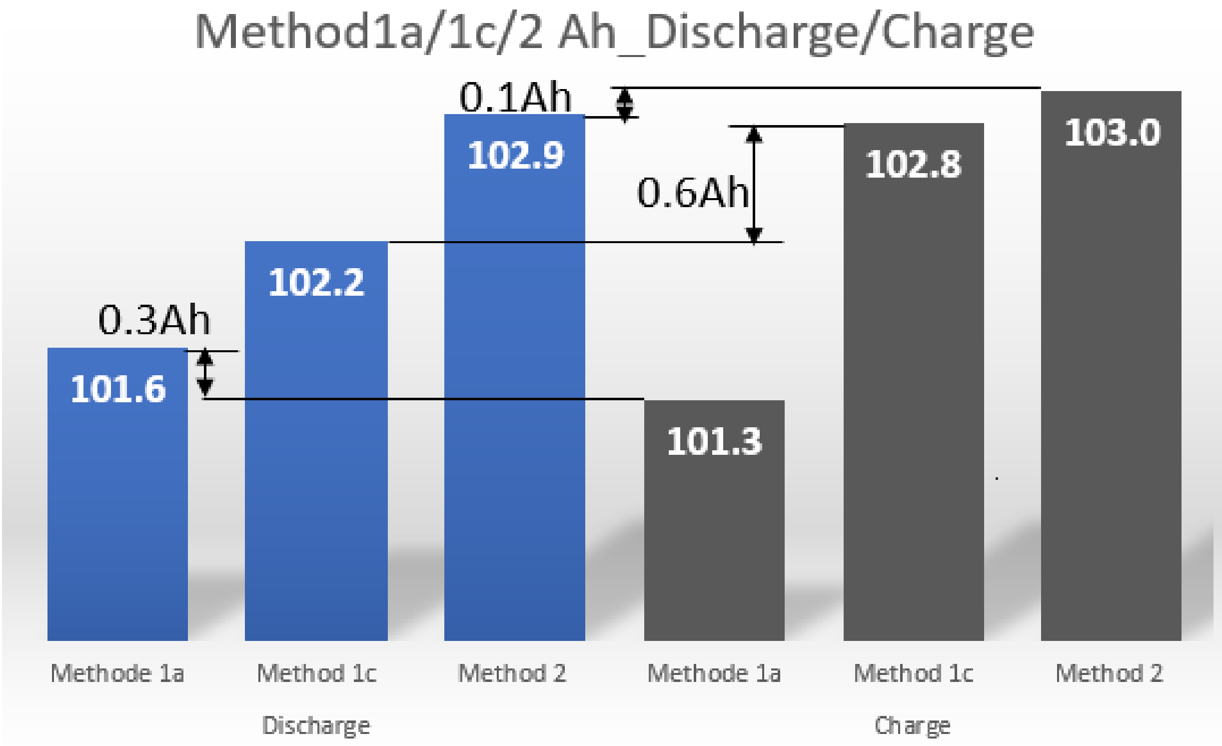
> RTE test results of discharging up to On-Board discharge and charging with DC/AC for each method.
> Compare average UBE(kWh) and UBC(Ah)



<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(3) Comparison Discharge vs. Charge

Compare UBC(Ah) between On-Board discharge and DA/AC charging by method



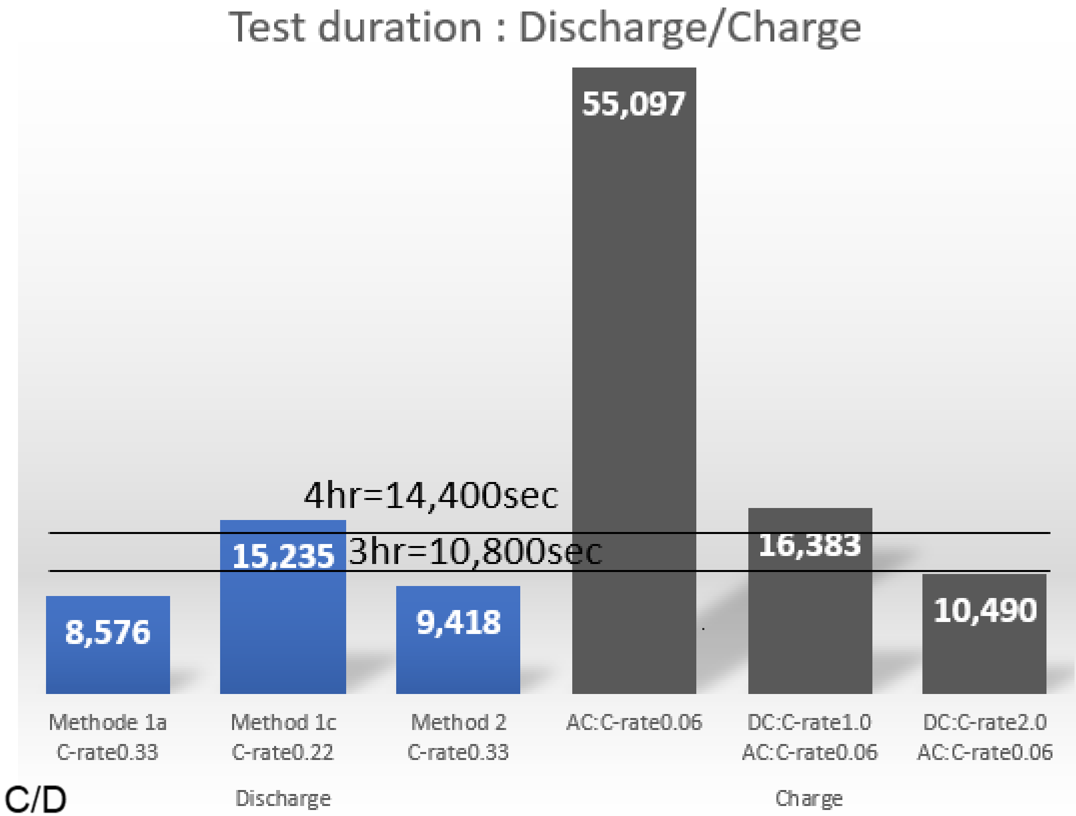
Method 1a is constant speed running on C/D

<Result>

> All result are within ±1.0 % :Method1a : 0.3Ah. Method1c : 0.6Ah. Method2 : 0.1Ah

Results(4) Comparison Test Duration

Compare test times by C-rate (Method) for Discharge and C-rate (DC/AC) for Charge.



Method 1a is constant speed running on C/D

<Result>

The Method, which can compete measurement within 4 hours.

> Discharging ; Method 1a(C-rate 0.33) and Method 2 (C-rate 0.33)

> Charging ; DC 100kW(C-rate 2.0) + AC3kW(C-rate 0.06)

Consideration

<Consideration>

> Break-off criterion :
VCU(Vehicle Control Unit) determines and stops the high voltage supply, and performs On-Board discharge until the warning lamp turns on.

> Selection UBE/UBC :
Select UBC(Ah), which allows the battery capacity to be defined regardless of discharging/charging.

> From HD characteristic (loading ration/bodywork/high battery capacity) :
Test methods that can avoid HD characteristic
- Discharging ; Method 2
- Charging ; DC charging

> Capacity measurement time @ISC :
The test method allows capacity measurement to be completed within 4 hours from 9:00AM to 1:00PM, and the vehicle can be returned to the customer before 5:00PM .
- Discharging ; Metod1a and Method2
- Charging ; Estimated battery capacity up to around 400 kWh with an upper limit of 150 kW-DC-charge.*1

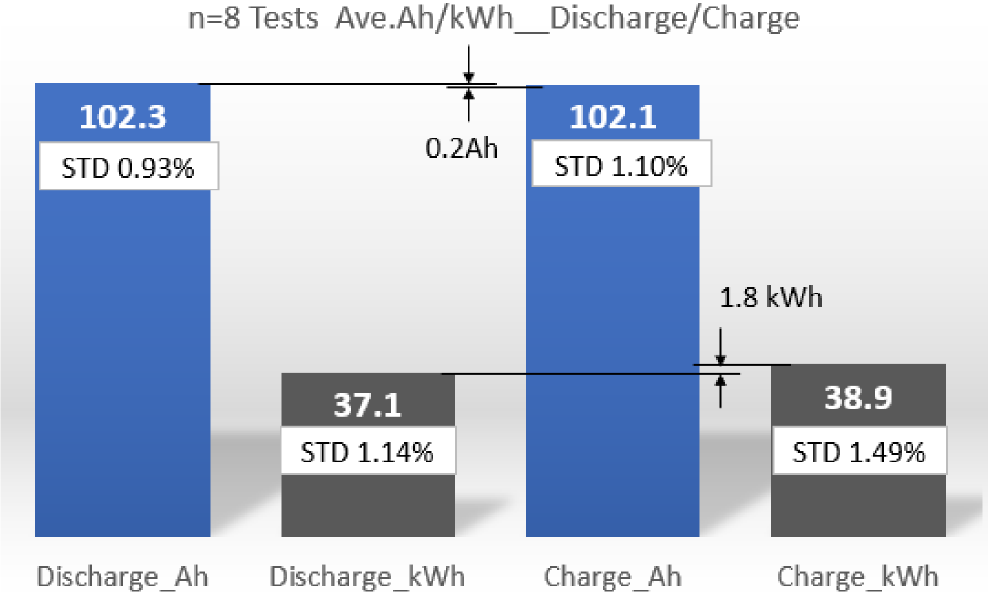
*1 ; JAMA propose that the upper limit output kW for NC charging for batteries with a capacity of over 300kWh should be set to C-rate 0.2.

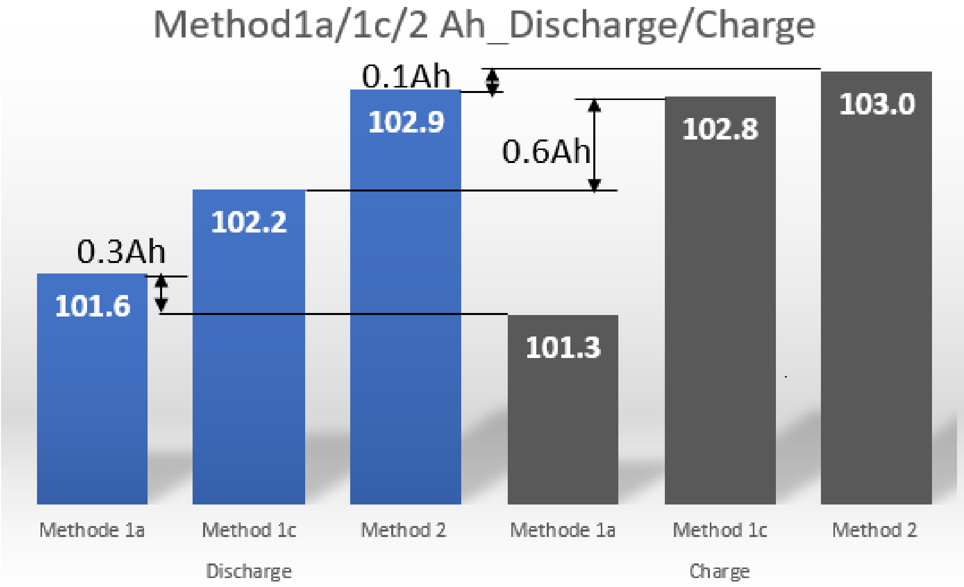
Thank you

This is an interim report, and to be continue.

Additional Information:
In December, the following tests will be conducted on a cold region test course.
- Discharge : Method1a -> Charge : DC and/or AC
- Discharge : Method1c -> Charge : DC and/or AC

Check the effect of environmental temperature on the test results below.





JAMA Position (reference)

<JAMA Position / Proposal>

> **Measured capacity** : UBC(Ah)-> Discharging and charging are the same value, so there is no need to distinguish between [discharging] and [charging].

> **Discharging** : Considering capacity measurement within 4 hours, temporary deterioration of the battery, and avoidance of additional vehicle maileage >>>
Fully charged determination using OEM specified method -> Overnight soak *2 -> Method 2<Bidi>(C-rate0.25 - 0.43) + 1c<On-Board> discharge

> **Charging** : Discharge regardless of Method 1a/1b/1c/2, >>>
and then discharge from SOC 5% using Method 1c<On-Board> to determines power shortage -> Overnight soak *3 -> DC and /or AC charging below NC charging upper limit output

*2 & *3 ; After confirming the maximum cell temperature ≦ room temperature +5 deg.C it is possible to re-execute "full charge determination using OEM specified method" and "power shortage determination using Method 1c<On-Board>"

JAMA Market Analysis for HDV Battery Deterioration

OBJECTIVE

<Objective>
The purpose of this study is to analyze the significance of the correlation between SOCE and "Mileage" or "energy consumption" of PEV/OVC-HEV HDVs from the market data of a certain HD-OEM in Japan.

<Sample Specifications>
- Number of samples: 10
- Vehicles: PEV trucks from GVW 3.5ton to 7.5ton
- Body work: Cargo van / 2 cases, with electric fridge and without electric configuration
- Customers: 2 cases, small deliveries and store deliveries
- Charging method: 2 cases, normal charging and first charging
- RESS: 2 cases, one with single pack and the other with double pack
- UBE measurement: On-Board CAN value

<Definitions>
- Energy Throughput: Lifetime discharge electric energy [kWh]
- Full Cycle Equivalent (FCE): Equivalent full discharge cycle [cycle]
-

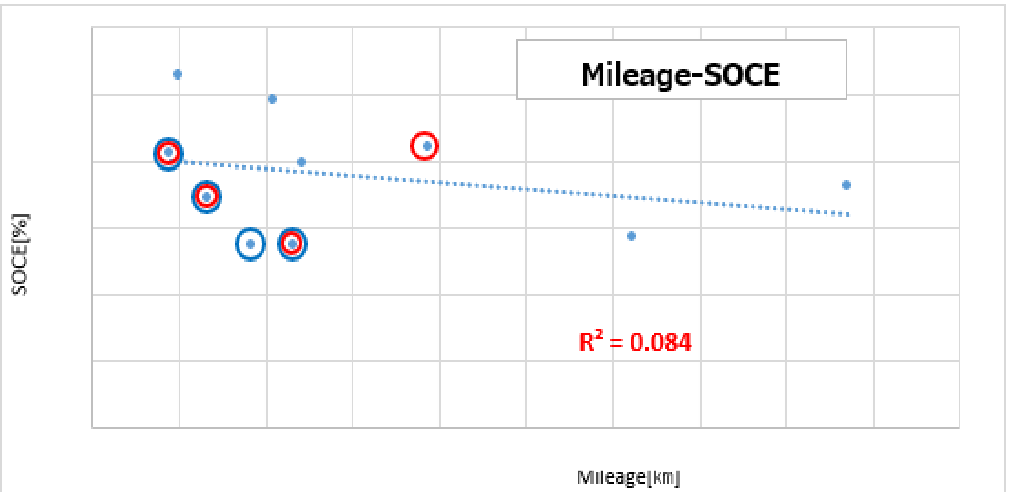
$$\text{FCE [cycle]} = \frac{\text{Energy Throughput}_{\text{on-board memory}} \text{ [kWh]}}{\text{UBE}_{\text{certificated}} \text{ [kWh]}}$$

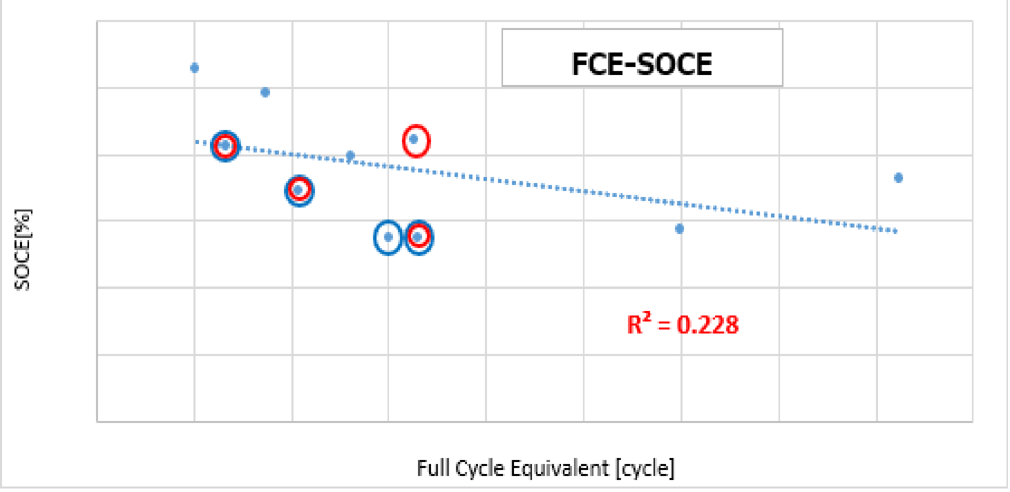
RESULTS

Veh. No	Customer	Numbers of Pack	Fridged Truck	Duration [months]	Mileage odo [km]	Energy Throughput [kWh]	FCE Full Cycle Equivalent [cycle]	SOCE [%]
1	BB1	2	+					
2	BB2	2	+					
3	AA1	1	-					
4	BB3	2	+					
5	BB4	2	+					
6	BB5	2	-			*1		
7	AA2	1	-					
8	AA3	1	+					
9	BB6	2	+					
10	AA4	1	-					

*1; We would like to disclose the actual figures for SOCE until the data for other regions become available.

<Results>
"FCE (R^2=0.228)" is higher than "Mileage (R^2=0.084)" in terms of correlation with SOCE.



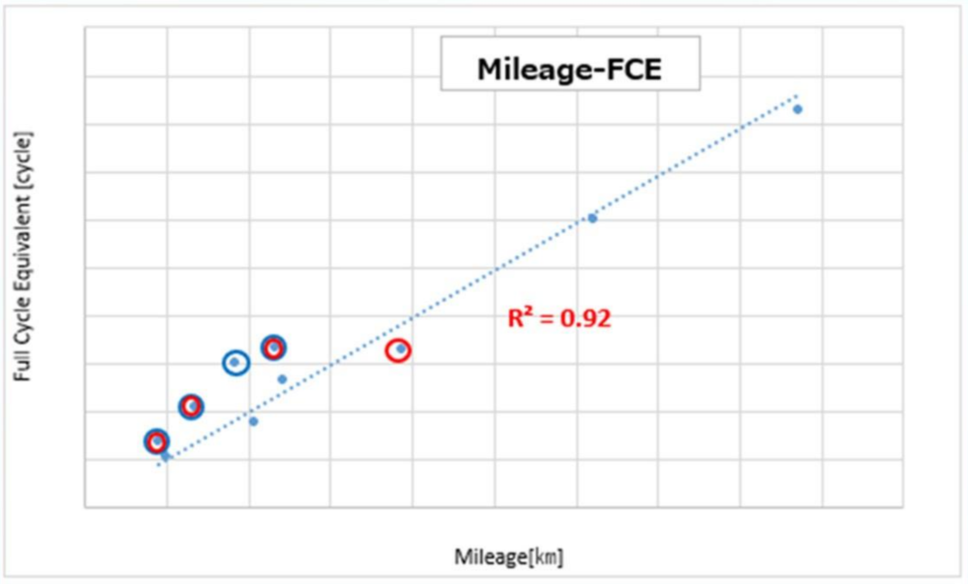


CONCLUSIONS

<Results>
“FCE (R^2=0.228)” is higher than “Mileage (R^2=0.084)” in terms of correlation with SOCE.

- **For the SOCE characteristics, "FCE" was more significantly correlated than "Mileage" for the PEV HDVs in this market sample.**

  However, since the correlation between "Mileage‟ and "FCE" is high (R^2=0.92), it is important to use one of them as the MPR metrics to avoid multiple correlations, "FCE" which has a significant correlation, seems to be appropriate.



Mercedes-Benz Vans Evaluation of HDV testing procedure on aged batteries

Charge vs. Discharge / Capacity vs. Energy

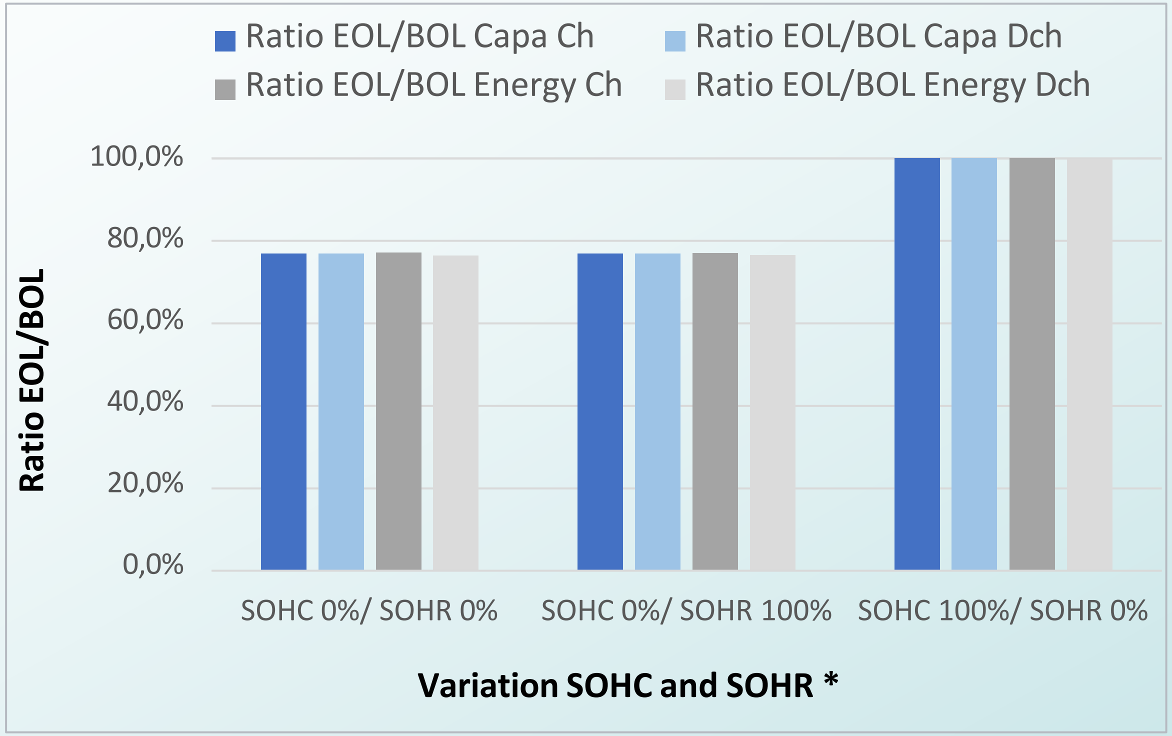
CHARGE/DISCHARGE CAPACITY & ENERGY TEST RESULTS BATTERY LIFETIME AT END OF LIFE

Test conditions:

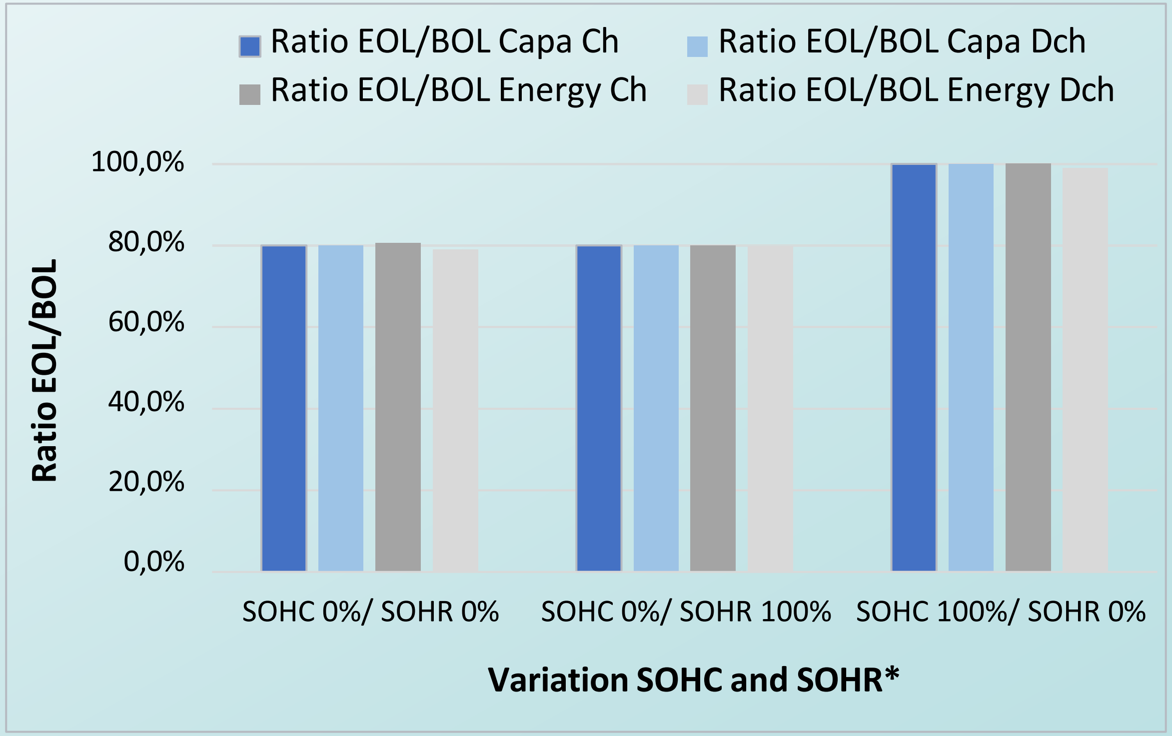
- Results on battery level
- Simulation results based on measurement results
- Customer-oriented real-world charging and driving profile
- Charge/ discharge rate EOL/ BOL testing with C/3 (constant)

Variation of aging parameters (SOHC/ SOHR)

- 100%: new battery (BOL)
- 0%: aged battery (EOL)



Sample 1 – Large battery size (van segment)



Sample 2 – Small battery size (van segment)

* SOHC (aging effects capacity) & SOHR (aging effects internal resistance)

Summary of the results and comparison between different battery sizes

- In general, overall differences between charge vs. discharge and capacity vs. energy are very small
  - Capacity: Equal results for charge and discharge
  - Energy: The differences between charge and discharge due to internal resistances are negligible
- Increasing internal resistance over lifetime has rarely no impact on the ratio EOL/BOL
- Same behavior is observed for different battery sizes

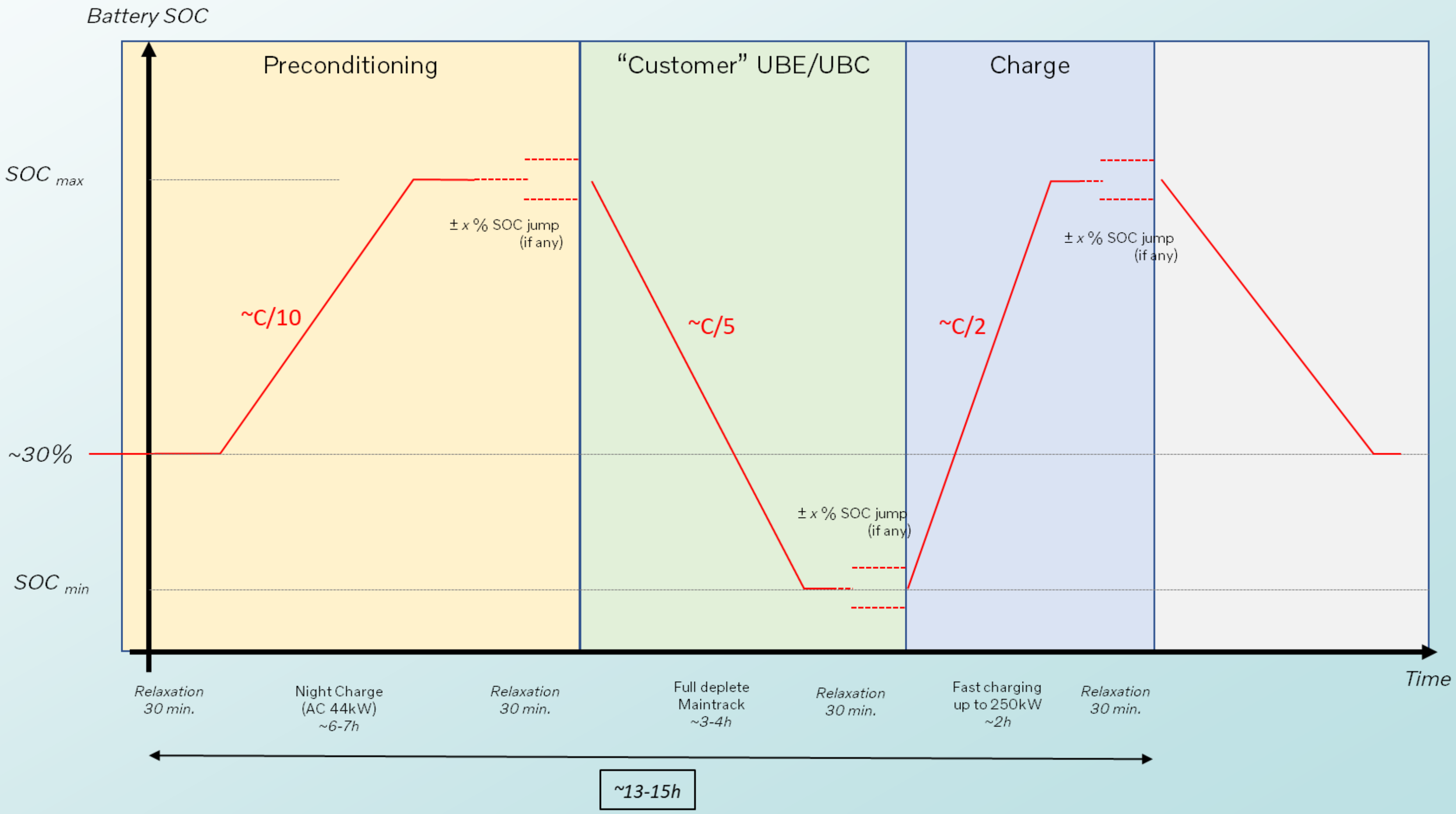
Volvo UBE/UBC

on-road circuit-track tests results

TEST METHOD

T4x2, 6 ESS BP (>540kWh nom. energy content)

- Discharge by driving on-road (test track) constant speed 90km/h, UBE & UBC measurement
- Slow Charging → Discharge Cycle → Fast Charging Cycle
- 3 measurements on different days, same SOC window
- Stop criteria:
  - Charge until SOC $_{max}$
  - Discharge until end of vehicle propulsion
- SOH ~94-95%



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

VOLVO ANALYSIS & RECOMMENDATION

Test procedure

- Good reproducible measurements with UBE & UBC measured with discharge by driving even with limited preconditioning

- For Volvo:
  - due to BMS SW design 1h relaxation time after charging does not secure relevant and robust UBC & UBE measurement. Flexibility needed on relaxation time (could be decided @ certification by manufacturer with same time between certification & in-service test)
  - increasing relaxation time would increase too much test procedure time for Volvo though. Only UBC charging would result in being away from actual capacity normally available to customers

➔We recommend flexibility for test procedure

Daimler Truck ACEA HDV Battery Durability procedure proposal

on-road public streets tests results

Test procedure & variants

Discharge with on-board equipment only would lead to 30h test duration @ 10kw (60h with long haul trucks next gen)

SoC on that slide = BMS (physically available capacity)

Important to know: physical SoC never 0 or 100 due to:
- Saving battery health
- Guarantee usable vehicle utilization

discharge during real driving cycle

dc. by cabin heater & air compressor

~1h recal.

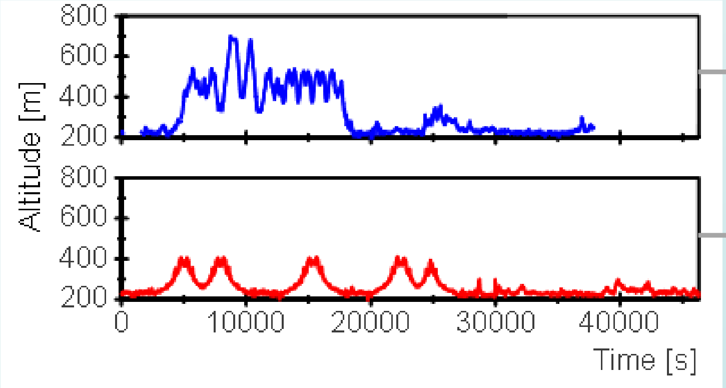
charge

	fast charging	mobile charging
charge time	~3.5h	~12.5h
max charge power	150 kW	40 kW

route

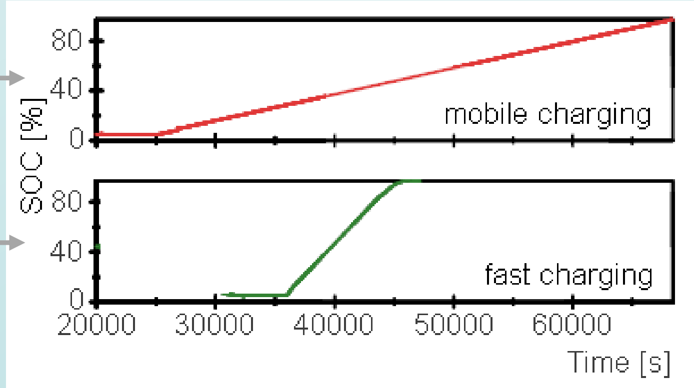
veh. weight

charge



40t

10,5t



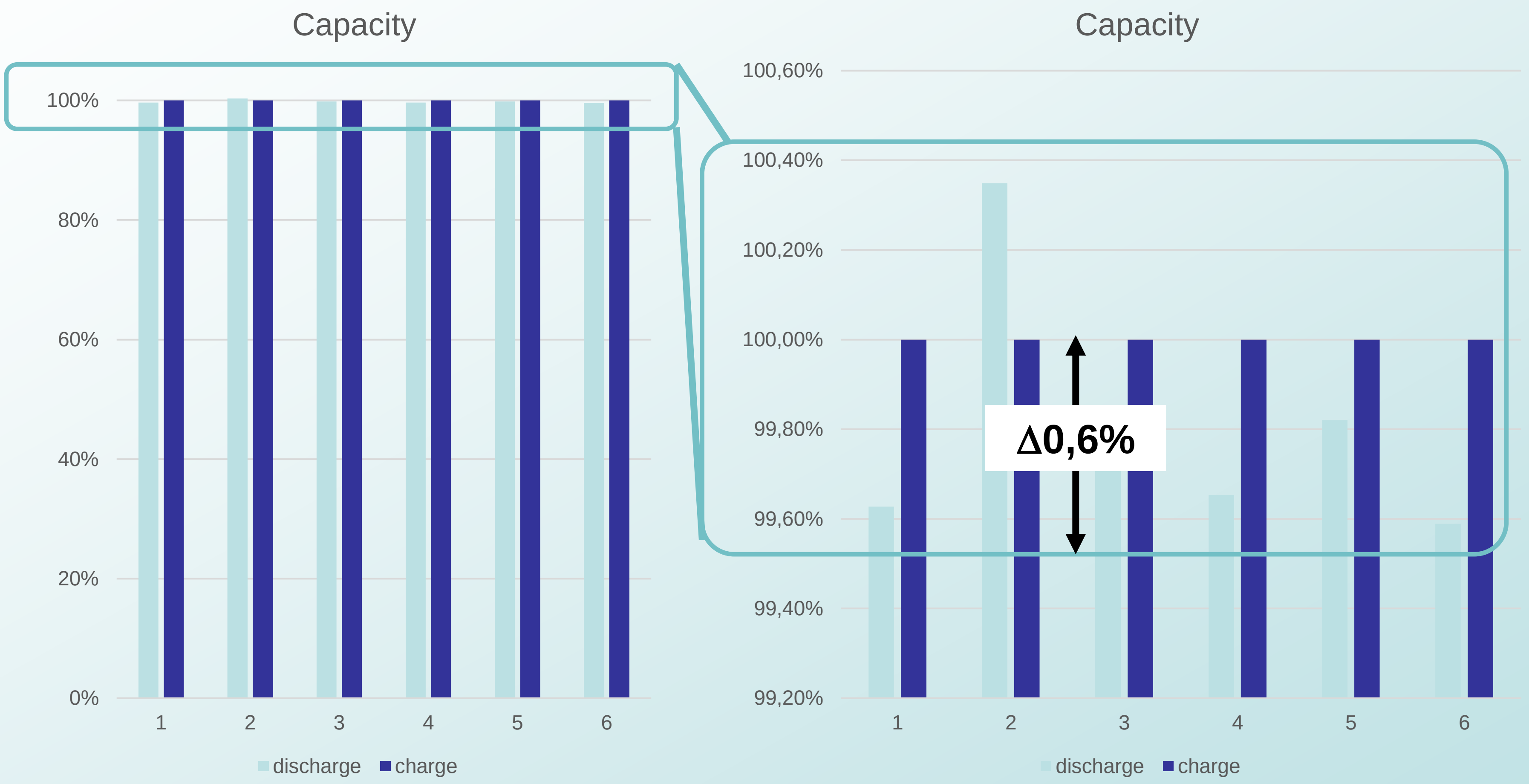
Test vehicle & tests

- Type: eActros 300 2740 L 6X2 (ML-C)
- total mileage: 44tkm
- total weight: Tests 1-3:10,5t; Tests 4-6: 40t
- HV Battery: ~336 kWh physically installed (3 packs installed at ~112 kWh each)
- **Important:** Vehicle control will restrict that energy to usable energy

test nr.	route	total weight [t]	charge
1	flat	10,5	fast**
2	flat	10,5	fast
3	flat	10,5	mobile**
4	hilly	40	fast
5	hilly	40	mobile
6	hilly	40	fast

*charging aborted
**fast P_{max} = 150 kW; mobile P_{max} = 40 kW

Results Capacity



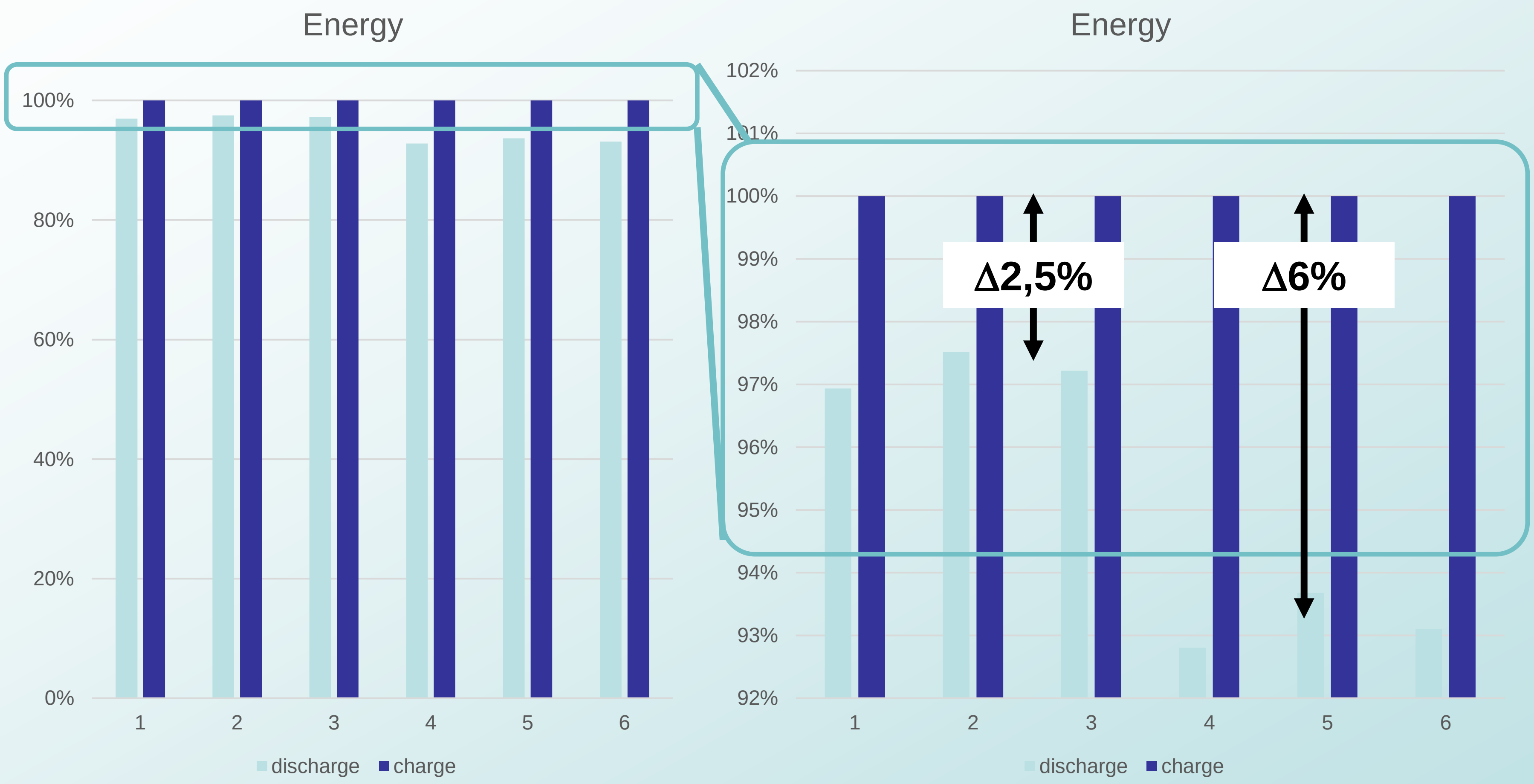
Tolerances:
Discharge: <1%
Charge: <1%

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

- no impact of road/load/ diff. charging

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

- significant impact of driving profile

Capacity vs. energy

Capacity

- very low scatter of the measurement results
- No impact of payload / route
- Very high reproducibility
- Accurate ampere sensor on-board

energy

- Still very low scatter of the measurement results within test 1-3 and 4-7 (e.g. compared to emission PEMS testing)
- „impossible“ to defince SoH over lifetime without perfectly reproduceable route and load
- Non-accurate voltage sensor on-board leads to added measurement result deviation

discharge vs. charge

discharge

- significant impact of payload / route (energy)
- with low payload level long discharge duration
- Not relalistic to discharge the last % SOC by driving (reach charging station)
- Discharge of last 1-2% SoC by cabin heater/air compressor (~10kW+5kW) , depends on vehicle installation
- Discharge with on-board auxiliary not possible for high battery energy due to required test duration
- after deactivating cabin heater by vehicle derating strategy very low load @ HV battery (even in todays convntional cars, battery charge is decreasing over time during ignition off/parking) ➔ very difficult to reach same SOC min level

charge

- no significant impact of different charging power
- with lower charging power very long charging time
- unattendet charging possible

Conclusion

1. **Energy throughput with higher correlation to SOCE** than mileage due to more diverse vehicle applications in truck business
2. **Loss of active material is domitating driver of cell aging** for all dimensions (energy, capacity, charging and discharging)
3. On road tests (reproducibility of capacity and energy amount) can be highly influenced by track profile, load and overall test conditions. **Consistent conditions can be realized more easily during charging test**

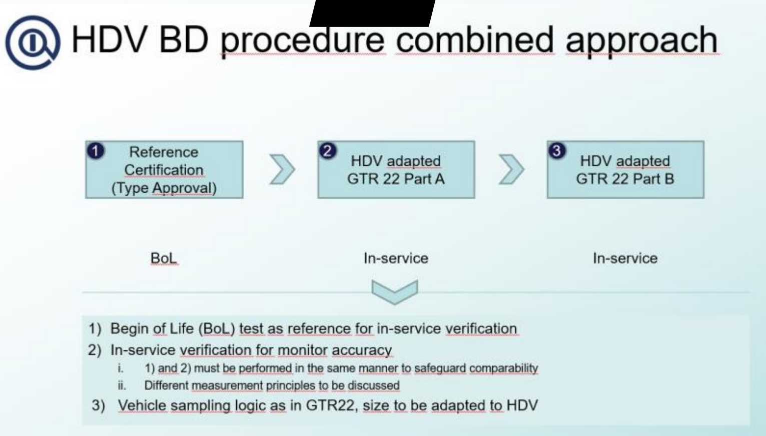
➢ **Keep flexibility regarding test procedures** as regional abilities and testing schemes are very diverse

OICA

General statement

OUR PATH OF COMMON EVE IWG AGREEMENTS UNTIL TODAY

1)



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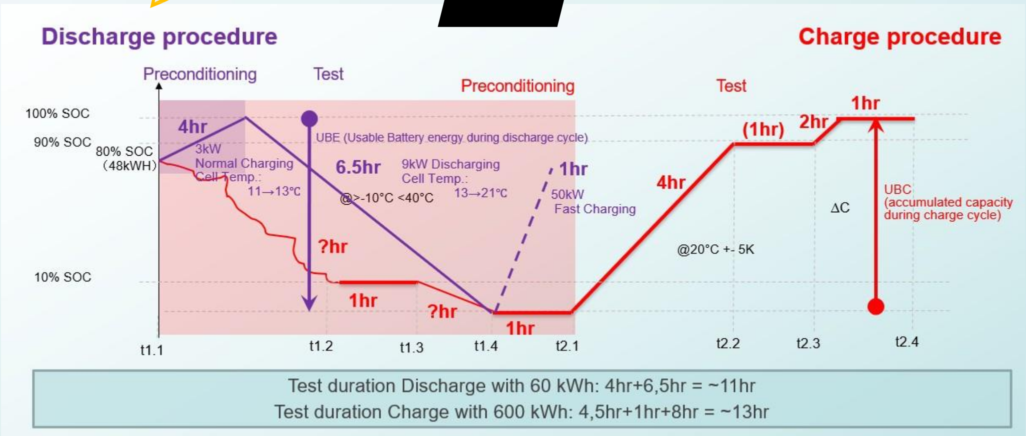

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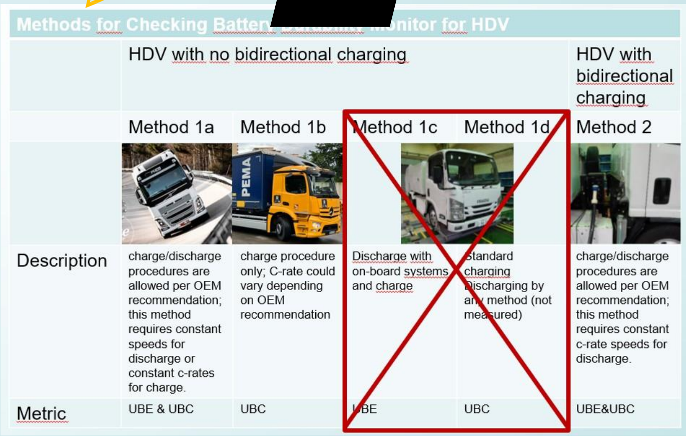


Methods for Checking Battery Durability Monitor for HDV

	HDV with no bidirectional charging				HDV with bidirectional charging
	Method 1a	Method 1b	Method 1c	Method 1d	Method 2
Description	charge/discharge procedures are allowed per OEM recommendation; this method requires constant speeds for discharge or constant c-rates for charge.	charge procedure only; C-rate could vary depending on OEM recommendation	Discharge with on-board systems and charge	Standard charging Discharging by any method (not measured)	charge/discharge procedures are allowed per OEM recommendation; this method requires constant c-rate speeds for discharge.
Metric	UBE & UBC	UBC	UBE	UBC	UBE&UBC

EVE IWG stakeholder's Achievements

1) We started with a general orientation early 2022, as a „truckified" GTR22
2) OICA proposed & measured possible procedures (more to follow…)
3) We aligned on remaining test-candidates with highest potential

AFTER 12 MONTH OF EVALUATION AND FIRST TESTING, OICA WOULD LIKE TO SUMMARIZE THE FOLLOWING

Our working group‘s core challenges

1) **HDV-Trucks are no passenger cars → scale!**
2) **Battery usage (driving + PTO), set up and variety from Truck to Truck is much higher –> complexity!**
3) **Customers demand their Trucks being available for daily operation in full function without any damage → running business!**

Basic principles:

1) **Non-invasive measurement procedures:** customer vehicles in service must be operated safely and without damaging the customers’ property

2) **External equipment while driving very problematic (robust measurement, non-invasive, vehicle hardware only for regulation):** Homologation of internal current sensor (high accuracy anyways basis for good battery performance) and checkup via repeated in service measurements

3) **Measurement procedure options charging and discharging:** to recognize different infrastructures and vehicle types

4) **Flexibilities on metrics capacity vs. energy:** taking different accuracies and allowed tolerances into account

5) **Additional lifetime requirement:** full cycle equivalent more meaningful than mileage in heavy duty business.

Part A – Monitor verification: comments

PART A: EXTERNAL MEASUREMENT EQUIPMENT

…Statement EVE IWG 64th meeting from Aaron Loiselle-Lapointe:

1) ***„We have measured LDV and HDV voltages many times.***
   a) *We often do this without OEM support but have robust procedures to do so safely.*
   b) *HIOKI is the gold standard for power measurement and*
   c) *we have a voltage divider to ensure that any wire exiting the vehicle to a power analyser is carrying a voltage between 0-10v maximum.*
2) ***Secondly, in regards to standardized voltage tap locations: we have tested vehicles that have voltage taps built into their electric powertrain.***
   a) *They are easy to access **despite the battery pack itself being built deeply into the chassis**. I personally like this idea.“*

PART A: POSSIBLE MEASUREMENT STRATEGY

INTERNAL VS. EXTERNAL SENSORS

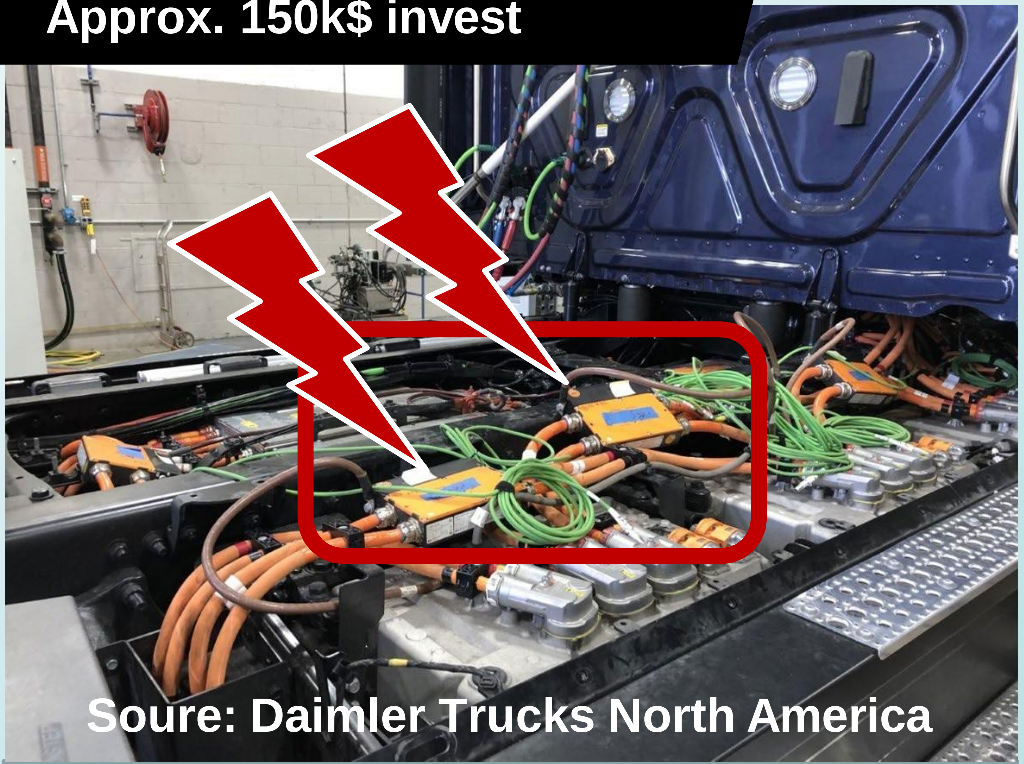
Battery current
Could be measured using a non-invasive method (measure magnetic field around conductor)
boundary condition: Single wire per potential + non-shielded

Link voltage
Can be measured using the voltage measurement port (only during standstill, adapter needed)

Cell voltage
Sum of cell voltages could be compared with link voltage measurement to check accuracy

⇒ Accuracy of voltage and current sensor could be validated without disassembling HV network
⇒ Still Accuracy of current sensor higher than voltage based on measurement knowledge

Approx. 150k$ invest



Soure: Daimler Trucks North America

Statement: if any external measurement equipment has to be applied, only non-invasive allowed
If HV cables are shielded – (HIOKI) inductive clamps will not work!

PART A: FURTHER ARGUMENTS AGAINST EXTERNAL CURRENT MEASUREMENT TECHNOLOGY IN VEHICLES

HV Breakout-Modul Typ 1.1 Seitenansicht


HV Breakout-Modul Typ 1.1 Ansicht von oben

Metrology in HV system:

- Intervention in the HV circuit of the vehicle
- Disconnect HV lines in front of each battery to install current sensors.
- After that, damaged pipes or new lines are necessary.
- Only possible with highly qualified personnel with special measurement technology.
- Risk of errors, accidents, damage to the HV system.

Analogy to internal combustion engine:

- PEMS measurements also rely on the torque/power signal from the engine control unit.
- The signal is previously homologated in a test bench certification.

Current Sensor Battery:

- Highly accurate. Necessary for OEM to operate cells safely.
- EU specific: If necessary, it could also be validated in battery pack certification on test

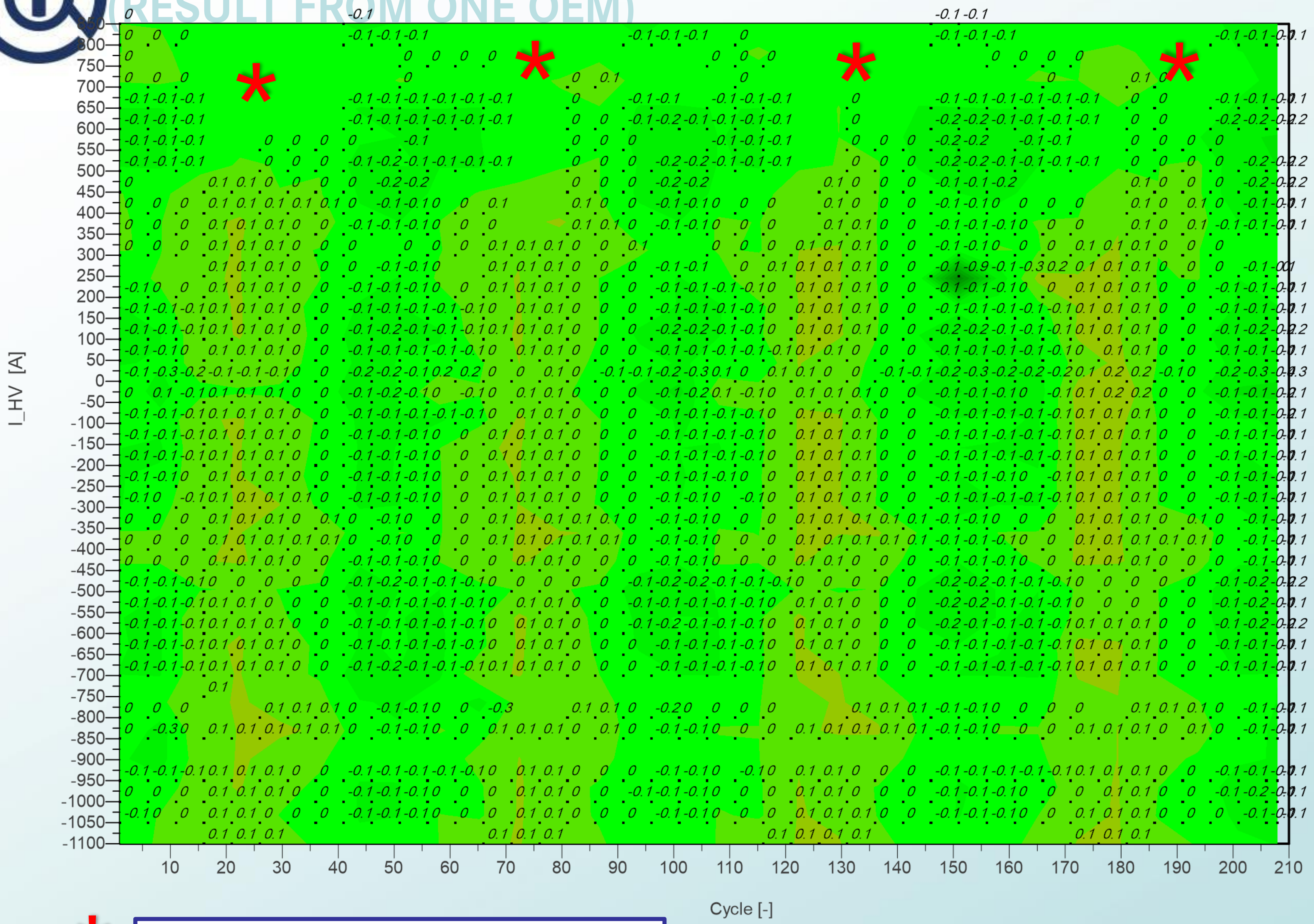
Analogy to UN GTR21, 6.1.2

6.1.2. Required measurements

The test vehicle shall be instrumented with measurement devices for measuring the necessary input values for the power calculation.

As an alternative to use of measurement devices, use of on-board measurement data [for engine speed, intake manifold pressure, and fuel flow rate]is permissible. [Use of onboard measurement data for other measurements 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 5.2] | [If TP1 is applied for the system power

NEARLY ZERO DEVIATION FROM TEST BENCH CURRENT SENSOR TO BMS (RESULT FROM ONE OEM)



* Load points not possible in cold condition

I_HV: Average Values (1s Stationary)

Deviation Test Bench Current Sensor to BMS [%]:

- X-Axis: Cycles
- Y-Axis: Current Range
- Z-Axis: Middle Value of Deviaton

-> Very good Accuracy
-> No Drift
-> Tendency of warm/cold conditions can be seen

Question:
Since BMS current sensors have already very high accuracies, why would an external measurement be neccessary?