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

EVE IWG - Session 64

-online-

September 19th, 2023

TEST PROCEDURE DISCHARGE & CHARGE

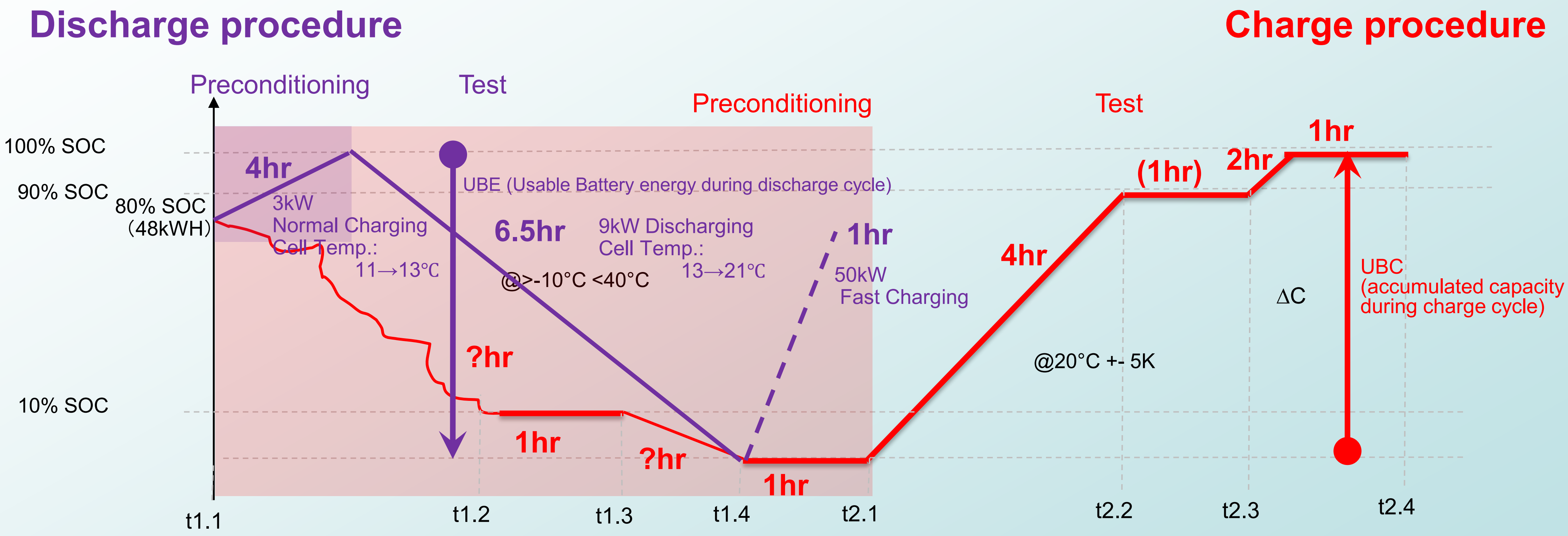
We are convinced that GTR22b shall give authorities and OEMs the **choice between different procedures** (independend from vehicle weight or type):

- Charging as reference
- Discharging as reference

<u>Based on:</u>

- testing infrastructure and
- market specific boundary conditions

OICAS MEMBERS MADE FIRST TESTS ON THEIR PROPOSALS



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

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]
-

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

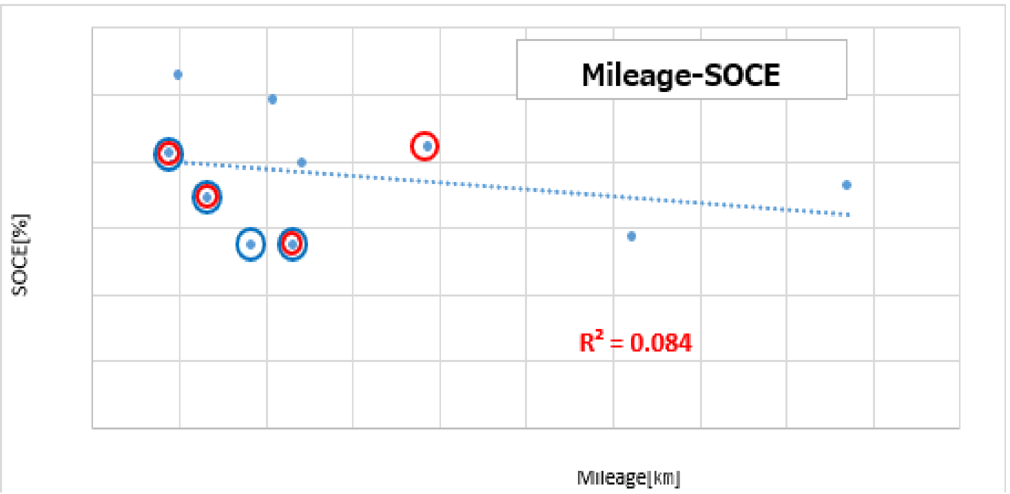
RESULTS

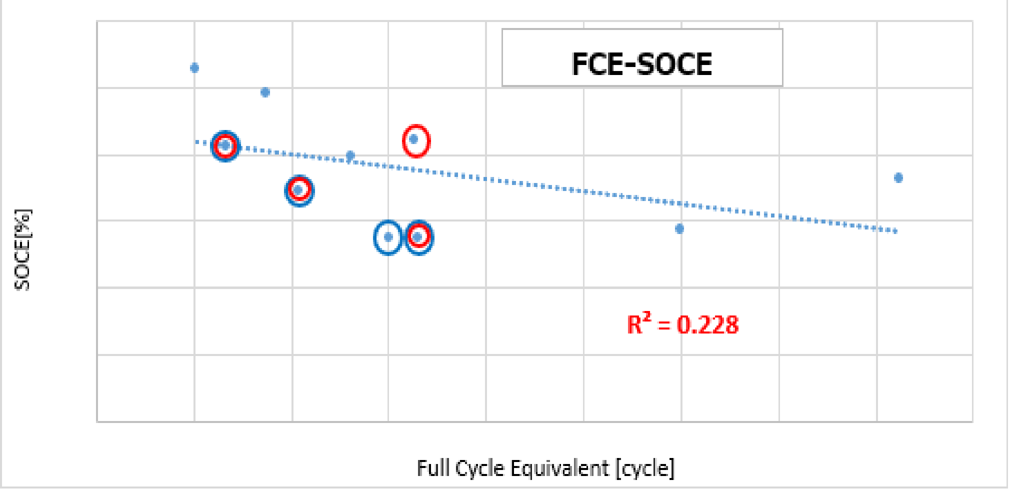
Veh. No	Customer	Numbers of Pack	Fridged Truck	Duration [months]	Mileage odo [km]	Energy Throughput [kWh]	FCE Full Cycle Equivalent [cycle]	SOCE [%]
1	BB1	2	+					
2	BB2	2	+					
3	AA1	1	-					
4	BB3	2	+					
5	BB4	2	+					
6	BB5	2	-			*1		
7	AA2	1	-					
8	AA3	1	+					
9	BB6	2	+					
10	AA4	1	-					

*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.



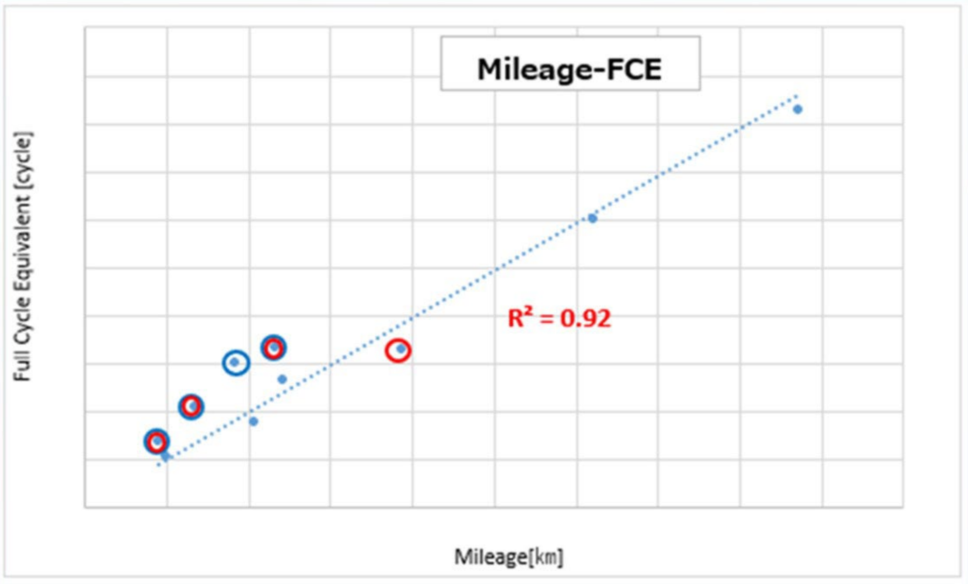


CONCLUSIONS

<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

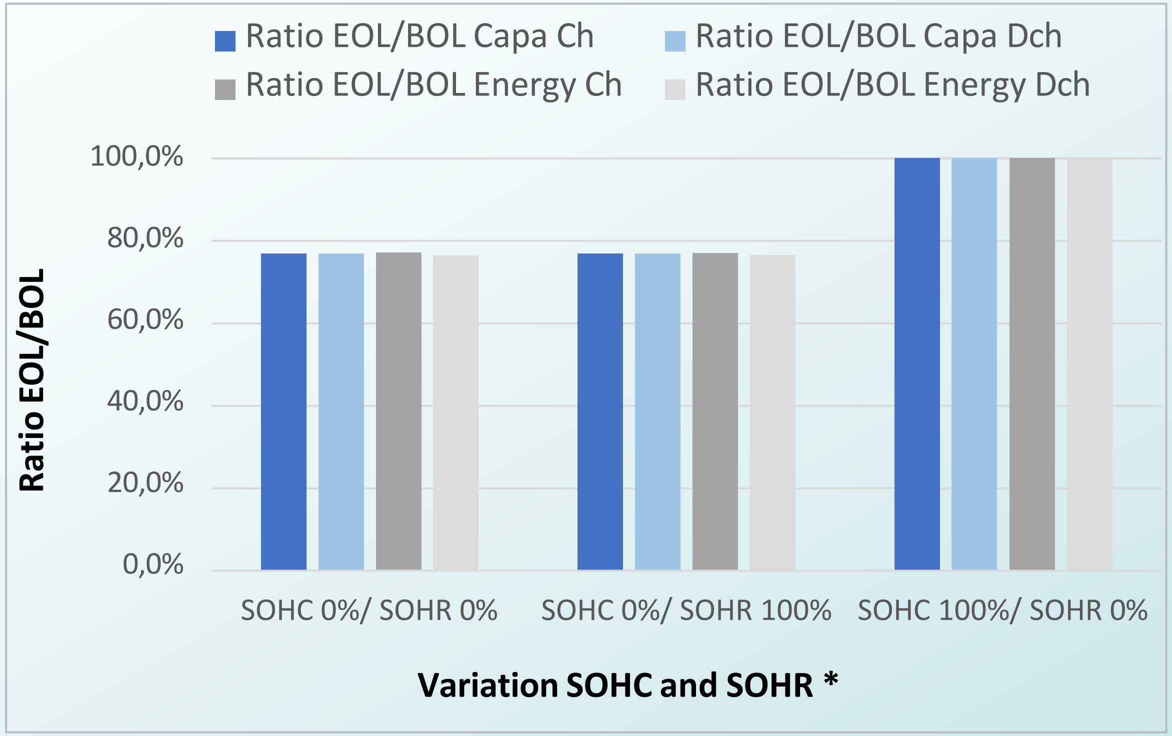
Test conditions:

- Results on battery level
- Simulation results based on measurement results

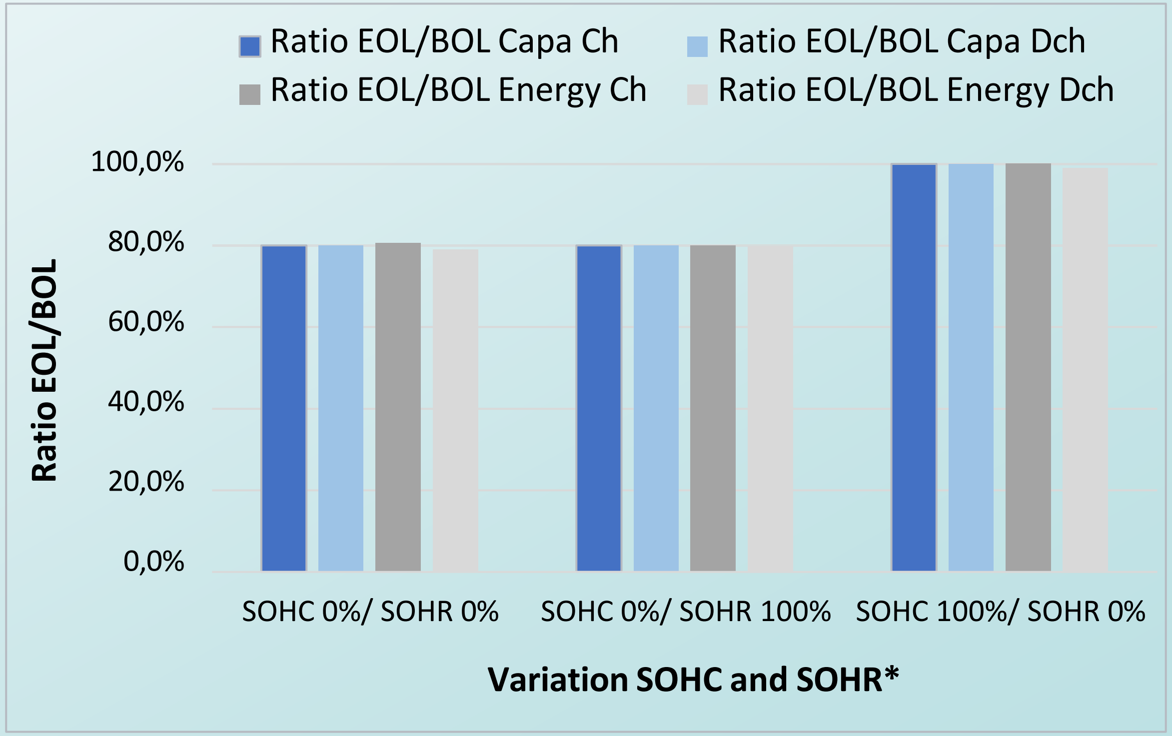
- Customer-oriented real-world charging and driving profile
- Charge/ discharge rate EOL/ BOL testing with C/3 (constant)

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

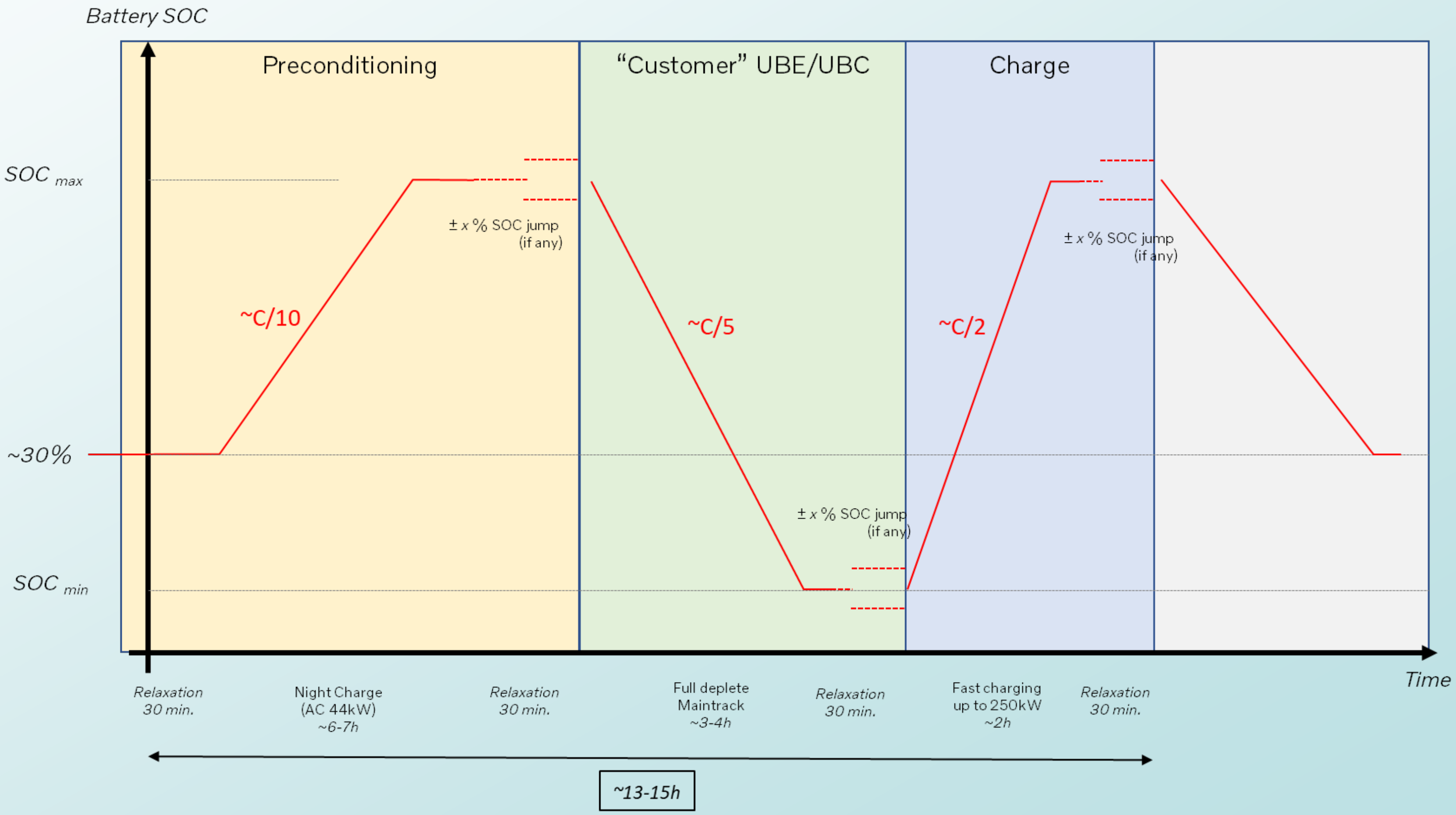
Volvo UBE/UBC

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.

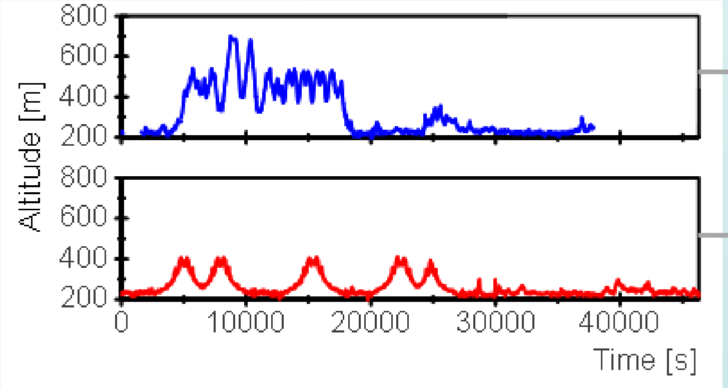
charge

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

route

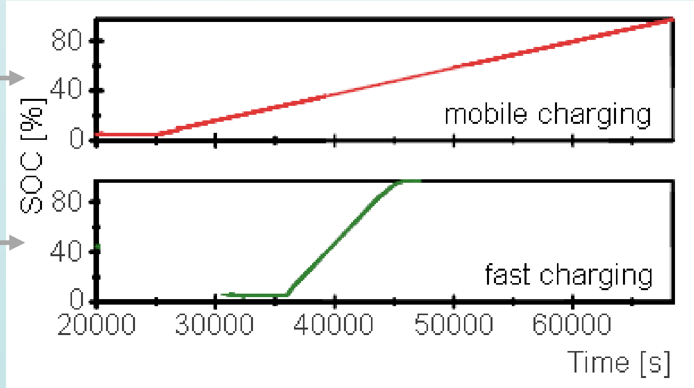
veh. weight

charge



40t

10,5t



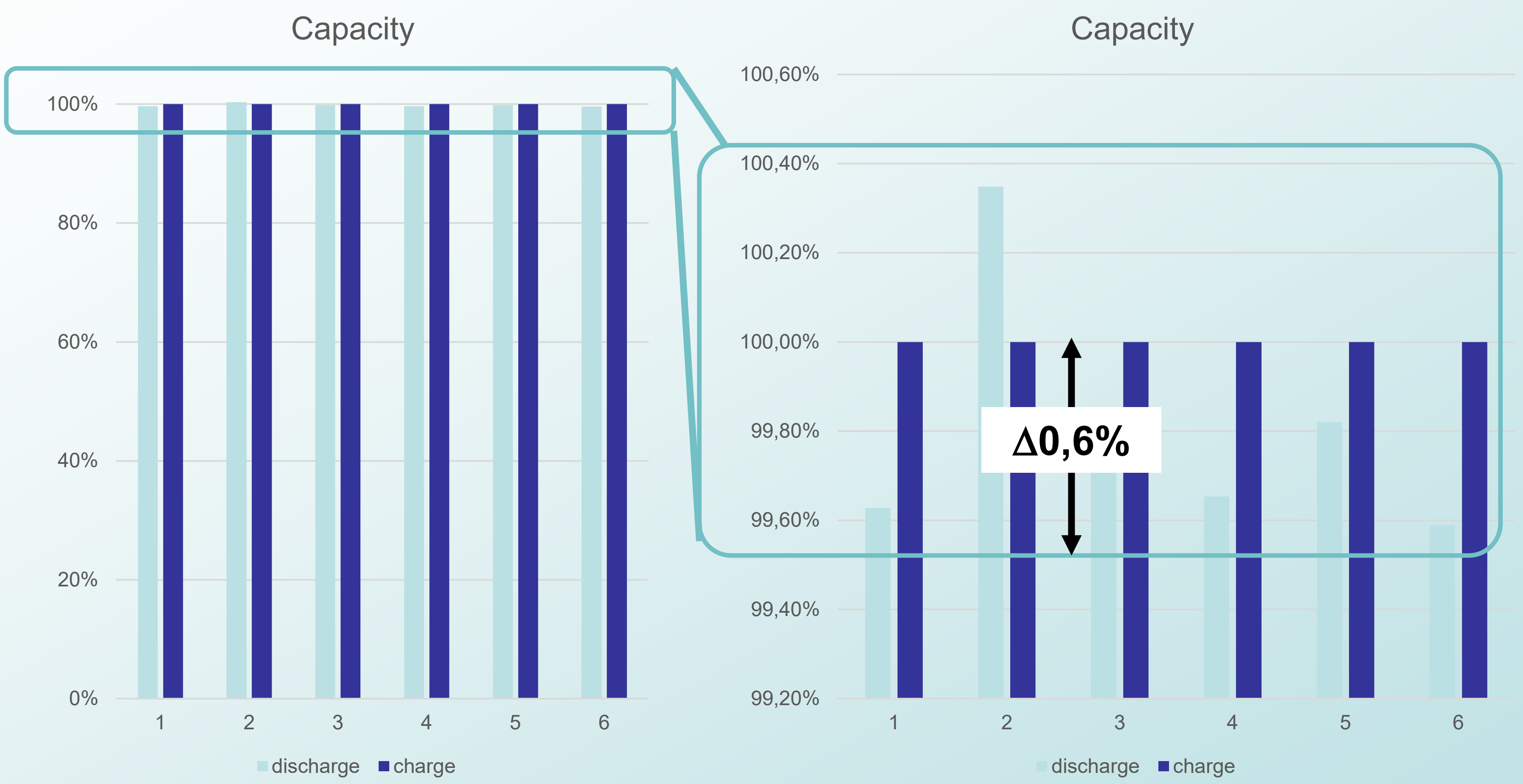
Test vehicle & tests

- 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%

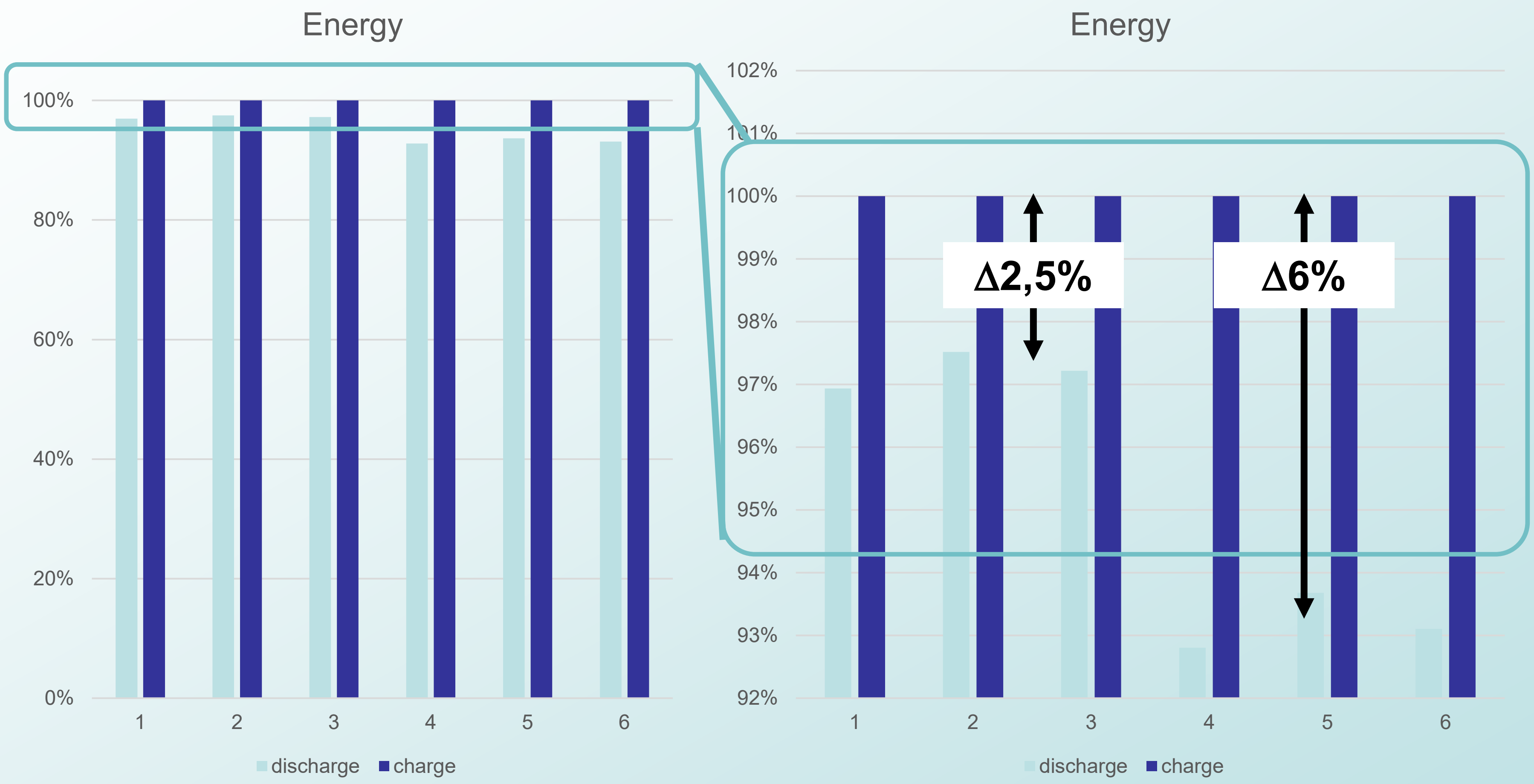
test Nr.	route	charge
1	flat 10,5t	fast
2	flat 10,5t	fast
3	flat 10,5t	mobile
4	hilly 39t	fast
5	hilly 39t	mobile
6*	hilly 39t	fast
7**	hilly 39t	mobile

* 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

Backup

BACKGROUNDS

In GTR22, SOCE (%) MPR criteria are "Year" and "Mileage".
It was created with reference to Geo-TAB market data and the JRC TEMA model.
<GTR22> MPR metrics: 5 years 100,000 km_SOCE80% or 8 years 160,000 km_SOCE70% <Backstop:10%>.

Figure I/1
Example of a capacity retention curve generated from JRC TEMA modelling for two different BEV configurations

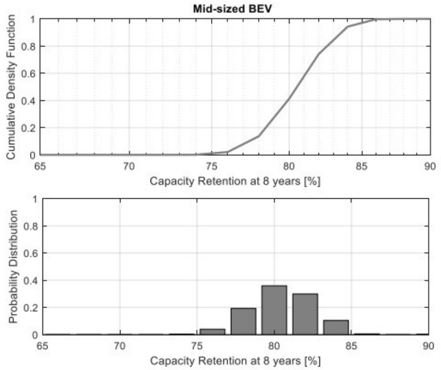
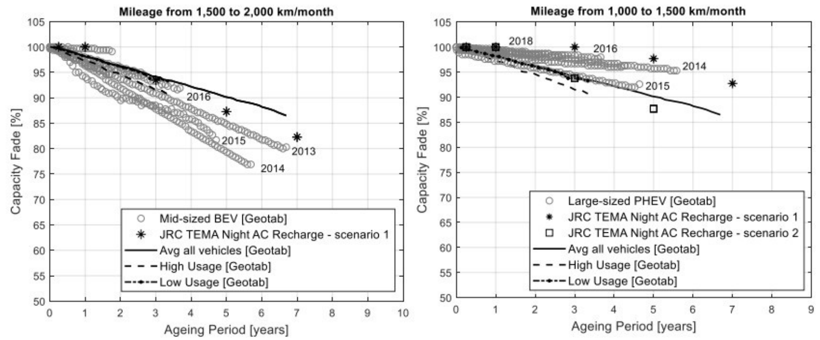


Figure I/2
Example comparison between estimated results from the TEMA model with in-use data from Geotab



<HD New GTR >
HD Commercial vehicles (N2/N3, M2/M3) which is a GVW exceeding 3.5ton generally have various energy consumption structures other than running such as refrigeration and cabin air conditioning .
And, for PEV/OVC-HEV HD commercial vehicles, we believe that "energy consumption" is more appropriate than "mileage" as an MPR metrics.
Therefore, we investigated the difference in the degree of correlation between SOCE and "mileage" or "energy consumption".

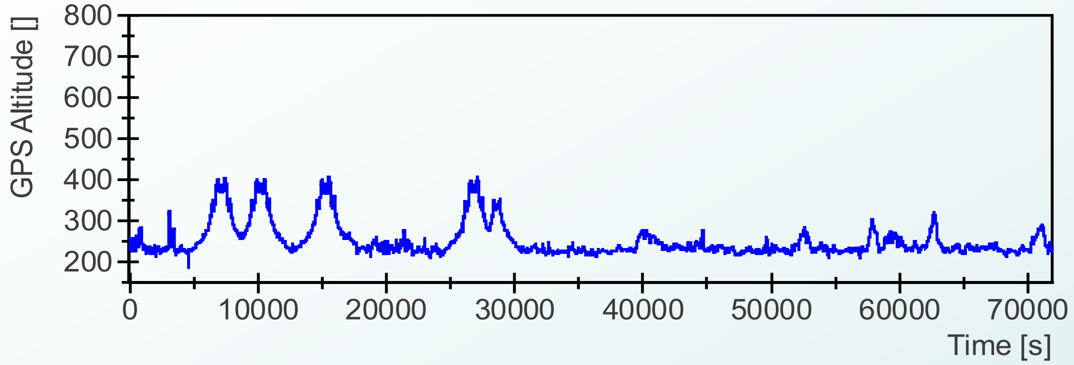
CONCLUSIONS

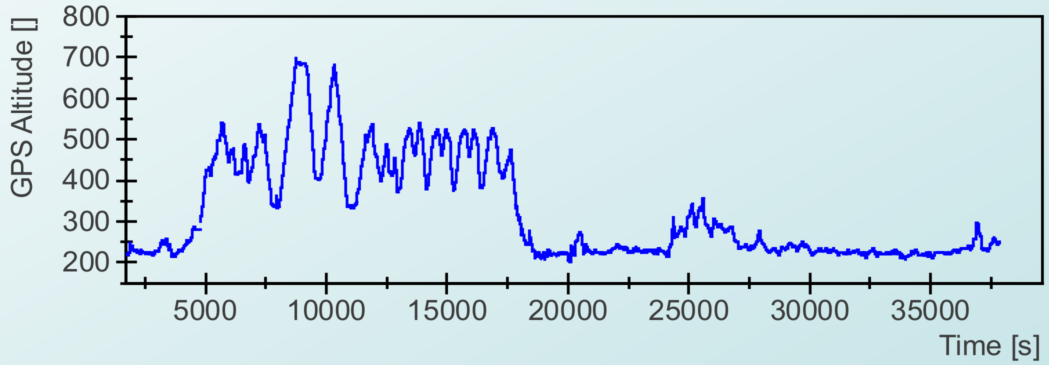
Proposal;

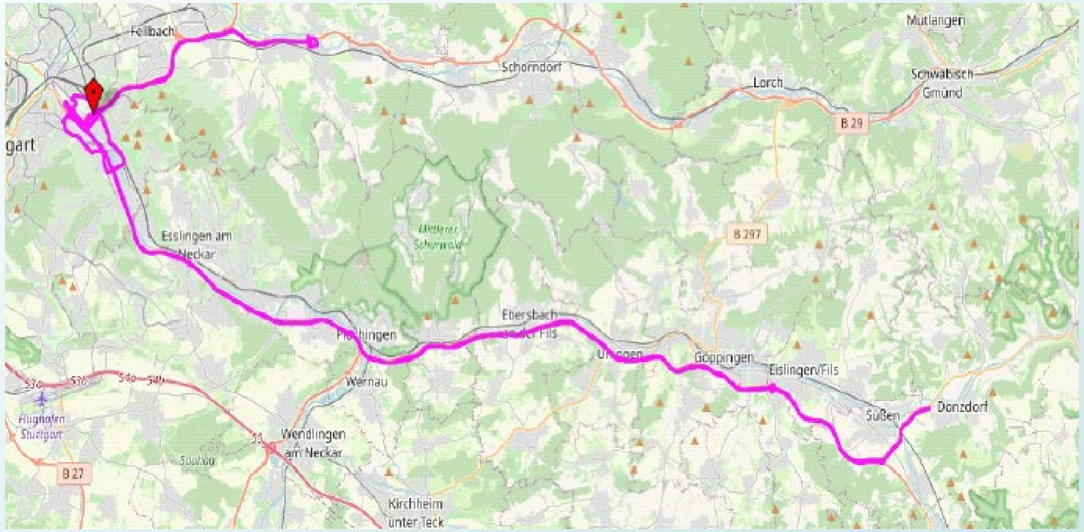
- This time, the results are based on limited market data, and data from a wider range of vehicle classes (over 7.5 tons, garbage trucks, etc.) need to be included.
  Therefore, for the new HD GTR, we would like to ask to set up a market monitor for Part A, just like GTR22. and we would like to set "Energy Consumption (FCE)" as a collection factor, collected data similar to "Mileage", and evaluated the correlation with changes in SOCE.
- Since it is not possible to discuss the MPR judgment threshold setting of 10% backstop based on this data at this time, we request that it be reserved until after the analysis of the market monitor in Part A.
- We believe that the "Energy Throughput (lifetime value)" registered in SAE for GTR22 will also be collected for the new HDV GTR.
- The newly defined "FCE [cycle]" may require SAE registration

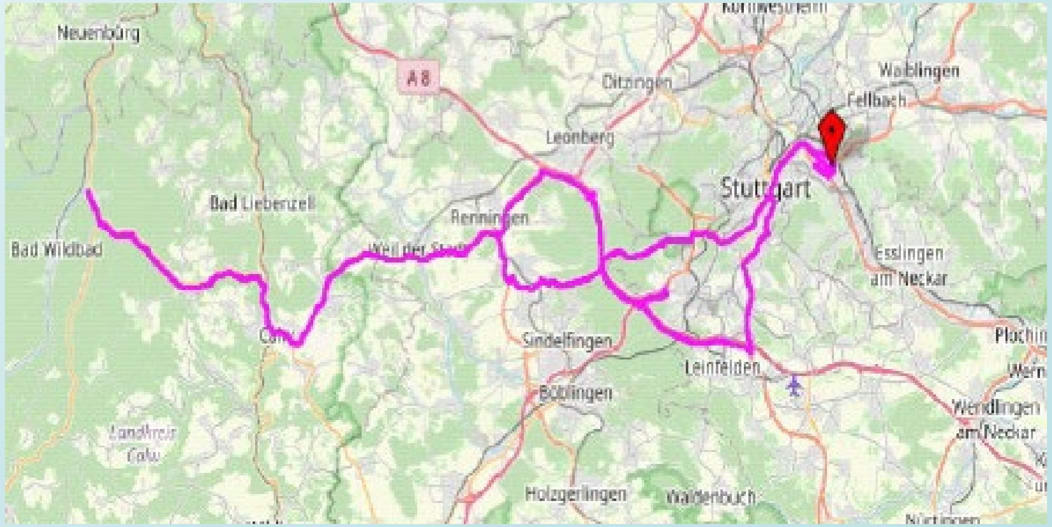
$$\text{FCE [cycle]} = \frac{\text{Energy Throughput}_{\text{on-board memory}}\ [\text{kWh}]}{\text{UBE}_{\text{certificated}}\ [\text{kWh}]}$$

Test routes – GPS

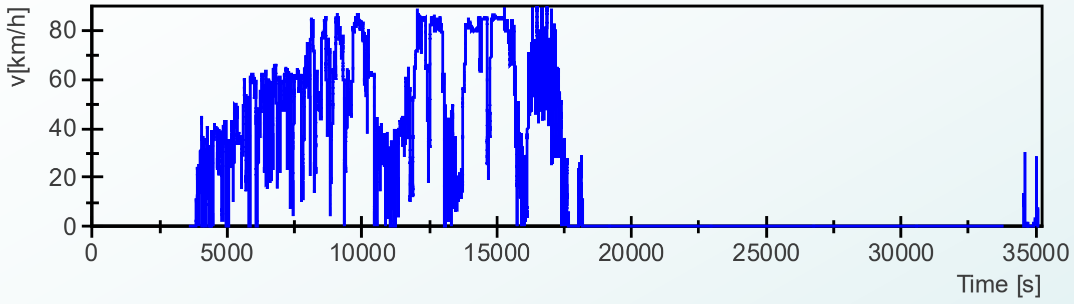


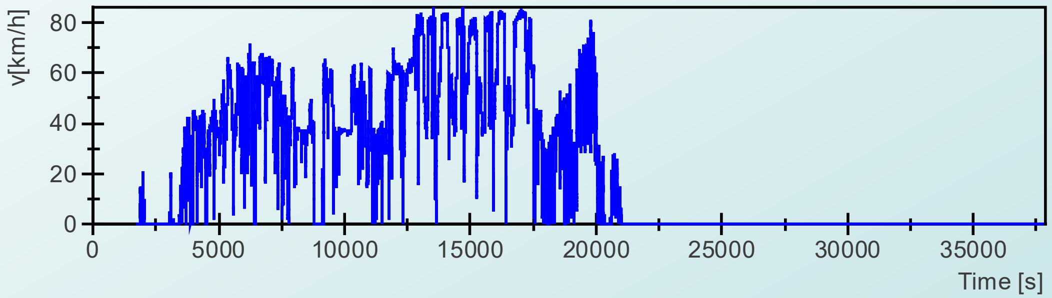


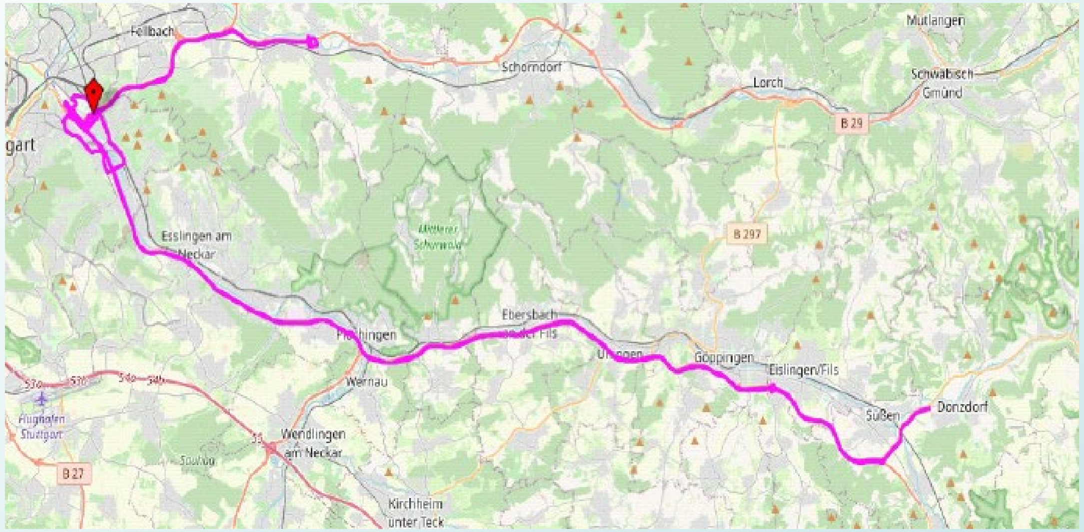


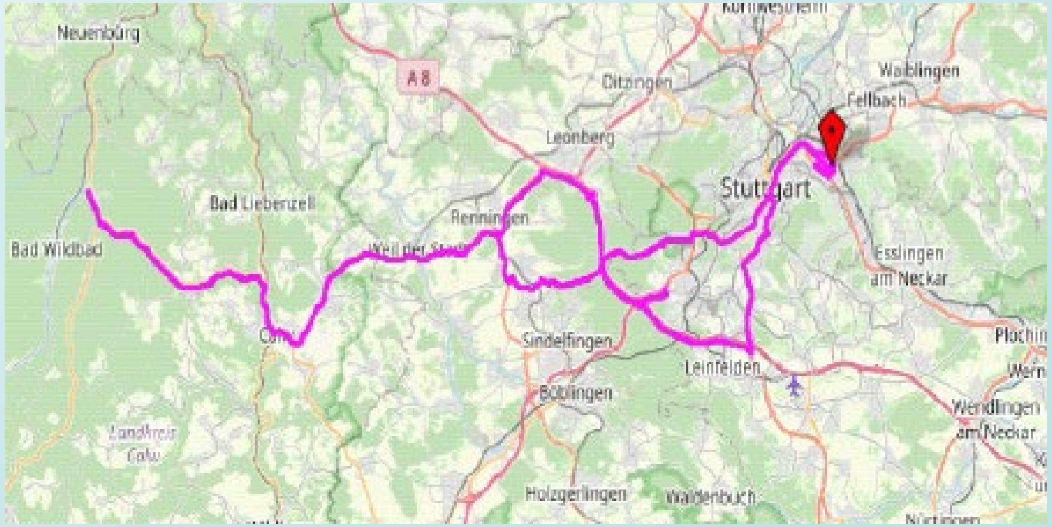


Test routes – Velocity

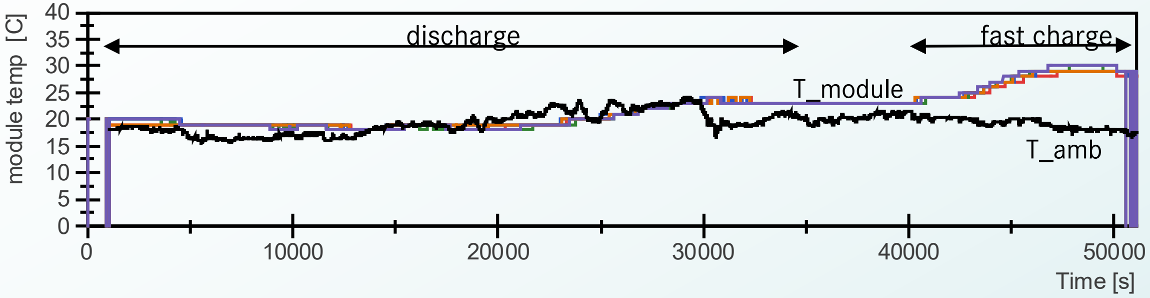


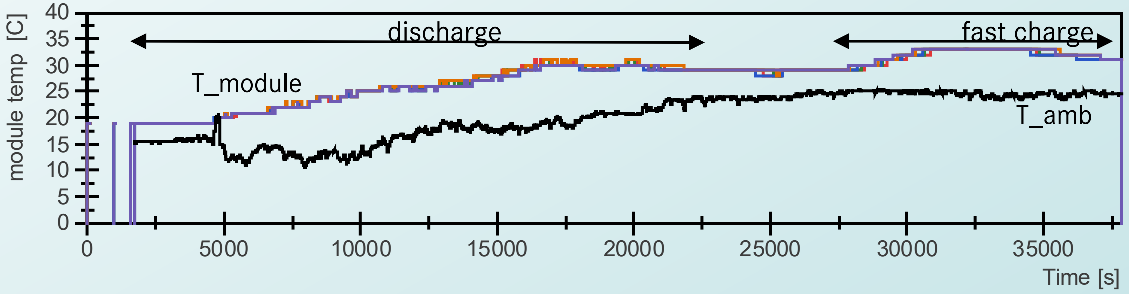


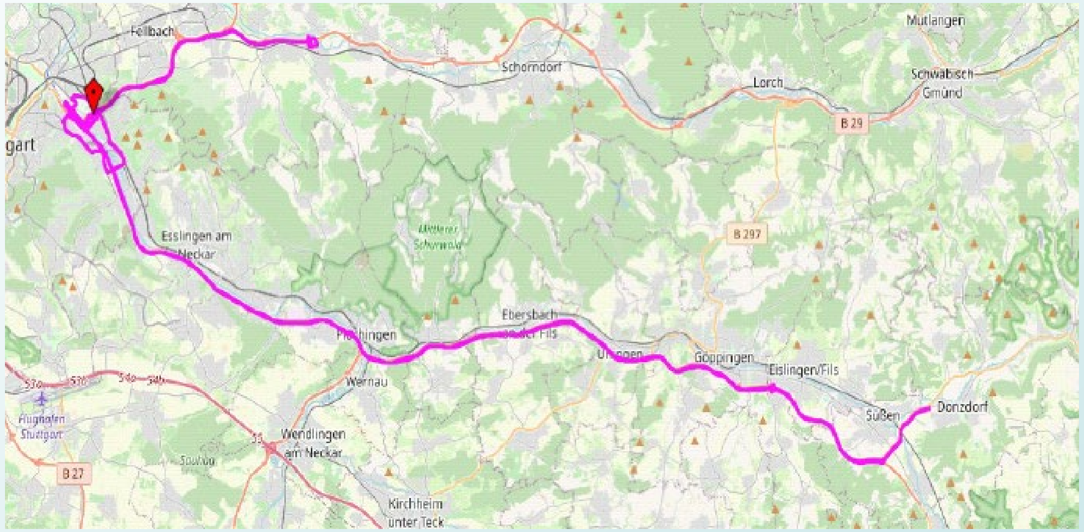


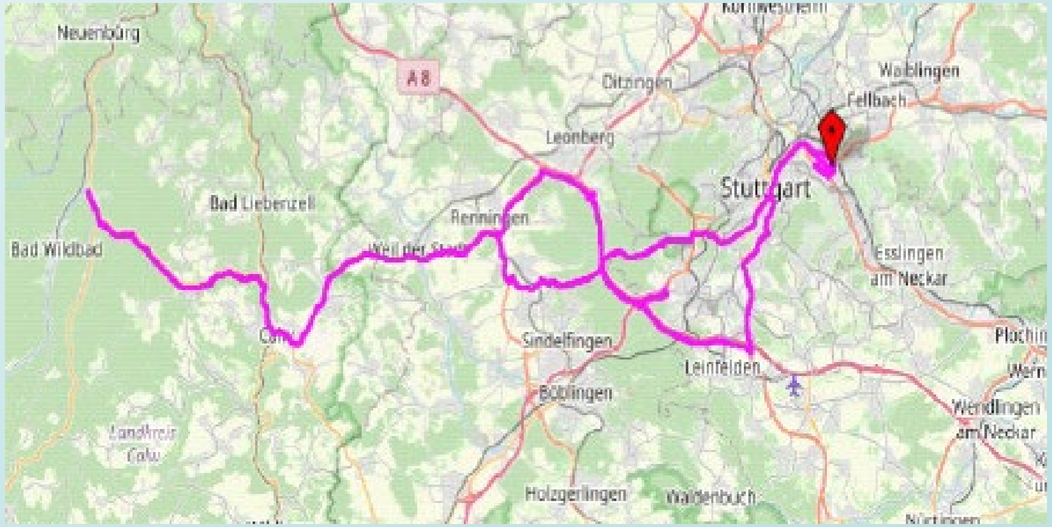


Test routes – Pack Temperatures





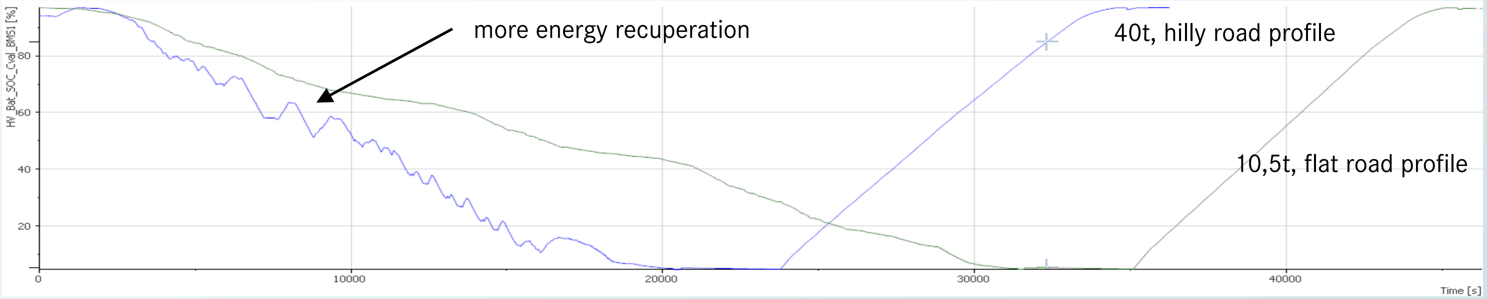




Test duration discharge

~0% payload 10.5t

~100% payload 40t

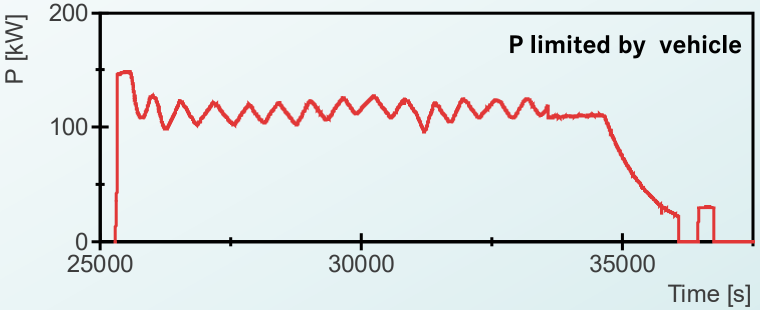


	hilly road profile 40t	flat road profile 10,5t
driving time	~4,5h	~8,5h
distance	~210 km	~450 km
recuperation	high	low

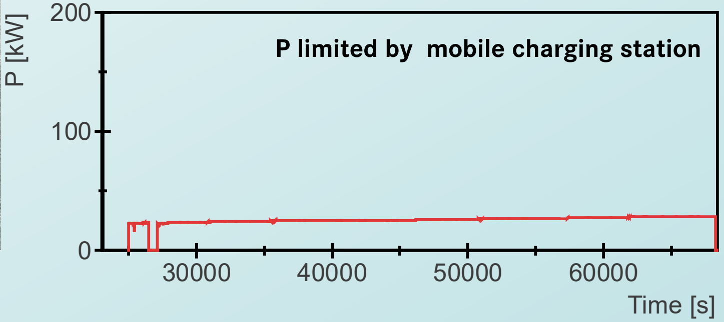
In comparison: To discharge batterys from eActros 400 (~440 kWh battery energy physically installed) with 0% payload by real driving cycle >10h estimated (more than the max permitted driving period for one driver). **Meaning:** the bigger the battery the longer the discharge duration on low loads.

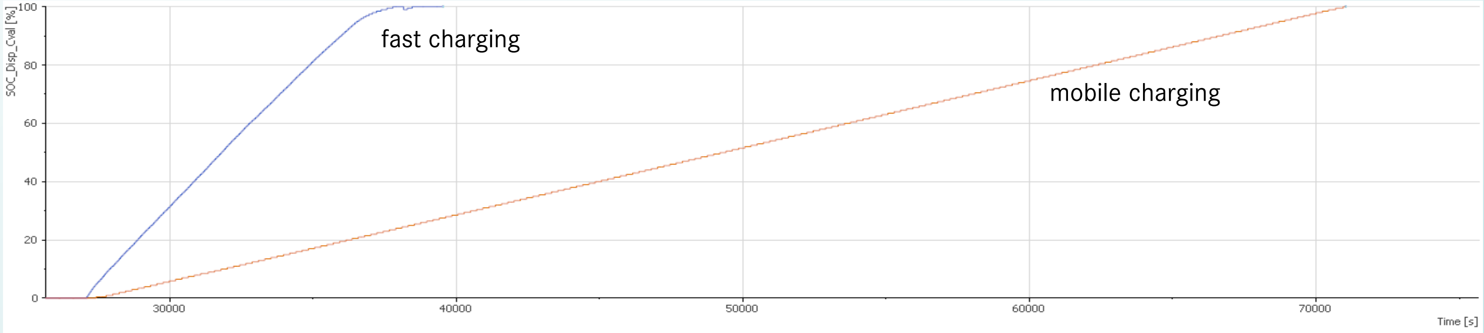
Test duration charge

max. 280kW



max. 40kW





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