EVE In-Vehicle Battery Durability

OICA TF EVE presentation for 36th EVE IWG day 2

July 7th, 2020 (web-audio)

EVE In Vehicle Performance Durability

Performance Criterion Capacity vs Range

Industry evaluation how to link the SOH indicator/battery durability indicator to capacity or range:

1. **Same for PEV and OVC-HEV → either range or capacity**
2. **Homologated figure from Type Approval as reference**
3. **Same physical test procedure in ISC as in TA (Vehicle test, not component test)**

	Vehicle test on chassis dyno		
	Capacity		Range
	UBE	E_AC	
Reflects battery performance	★★★	★★	★
Reflects total vehicle performance	★★	★★	★★★
Test to test variation	★★★	(★★) (★★★)	★
ISC / 3rd Party testing ability	★★ (ok with onboard data)	★★★	★★ (ok with onboard data)
Conclusion	• Reflects best the remaining battery energy • Lowest test to test variation	• Good reflection of most parameters • Most easy to check through 3rd Party • Charging losses need to be considered	• Best for total vehicle performance • Test to test variation too high

- SOH-indicator/battery durability indicator based on UBE reflects the remaining energy of the battery in %
- Actual warranty from OEM is also based on remaining energy of the battery, not on vehicle range
- Beneficial: UBE is a general parameter which does not differ in definitions of regional legislation and would allow to provide harmonisation for different TA test procedures

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OVC-HEV and PEV: UBE determination vs. E_{AC} measurement

- To measure E_{AC} for OVC-HEVs in the same way than in Type Approval, you need to have the same income condition in ISC than in Type Approval
  → Before starting E_{AC} measurement, end-of-test criterion from the test procedure needs to be met (NEC or SoC criterion in US, REEC criterion in WLTP)
  → Means: current and voltage need to be measured and recorded anyway

- When measuring E_{AC}, the recharging losses will be measured as well
  → Recharge losses are changing depending on what charging device is being used (maybe the one used in TA is not available anymore when vehicle is coming to ISC)
  → Recharge losses are also depending on the grid performance (less/more performant grid has influence on length of charge duration and therefore on losses)
  → Means: E_{AC} need to be converted to E_{DC} to eliminate the recharging losses (adding complexity)

- If E_{AC} is not fitting together with battery durability indicator, the reasons could be various:
  - Battery
  - Recharge device
  - Grid

<u>Solution:</u>

Select UBE → measurement of current and voltage for OVC-HEVs required anyway; eliminating the not required complexity coming with EDC which is adding not additional value and which does not ease the measurement; option to use onboard-data a must as ISC-test done on customer vehicles

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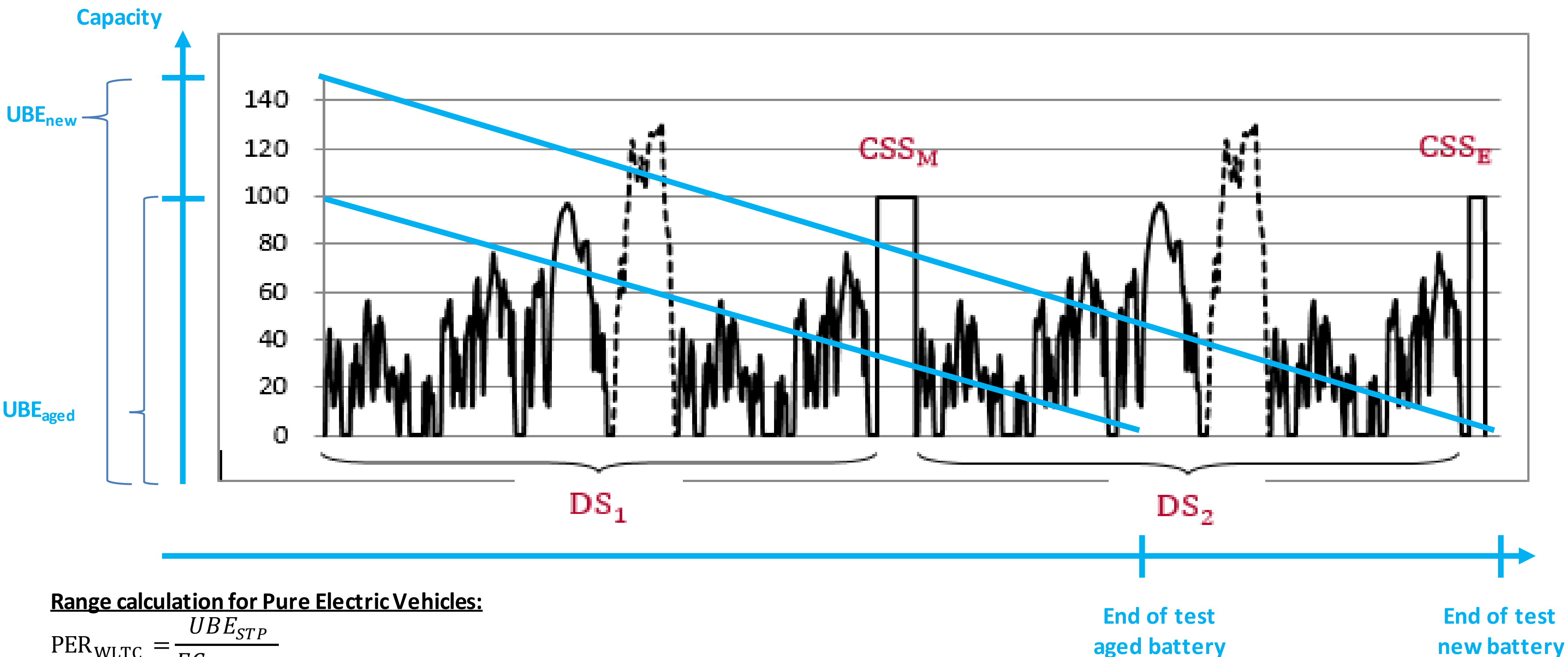
PEV: Range calculation vs. UBE determination out of Shortened Test Procedure



Range calculation for Pure Electric Vehicles:

$$PER_{WLTC} = \frac{UBE_{STP}}{EC_{DC,WLTC}}$$

where:

$$UBE_{STP} = \Delta E_{REESS,DS_1} + \Delta E_{REESS,DS_2} + \Delta E_{REESS,CSS_M} + \Delta E_{REESS,CCS_E}$$

$$EC_{DC,WLTC} = \sum_{j=1}^{2} \frac{\Delta E_{REESS,WLTC,j}}{d_j} \times K_{WLTC,j} \text{ with } K_{WLTC,1} = \frac{\Delta E_{REESS,WLTC,1}}{UBE_{STP}} \text{ and } K_{WLTC,2} = 1 - K_{WLTC,1}$$

Note (Annex8, Paragraph 4.4.2.):

The ranges determined shall only be calculated if the vehicle was able to follow the applicable WLTP test cycle within the speed trace tolerances during the entire considered period.

Problem with range:

- **Range is not just a read out of the test bench, it is value calculated based on UBE** and the energy consumption in the relevant cycle phases
- A deteriorated battery could lead to the situation that the range value cannot be calculated based on the given calculation scheme (if e.g. in the second WLTP cycle, the vehicle cannot follow the prescribed driving curve within the given tolerances)

Solution:

- Select UBE → Determination of UBE would be independent from that as this is referring to the start and to the end of the test procedure only

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PEV: Range calculation vs. UBE determination in context of test to test variation

Range is not only sensitive to the battery performance but also sensitive on effects coming from parameters not related to the battery, e.g.

- the driver,
- the test bench,
- the road load adjustment
- other effects coming from the power train

As impact of these not-battery-related factors on UBE is lower, UBE has a lower test to test variation.

→ Further explanation see next slides

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PEV: Range calculation vs. UBE determination in context of test to test variation

Explanation based on calculation scheme

Range calculation for Pure Electric Vehicles:

$$\mathrm{PER}_{\mathrm{WLTC}} = \frac{UBE_{STP}}{EC_{DC,WLTC}}$$

where:

$$\mathrm{UBE}_{\mathrm{STP}} = \Delta \mathrm{E}_{\mathrm{REESS,DS_1}} + \Delta \mathrm{E}_{\mathrm{REESS,DS_2}} + \Delta \mathrm{E}_{\mathrm{REESS,CSS_M}} + \Delta \mathrm{E}_{\mathrm{REESS,CCS_E}}$$

And:

$$\mathrm{EC}_{\mathrm{DC,WLTC}} = \left(\frac{\Delta \mathrm{E}_{\mathrm{REESS,WLTC1}}}{d_{WLTC1}} \times K_{WLTC1}\right) + \left(\frac{\Delta \mathrm{E}_{\mathrm{REESS,WLTC2}}}{d_{WLTC2}} \times K_{WLTC2}\right)$$

With

$$\mathrm{K}_{\mathrm{WLTC,1}} = \frac{\Delta \mathrm{E}_{\mathrm{REESS,WLTC,1}}}{\mathrm{UBE}_{\mathrm{STP}}} \text{ and } \mathrm{K}_{\mathrm{WLTC,2}} = 1 - \mathrm{K}_{\mathrm{WLTC,1}}$$

- More aggressive driver during DS 1 and DS 2 → higher ΔE in shorted distance d, means higher EC
- No impact of more aggressive driver in CSS_M and CSS_E (no dynamic, just constant speed)

➔ Influence of driver on UBE will get lower, the bigger the REESS will be
➔ Influence of driver on EC will remain same as EC always just based on the two cycles
➔ Influence of driver on range would be there two times → 1 x for UBE (getting less), 1 x for EC (remain identical)
➔ Means: more aggressive driver can lower the range value without lowering the UBE

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PEV: Range calculation vs. UBE determination in context of test to test variation

Additional explanation for Increased Variability in Range

	Useable Energy (kWh)	Energy Consumption (Wh/mile)	Label Range (mi)
Roadload adjustment		X	X
Non-Battery Vehicle to Vehicle Variation (generic powertrain differences, minor part differences, differences in driveline losses etc		X	X
Battery Vehicle to Vehicle Variation & Performance (fast charging / usage / storage temp /age etc.)	X	X	X
Site to site variations		X	X
Auxiliary Loads – aux load variation on cycle e.g. pump usage, trim level and options in the customer vehicles.		X	X
12V Battery (linked to aux loads) – health and SOC level of 12V		X	X
Driver (longer test cycle for range testing can lead to increased driver deviation)		X	x

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PEV: Range calculation vs. UBE determination in context of test to test variation

Data from measured vehicles

Japan data:

表 2　電気自動車のばらつき解析結果

Leaf	WLTC N=1	WLTC N=2	WLTC N=3	最大と最少 Max. difference	最大と最少 合
EV range 離 (4phase)	262km	255 km	255km	7km	2.7%
AC Charge Amount	44.68kWh	44.67kWh	44.67kWh	0.01kWh	0.0%

ACEA data:

- Study 1 → 8 tests on 2 vehicles (same powertrain, etc.), US MCT; multiple sites, multiple drivers

Study 1	UBE (kWh)	EC (Wh/mi)	Range (mi)
Max. difference	1.6%	4.8%	3.1%
Standard deviation	0.6%	1.6%	1.0%

- Study 2 → 16 tests on 4 vehicles (4 different powertrains); WLTP STP

Study 2	UBE (kWh)	Range (km)
Average Max. difference	1.2%	4.7%
Average Standard deviation	0.7%	2.2%

Vehicle	# of tests
A	3
B	4
C	4
D	5

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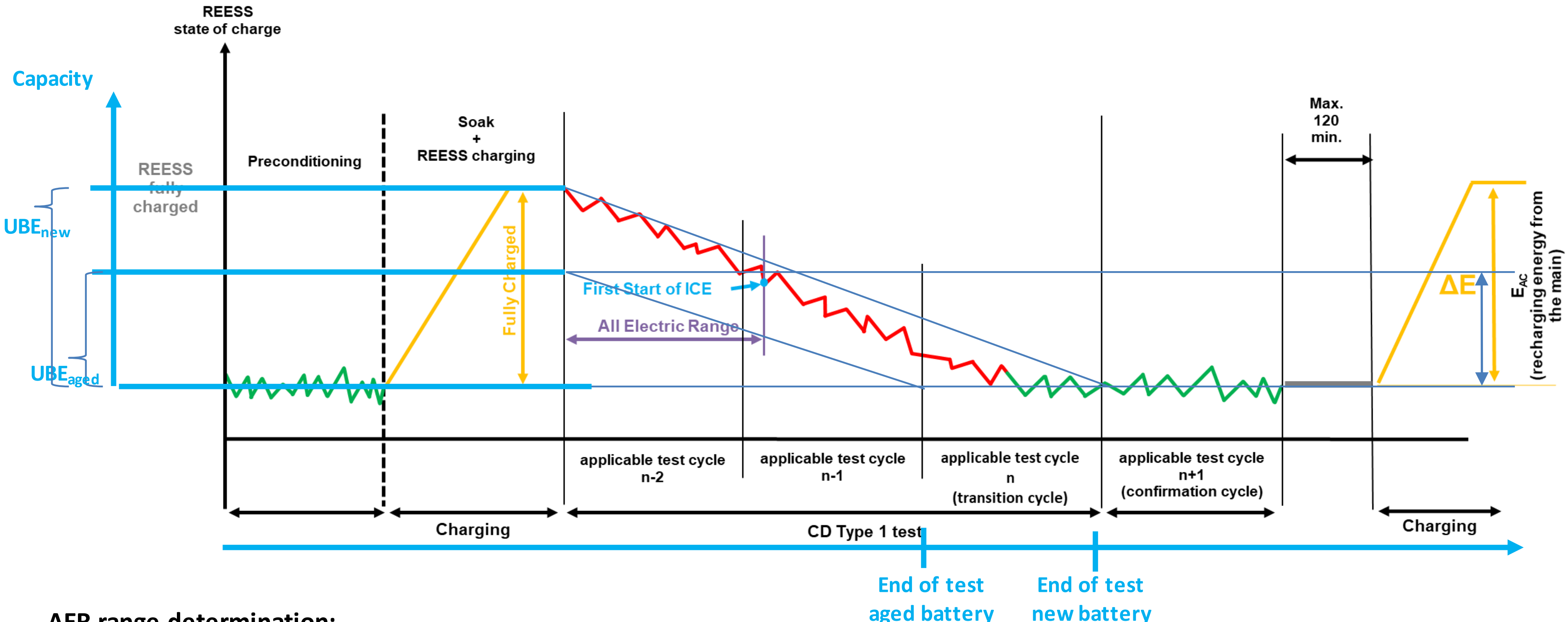
PHEV: Charge-Depleting Type 1 Test Procedure



AER range determination:

- The AER is defined as the distance driven from the beginning of the charge-depleting Type 1 test to the point in time where the combustion engine starts consuming fuel
- The start of the combustion engine can have various reasons:
  - Battery
  - Driver driving between the allowed tolerances
  - Other factors
- The not-battery-related factors could lead to a low AER range while the capacity is still ok
- Challenging/impossible to cover all this non-battery related influences in a robust battery durability indicator

Solution:

Select UBE → Determination of UBE independent from start of the combustion engine as the determination is just referring to the start and to the end of the test procedure only

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PHEV: EAER as an option to UBE if test-to-test variation acceptable?

AER is not option for industry as range parameter in the context of durability
→ Big influence of not-battery related factors (see previous slide)
→ AER in case of a blended PHEV ➔ no value

<u>EAER as an option:</u>
EAER could be an option as it is indirectly related to the battery capacity:
→ less capacity means higher average CD CO_2 mass emission during the Charge-Depleting Test
→ Disadvantage EAER: not only CD-test required but also CS-test

EAER is not only sensitive to the battery performance but also sensitive on effects coming from parameters not related to the battery, e.g.

- the driver,
- the test bench,
- the road load adjustment
- other effects coming from the power train

As impact of these not-battery-related factors on the delta E over the CD-test (UBE) is lower, Delta E (UBE) has a lower test to test variation.

→ Further explanation see next slide

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PHEV: EAER as an option to UBE if test-to-test variation acceptable?

Explanation based on calculation scheme

EAER calculation for OVC-HEVs:

$$EAER = \left(1 - \frac{M_{CO2,CD,avg}}{M_{CO2,CS}}\right) \times R_{CDC} \text{ with } M_{CO2,CD,avg} = \frac{\sum_{j=1}^{k}(M_{CO2,CD,j} \times d_j)}{\sum_{j=1}^{k} d_j}$$

- More aggressive driver → earlier engine start; less ΔE in the considered cycle, means lower EC and higher CO_2
- More aggressive driver could even lead to a longer R_{CDC} if the break-off-criterion is reached later
  → Premise: Delta E need to remain always above 4%
- This leads to a higher EAER if the resulting higher average CO_2 in the CD-test is not compensating the longer R_{CDC}
- Driver has also influence on the CO_2 value in the CS-test (but less than in case of the CD-test)

➔ Influence of driver on EAER depending on the way of driving
(could be both ways: to the advantage and disadvantage of the manufacturer)

➔ Influence of driver on Delta E is lower (if battery is empty, it is empty)

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PHEV: Range calculation vs. UBE determination in context of test to test variation

Data from measured vehicles

Japan data:

表１プラグインハイブリッド車のばらつき解析結果

Prius PHV		JC08 N=1	JC08 N=2	1回目と2回目の：difference	1回目と2回目 割合	1回目 2回目 Difference of Drive Index の差(RMSSE)	の差(IWR)
EV range	Vehicle A	65.8km*	68.5km	2.7km	4.1%	0.03km/h	0.08%
	Vehicle A With compensation	67.8km	68.5km	0.7km	1.0%	0.03km/h	0.08%
	Vehicle B	68.8km	67.4km	1.4km	2.1%	0.02km/h	0.01%
AC Charge Amount	Vehicle A	6.14kWh	6.07kWh	0.07kWh	1.2%	–	–
	Vehicle B	6.09kWh	6.09kWh	0.00kWh	0.0%	–	–

*The vehicle was stopped for 40 minutes due to the emission analyzer trouble.

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BACK-UP

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Performance Criterion Capacity (UBE or E_{AC}) vs **Range**

Pro's Range:

- Reflects total vehicle performance

Con's Range:

- Several range values are available in one regulation (AER, EAER) for total cycle profiles, city cycle profiles and phase specific profiles → need to be considered in the GTR development; makes the work in the GTR development more complex; denominator for harmonization is smaller
- Range is not only influenced by the battery performance but is also sensitive on effects coming from parameters not related to the battery, e.g.
  - the driver,
  - the test bench,
  - the road load adjustment
  - other effects coming from the power train
- If range is not meeting the minimum performance requirement, not necessarily the battery is the reason; e.g. AER as range value could drop significantly caused by factors which are not related to battery performance (not always but it could be) → in this case, it will be challenging to reflect the battery performance in the indicator
- As range is not only dependent on the battery performance, an indicator based on range is quite challenging to be set up (as it need to take into consideration all these effects) → Risk that indicator and range are not fitting together and might cause a recall to fix the indicator

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Performance Criterion **Capacity (UBE or E_{AC})** vs Range

Pro’s Capacity:

- Reflects battery performance which is the scope and excludes influencing parameters coming not from the vehicle to a minimum
- Capacity measurement procedure can be defined independent from the driving cycle; this would be a big benefit in terms of harmonization as delta E or UBE know in the various regulations while in terms of range, different range values and calculations schemes available
- In context of capacity, only generic topics would need to be described (see sub-bullet points)
  - For UBE: start current and voltage measurement at the start of the range test; end current and voltage measurement as soon as test break-off-criterion is reached
  - For E_{AC}: The end of test criterion need to be reached before starting the measurement of the recharged energy (in case of OVC-HEVs: current and voltage measurement required for the determination of the end of test criterion REEC for WLTP; NEC or SoC criterion for US cycles)
- Customer also understands capacity as an indicator as that is used by OEMs already in warranty

Con’s Capacity:

- Losses coming from the charger are considered in the E_{AC} value; but these losses could vary over lifetime of the vehicle as charger will change over lifetime of the vehicle; losses in context of the recharge are also a function of the grid performance
  → these losses need to be eliminated which is adding additional and not required complexity
- Current and voltage measurement (important: as customer vehicles, on-board data must be accepted
  → Required for UBE determination
  → Required for EAC determination of OVC-HEVs