# Follow-up feasibility study on sustainable batteries under FWC ENER/C3/2015-619-Lot 1

Task 2 Report

CHARACTERISATION OF PERFORMANCE AND SUSTAINABILITY REQUIREMENTS FOR RECHARGEABLE BATTERIES WITH INTERNAL STORAGE FOR CHEMISTRIES OTHER THAN LITHIUM-ION FOR BOTH ELECTRO-MOBILITY AND STATIONARY APPLICATIONS

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"space" as thousand separator

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**Contents**

# 2. Task 2 – Characterisation of performance and sustainability requirements for rechargeable batteries with internal storage for chemistries other than lithium-ion for both electro-mobility and stationary applications

## 2.0. General introduction to Task 2

The original study has focused primarily on lithium-ion batteries, which is likely to remain as the predominant technology in the market in the near future. However, any potential regulation that is proposed, after the analytical phase has concluded, should be as technology neutral as possible.

Therefore, there is a need to verify that the performance and sustainability requirements suggested in the original study are applicable for battery technologies and chemistries other than lithium ion, and what adjustments might be necessary to make an possible regulation and technology and chemistry neutral as possible. This should include an analysis of existing and prospective battery chemistries, including lithium metal, sodium-sulphur and nickel metal hydride.

## 2.1. Key Challenges

Key challenges are:

- Considering the current state of the proposed requirements on sustainability, for example carbon footprint information, can be easily applied to other chemistries and is relatively straightforward.
- The extension of the proposed performance requirements on battery lifetime is considered a much larger challenge, because standards are missing and here again a reliable set of public available data to set thresholds.
- In general, for ESS a technology agnostic test standard exists, but seems especially written for lead-acid batteries. Specific standards for ESS application exist for lithium, lead-acid, nickel metal hydride and high temperature sodium batteries. Standards on EVs mainly focus on the Li-ion chemistry.

## 2.2. Scope considerations

### 2.2.1. Existing scope definition for Lithium Chemistries

In line with Task 1 of the preparatory study the proposed scope is 'high energy rechargeable batteries of high specific energy with solid lithium cathode chemistries for e-mobility and stationary energy storage (if any)'.

High specific energy is hereby defined by a gravimetric energy density 'typically' above 100 Wh/kg at cell level.

High capacity means that a total battery system capacity between 2 and 1000 kWh.

See Task 1 for more details.

This does not include power electronics neither heat nor cool supply systems for thermal management, which can be part of what the study defined as a battery *application* system.

Further on in Task 7 of the original study the applications EV and stationary energy storage was proposed for the regulation.

### 2.2.2. New scope definition including other than lithium chemistries

The scope of Task 2 is the original scope extended to all rechargeable battery chemistries with internal storage, covering the original applications (EV & ESS).

The scope becomes therefore:

‘rechargeable batteries of high capacity with internal storage for e-mobility and stationary energy storage (if any)’. High capacity means that a total battery system capacity between 2 and 1000 kWh.’

## 2.3. Example of chemistries

### 2.3.1. For electric vehicles applications

We do not consider that other than lithium chemistries will play a significant role in near future. This has been underpinned recently by attributing the Noble prize for the development of lithium chemistries. Lithium chemistries have the highest energy density of all rechargeable battery types.

Lithium chemistries include besides Li-ion, also lithium alloys, lithium metal and lithium sulphur batteries. The international standardisation committee IEC SC21A includes those types in their scope of lithium batteries. Nevertheless, their prescribed test methods and rules, including battery marking, are skewed to the lithium ion industry as that is the most dominant.

### 2.3.2. For stationary energy storage applications

For electric vehicle applications only lithium chemistries are envisaged due to their high specific energy density. In case of stationary energy storage this is not a decisive parameter and therefore other chemistries can remain and/or enter the market. Hence the remainder of this report will focus on these chemistries for ESS. The following chemistries are taken into the evaluation:

- Li-ion
- Li-metal
- Lead-acid
- Advanced lead
- NiMH
- NiFe
- $NaNiCl_2$
- NaS
- hybrid-ion
- LiS
- Na-ion

Recent market data from Germany showed that for residential grid energy storage applications the market converges to lithium chemistries, despite above mentioned argument for investigating other chemistries. Consequently, it will also be difficult to obtain representative market data for other chemistries than Li-ion and much in the study will be based on assumptions.

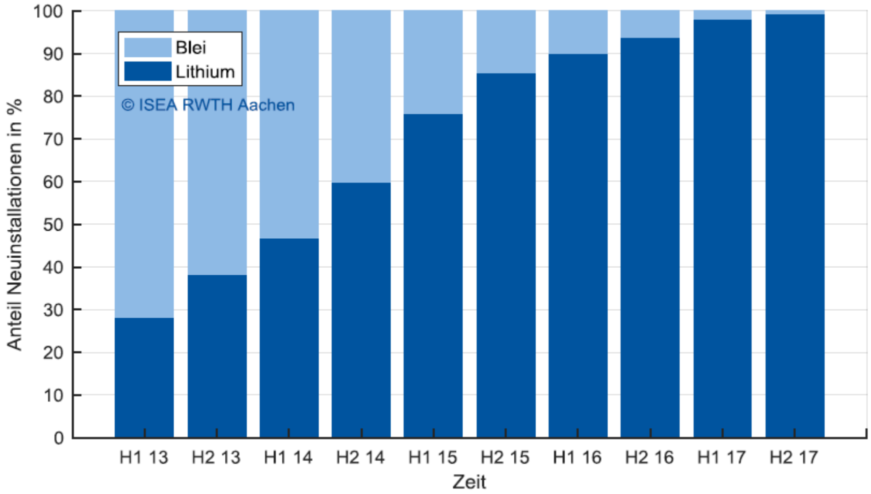


*Figure 2-1: Evolution of market share between lead-acid batteries ('Blei') and Li-ion batteries ('Lithium') on the German market for PV energy storage. Source: Speichermonitoring Jahresbericht 2018, RWTH Aachen.*

### 2.3.3. Battery standards

The extended scope requires also an augmentation of the inventory on battery standards. For performance related standards this is given in the annex, Table 2-8.

## 2.4. Screening of the originally proposed scope versus proposed policy in follow-up study

In task 7 of the preparatory study for ecodesign batteries policy propositions were given on 6 topics:

1. Minimum battery pack/system lifetime requirements
2. Requirements for battery management systems
3. Requirements for providing information about batteries and cells
4. Requirements on the traceability of battery modules and packs
5. Carbon footprint information and the option for a threshold
6. Minimum battery pack design and construction requirements

Hereafter it is evaluated how well they fit for the other battery chemistries in the case of stationary energy storage (this case has been selected in the previous section as the only case where other batteries are considered than lithium chemistries).

### 2.4.1. Minimum battery pack/system lifetime requirements

The original lifetime requirements from the preparatory study, task 7, for stationary energy storage are reproduced here. The requirements were split into requirements at mid-life that are tested according to a cycle-life test (see Table 2-1) and into warranty requirements (see

Table 2-2). **Error! Reference source not found.**. These requirements are for new batteries. Storage systems made of second life batteries cannot be re-submitted to the original requirements.

The evaluation of the requirements is performed with help of three subsequent tables:

- Coverage of performance criteria in standards (Table 2-3);
- Possible performance of the selected chemistries for ESS application (Table 2-4);
- Evaluation against currently proposed criteria, including conclusion and standardisation need per chemistry (Table 2-5).

Of each battery chemistry many battery types are produced with a different set of design requirements. Even for stationary energy storage, one brand can produce several battery types with difference in predicted lifetime, maintenance need and certainly in price. The possible performances shown in the Table 2-4 is therefore not valid for all battery types. They have been assumed as plausible and the source is mentioned. Hardly, data on efficiency exists. In some case data from the battery testing lab is given as an indication. This is clearly documented in the table.

After the tables (2-1 to 2-5) conclusions are derived.

*Table 2-1: Summary of minimum battery system lifetime compliance requirements as tested before bringing on the market for the ESS application. This test represents a mid-life condition (copied from Table 7-2 in the previous task 7 report).*

| **Application** | **Remaining capacity** (relative to the declared value) | **Maximum internal resistance increase** | **Minimum round-trip energy efficiency** | **Standards** (provisional -see notes on review) |
|---|---|---|---|---|
| ESS | 90 % @ 2000 cycles | NA | 94 % @ 2000 cycles | IEC 61427-2 Cycle-life test according to declared application(s) |

*Table 2-2: Summary of minimum battery system lifetime minimum warranty requirements (copied from Table 7-3 in the previous task 7 report).*

| **Appli-cation** | **Warranty period** | (whatever reached first) | **Minimum warranty** | | | | **Methods** |
|---|---|---|---|---|---|---|---|
| | Calendar life[1] warranty | Exceedance of minimum warranted amount of stored energy during the lifetime | Minimum energy that can be stored over life time in kWh | Remaining capacity (relative to the declared value) | Maximum internal resistance increase | Minimum round-trip energy efficiency | Standards (provisional -see notes on review) |
| ESS | 12 years | See prescription at the right | Declared capacity [kWh]x2000 | 80% | NA | 88% | IEC 61427-2 Cycle-life test according to declared application(s) |

[1] Measured from the manufacturing time (see information proposal in previous Task 7 report).

*Table 2-3: Evaluation of standards for the needed performance characteristics. (Resistance test is given. It is important for EV application, but no threshold was given for this in case of ESS. Therefore, this column is in grey colour).*

| Chemistry | Standard | Cycle-life test | Description test | (Remai-ning) capacity test | Energy deter-mination | Efficiency test | Resistance test | Conclusion (standardisation need) |
|---|---|---|---|---|---|---|---|---|
| Agnostic | IEC 61427-2 | yes | Cycles for 4 applications, mostly 1 cycle per 24h. No EOL criteria. | no | no | no | no | Insufficient (see previous task 7 for details). |
| Li-ion | IEC 62620 | yes | 500 cycles with 1/5$I_t$. 1$I_t$ allowed. The capacity must remain above 60% of initial capacity. The cycle test can be repeated several times until the EOL criterion. | yes | no | no | yes | Sufficient, but officially only for industrial applications. |
| | BVES Effizienzleitfaden | no | – | no | no | yes | no | Insufficient, focusses on performance of application system instead of battery life. |
| | White Paper on Test methods for improved battery cell understanding | yes | Large dataset of many conditions | yes | yes | yes | yes | Insufficient: cell level only; not application oriented. |
| | *Summary* | | IEC 62620 can be sufficient if it is allowed to be used for residential storage too. The test cycle is not application dependent but with a C/5-rate representative for ESS. Other standards are insufficient. | | | | | IEC 62620 can be sufficient if it is allowed to be used for residential storage too. The test cycle is not application dependent but with a C/5-rate representative for ESS. Other standards are insufficient. |
| Li metal | IEC 62620 | see above | | | | | | See for Li-ion. |
| Lead-acid | IEC 61427-2 | see above | | | | | | The cyclelife tests in IEC 61427-2 are designed for lead batteries, but take too long for being applicable. |
| | IEC 60896 series | yes | Float service (daily a 40% DOD (2h) at $C_{10}$, until 80% of initial capacity). | yes | no | no | yes | The cyclelife test is hardly representative and slow procedure. It is more applicable for UPS service. |
| | IEC 61056-1 | yes | 2 test cycles: float service and for cycle service endurance (daily a 50% DOD( $C_{10}$) (4 to 6h) until 50% of initial capacity). | yes | no | no | no | The discharge time in the cycle service endurance test is representative. Charge does not reflect solar energy charging. A slow procedure. |
| | *Summary* | | | | | | | Cycle life tests in standards take too long, performance indicators not all covered. Charge is not representative in the standards |

| Chemistry | Standard | Cycle-life test | Description test | (Remai-ning) capacity test | Energy deter-mination | Efficiency test | Resistance test | Conclusion (standardisation need) |
|---|---|---|---|---|---|---|---|---|
| Advanced lead | like lead-acid | see above | see above | | | | | See for lead-acid |
| NiMH | IEC 63115-1 | yes | Cycle life consists of 2h20' discharges at $I_t/4$ and charge with same rate, until 70% of initial capacity. | yes | no | no | no | Performance indicators are mostly not covered. |
| | IEC 62675 | yes | Cycle life consists of 3h discharges $I_t/5$ and charge with same rate, until 70% of initial capacity. | yes | no | no | no | Performance indicators are mostly not covered. |
| | *Summary* | | | | | | | Performance indicators lacking, cycle life tests not representative for ESS applications (more for UPS). |
| NiFe | lacking | - | - | - | - | - | - | No standard |
| $NaNiCl_2$ | IEC 62984-3 | yes | Cycle life test is a 8h discharge at 80% DOD, repeated 300 times, with a max. energy contents loss of 5%. | yes | yes | yes | no | Cycle life test seems representative, but shorter in cycles than envisaged with the policy proposition. |
| NaS | IEC 62984-3 | see above | ,, | | | | | ,, |
| Hybrid ion | lacking | - | - | - | - | - | - | No standard |
| LiS | lacking | - | - | - | - | - | - | No standard |
| Na-ion | lacking | - | - | - | - | - | - | No standard |

*Table 2-4: Possibilities of the chemistries for ESS*

| Chemistry | Reasonable # cycles | Reasonable # calendar years | DOD per cycle | Capacity retention at EOL | Lifetime energy (equivalent cycles: correction for DOD and avg. SOH)> | Lifetime estimation (min. of calendar life and cycle life) | Characteristic efficiency | Source |
|---|---|---|---|---|---|---|---|---|
| *Proposed* | *2000 at midlife (4000 in total)* | *12 at midlife (25 in total)* | *80%* | *90% at midlife (80% at EOL)* | *2880 (80% DOD, 90% SOH on avg., 200 cycles/yr)* | *20* | *94% (at midlife)* | *From task 7* |
| Li-ion | 4000 | 20 | 80% | 80% | 2880 | 20 | 94% | From task 7 |
| Li metal | unknown | unknown | unknown | unknown | unknown | unknown | unknown | Not found |
| Lead-acid | 3000 | 8 | 40% | 80% | 576 | 8 | 90%[2] | http://www.sonnenschein.org/PDF%20files/GelHandbookPart2.pdf |
| Advanced lead | 2400 | 10 | 60% | 80% | 1080 | 10 | unknown | http://lead-crystalbatteries.co.uk/images/docs/Data/2V/BLC-CNFJ-300.pdf |
| NiMH | 8000 | 20 | 50% | 80% | 1800 | 20 | 90%[3] /unknown | https://www.nilar.com/wp-content/uploads/2019/05/Product-catalogue-Nilar-EC-Series-EN.pdf |
| NiFe | 4000 | 20 | 50% | 70%[3] | 1700[4] | 20 | 70%[5]/ unknown | https://batterysupplies.be/wp-content/uploads/docs/catalog/BSCataloogENG_web_nife.pdf |
| $NaNiCl_2$ | 3000 | 15 | 80% | 70%[5] | 2040[6]/ unknown | 15 | 84% [7] | https://www.electrilabs.co.za/Electrilabs%20-%20Sodium%20 Nickel%20batteries.pdf |
| NaS | 4500 | 20 | 50% | 80% | 1800 | 20 | 75% | http://ease-storage.eu/wp-content/uploads/2018/09/2018.07_ EASE_Technology-Description_NaS.pdf |
| Hybrid ion | 3000 | 15 | 50% | 70% | 1275 | 15 | 85% | http://www.eventhorizonsolar.com/pdf/Batteries/aquion_energy_aspen_ 48m_25_9_product_specification_sheet__1_.pdf |

[2] Not in datasheet; based on solar cycle tests at VITO with a multitude of lead-acid batteries.
[3] Based on measurement at VITO with NiMH for LEV it is 90% with a 50% SOC window. The datasheet in the source does not provide it.
[4] Remaining capacity as EOL criterion is not given in datasheet: 70% is assumed.
[5] Not in the datasheet. 70% is found in internet sources.
[6] EOL capacity not given. Based on extrapolation of the standard (cat.A) it can be 70%.
[7] Communication from ENEL as answer on the question in this study for data, communicated as 83 to 85%.

| Chemistry | Reasonable # cycles | Reasonable # calendar years | DOD per cycle | Capacity retention at EOL | Lifetime energy (equivalent cycles: correction for DOD and avg. SOH)> | Lifetime estimation (min. of calendar life and cycle life) | Characteristic efficiency | Source |
|---|---|---|---|---|---|---|---|---|
| LiS (Laboratory scale) | 1500 | unknown | 80% | 80%[8]/ unknown | 1080/ unknown | unknown | unknown | https://oxisenergy.com/wp-content/uploads/2016/10/OXIS-Li-S-Ultra-Light-Cell-v4.01.pdf |
| Na-ion (Laboratory scale) | 2000[9] | unknown | 100% | 80% | 1800 | unknown | 90% [9] | https://pubs.rsc.org/en/content/articlepdf/2016/ee/c6ee00640j (Peters, Jens, et al. "Life cycle assessment of sodium-ion batteries." Energy & Environmental Science 9.5 (2016): 1744-1751) |

[8] Assumption: like Li-ion.

[9] Based on the assumption mentioned in the source.

*Table 2-5: Evaluation of currently proposed policy propositions*

| Chemistry | Performance: # cycles | Performance: remaining capacity | Performance: min. efficiency | Warranty: period | Warranty: # cycles | Warranty: remaining capacity | Warranty: min. efficiency | Conclusion | Standardisation need |
|---|---|---|---|---|---|---|---|---|---|
| Li-ion | OK | OK | OK | OK | OK | OK | OK | Proposition is executable | IEC 62620 is proposed. |
| Li metal | Unknown | | | | | | | Unknown if proposition is feasible due to lack of performance data. Inclusion needed of energy consumption to keep battery at elevated temperature | See above. Heating energy must be included however: extension needed. |
| Lead-acid | For most lead batteries, proposition is too much. | OK (in line with IEC 60896 series) | Not attainable. | too long | too much. | Correct. | Too high | Adaptation of requirements is needed. | Need to cover energy and efficiency determination. A quicker test procedure is needed too. |
| Advanced lead | Requirement is higher than possible | OK | Unknown | should be half. | too much. | Correct. | unknown | See lead-acid | See lead-acid |
| NiMH | Good | good | unknown | good | good | good | unknown | This chemistry can fulfil lifetime criteria, but at slightly lower efficiency. | Need for performance indicators in test regime. Shorter test cycle is needed. |
| NiFe | Good | unknown | Not attainable. it has low efficiency. | good | good | unknown | unknown | This chemistry can fulfil lifetime criteria, but at low efficiency. | Standard is necessary. |
| $NaNiCl_2$ | Requirement is higher than possible | unknown | unknown. | too long | too high | unknown | Too high | A suitable standard exists. Little data available. The proposed requirements are too high for this chemistry. | Correct. |
| NaS | Good | unknown | Not attained. | good | good | unknown | Too high | For lifetime the criteria are good. For efficiency too high. | Correct. |
| Hybrid ion | Requirement is higher than possible | Too high | Not attained. | too long | too high | too high | too high | The proposed criteria are for lifetime and efficiency too high. | Standard is necessary. |
| LiS | Too high in the short term. | unknown | unknown | unknown | too high | unknown | unknown | It is a future type, little information available. Progress possible on cycles. | Covered by lithium standards, but methods may be too much dedicated at Li-ion currently. |
| Na-ion | Probably good | Probably good | Probably good | Probably good | Probably good | Probably good | Probably good | It is a future type, it seems close to Li-ion and therefore the propositions are OK. | Probably this chemistry can fall under Lithium(-ion) standardisation. |

#### 2.4.1.1. Conclusion on policy measure

The current policy propositions appear only feasible with Li-ion batteries. This is mainly due to a lower efficiency for all other battery chemistries (as far as information was found).

The best batteries after Li-ion regarding efficiency are NiMH and lead-acid, under the condition that they are not often fully charged since most energy loss occurs at almost fully charged batteries for NiMH and lead-acid batteries. For NiMH it is not problematic to avoid full charges, even in the contrary (their lifetime increases if they are not fully charged regularly). For lead-acid abstaining from frequent full charges is only possible for batteries that are dedicated for so-called “partial SOC” (pSOC) operation.

A lifetime of 20 years is for several chemistries possible: Li-ion, NiMH, NiFe and NaS. If this criterion is decreased to 15 years also $NaNiCl_2$ and hybrid-ion are possible.

#### 2.4.1.2. Conclusion on the standards analysis

The analysis of the standards in Table 2-3 shows that standards are lacking for NiFe, hybrid-ion, LiS and Na-ion. Only for $NaNiCl_2$ and NaS all needed information is covered by a standard, being a representative cycle life test and measurement methods of the needed performance indicators, being the (remaining) energy contents and the efficiency. Of the other batteries, the standards do not cover the performance indicators and the cycle life tests are sufficiently useful: they are not representative enough or too time consuming.

### 2.4.2. Requirements for battery management systems

In task 7 of the preceding study requirements have been proposed for battery management systems. This covers several topics:

- Provision of partially open data covering:
    - State of *BMS update possibilities* Coupling to the information about traceability of battery modules and packs
- Diagnostics connector
- BMS update possibilities

The evaluation of the BMS requirements is given in the subsequent table (Table 2-6).

#### 2.4.2.1. Conclusion on policy measure

Half of the chemistries use a BMS, i.e. Li-ion, Li-metal, sometimes NiMH, $NaNiCl_2$, NaS and Na-ion. They are probably of the advanced type, that is capable to perform analytics on the remaining capacity and the change in resistance (for ESS resistance was not seen as an issue). Currently only the Li-ion battery type is used for repurposing means, creating a necessity of partial open data on the remaining battery quality. This need is less existing for other batteries, but still sustaining a long first life operation possibility, by the means of being able to follow up the battery degradation.

For the battery types that would be able to fulfil the (adapted) policy requirements for system lifetime, it is recommended that they also fulfil the BMS requirement, at least to enable the degradation awareness. If a battery does not need a BMS for safety reasons, the ageing diagnostics can be added by an external analysing and logging device.

*Table 2-6: Evaluation of battery management system requirement*

| Chemistry | Availability BMS | Repurpo-sing[10] | Communication method | BMS: partially open data | | | | | Diagnostics connector | BMS update possibility | Conclusion | Standardisation need |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SOH info | SOH definition | Lifetime info | Traceability info | Conclusion | | | | |
| Proposed | advanced BMS | yes | CAN | necessary | capacity, power, resistance, other | necessary | necessary | Partial open data is possible | necessary | possible | | |
| Li-ion | yes, advanced BMS | yes | mostly CAN | possible | capacity, power, resistance | possible | possible | Partial open data is possible | Possible | In potential | The proposition is feasible. | Yes, as proposed. |
| Li metal | yes, advanced BMS | no | unknown | possible | unknown | possible | possible | Partial open data is possible | Possible | In potential | The proposition is feasible. | Yes, as proposed. |
| Lead-acid | no | no | n.a. | no | n.a. | no | no | Not possible without external analysing& logging device | n.a. | n.a. | n.a. | n.a. |
| Advanced lead | no | no | n.a. | no | n.a. | no | no | Not possible without external analysing& logging device | n.a. | n.a. | n.a. | n.a. |
| NiMH | sometimes, unknown whether a simple BMS or advanced. | maybe from HEV | unknown | sometimes possible | capacity | sometimes possible, but unknown if BMS advanced enough. | sometimes possible | Sometimes possible | Possible | Unknown | Unknown | Yes, as proposed. |
| NiFe | no | no | n.a. | no | n.a. | no | no | Not possible without external analysing& logging device | n.a. | n.a. | n.a. | n.a. |
| $NaNiCl_2$ | yes, advanced BMS | no | unknown | possible | capacity | possible | possible | Partial open data is possible | Possible | In potential | The proposition is feasible. | Yes, as proposed. |
| NaS | yes, advanced BMS | no | unknown | possible | capacity | possible | possible | Partial open data is possible | Possible | In potential (these systems are not used for second life applications). | The proposition is feasible. | Yes, as proposed. |
| Hybrid ion | no | no | n.a. | no | n.a. | no | no | Not possible without external analysing& logging device | n.a. | n.a. | n.a. | n.a. |
| LiS | unknown | no: research | unknown | no | n.a. | no | no | Not possible without external analysing& logging device | unknown | Unknown | Unknown | Yes, as proposed. |

[10] Used for 2nd hand & 2nd life application or can come from first life application

| Chemistry | Availability BMS | Repurpo-sing[10] | Communication method | BMS: partially open data | | | | | Diagnostics connector | BMS update possibility | Conclusion | Standardisation need |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Na-ion | yes, advanced BMS | no: research | unknown | possible | unknown | possible | possible | Partial open data is possible | Possible | In potential | The proposition is feasible. | Yes, as proposed. |

### 2.4.3. Requirements for providing information about batteries and cells

To allow repair, reuse, remanufacturing and repurposing but also recycling of batteries data and information about the battery is required. In task 7 of the preceding study an information proposal is given for battery systems, packs and modules. A similar proposal exists for cell level.

The proposal is that the individual battery should carry at all levels (battery system, battery pack and module) a bar code, QR code or similar with an EAN number and serial number. This code provides access to a European database with information on batteries and cells, which the manufacturer or supplier bears the responsibility of updating, e.g. similar to the European Product Database for Energy Labelling (EPREL[11]), in three levels of:

- Level 1: Public part (no access restriction) covering:
  - Carbon footprint information in $CO_2$eq
  - Battery manufacturer
  - Battery type, and chemistry
  - Percentage of recycled materials used in the cathode and anode material
  - A reference to a recycling method that can be used.
- Level 2: Data available to third party accredited professionals:
  - Performance data
  - BMS related data
  - Repair & dismantling information
- Level 3: Compliance part (Information available for market surveillance authorities only, protected access for intellectual property reasons).

In the subsequent table (Table 2-7) the requirements for providing information about batteries are given. To allow this evaluation the following topics are added to the table:

- Minimum traded unit
- Possibility to carry a code
- Current possibility recycling

The level 3 data (compliance) has been left out. This mainly depends whether standards are available. That analysis was performed in Table 2-3.

No evaluation for the information on cell level has been carried out. This would be identical to the analysis on battery level, except that cells must be freely on the market, from which another manufacturer makes batteries. For NiMH, $NaNiCl_2$, NaS and Hybrid-ion this is not the case.

[11] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/european-product-database-energy-labelling_en

#### 2.4.3.1. Conclusion on policy measure

Since not for all battery types an PEFCR exists, the carbon footprint cannot be given for all types.

Note that only marking symbols exist for Lithium, Li-ion, lead-acid and NiMH in IEC standards. The following chemistries lack an official marking:

- NiFe
- NaNiCl2
- NaS
- Hybrid-ion
- Na-ion

The $NaNiCl_2$ and NaS have nevertheless an UN number for transportation as sodium battery (UN 3292).

For recycling Li-ion chemistries it is helpful to know not only the family (such as Li-ion) but also subclass information like cobalt-based or iron phosphate based. This is included in standards with marking for Li-ion batteries. For most chemistries only the family name is important since there is hardly variation in materials, except Li-ion, Li-metal, Na-ion and advanced lead.

The previously proposed information requirement (preceding task 7) covers the percentage of recycled materials in the battery and also the recycling method that can be used. Currently, not for all battery types specific information on the recycling method seems to exist. To include information on the recycled material contents, recycling up to battery must exist in the first place. For e.g. sodium and sulphur this seems not the case currently. For Ni, Co but also Li this is already possible.

*Table 2-7: Evaluation of the requirements for providing information about batteries*

| Chemistry | Minimum traded unit | Possibility to carry a code | Current possibility recycling | Level 1 data (public) | | | | Level 2 data (professionals) | | | | Conclusion |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Carbon footprint | Manufac-turer | Battery | Recycling | Performance | BMS related | Chemistry identification | Repair & dismantling | |
| Li-ion | Cell | yes, better at higher level such as module level since many cells involved. | yes | PEFCR exists | yes | yes | yes | yes | yes | yes | yes | Correct |
| Li metal | Battery system | yes | yes, like Li-ion | no | yes | yes | yes | yes | yes | yes | yes | PEFCR lacking |
| Lead-acid | Cell | yes | yes, best example | PEFCR exists | yes | yes | yes | not all, lack of suitable standard | yes | family, not necessary for subclass | yes | Correct, but performance must be standardised better. |
| Advanced lead | Cell | yes | yes, best example | no | yes | yes | yes | not all, lack of suitable standard | no: no BMS | yes | yes | PEFCR lacking but performance must be standardised better. |
| NiMH | Cell | yes | yes | PEFCR exists | yes | yes | yes | yes | no: mostly no BMS | family, not necessary for subclass | yes | Correct |
| NiFe | Cell | yes | yes | no | yes | yes | yes | no, no standard | no: no BMS | family, not necessary for subclass | yes | PEFCR lacking but performance must be standardised better. No family marking symbol. |
| $NaNiCl_2$ | Battery system | yes | unknown | no | yes | yes | unknown | yes | yes | family, not necessary for subclass | | PEFCR lacking. No family marking symbol. |
| NaS | Battery application system | yes, better at lower level, although not traded as such. | unknown | no | yes | yes | unknown | yes | yes | family, not necessary for subclass | | PEFCR lacking. No family marking symbol. |
| Hybrid ion | Battery system | yes | yes, cradle to cradle certified. | no | yes | yes | unknown | no, no standard | no: no BMS | family, not necessary for subclass | | PEFCR lacking. No family marking symbol. |
| LiS | Research only | yes, better at higher level such as module level since many cells involved.. | no | no | yes | yes | unknown | no, research currently | currently not: research | family, not necessary for subclass | | PEFCR lacking |

| Chemistry | Minimum traded unit | Possibility to carry a code | Current possibility recycling | Level 1 data (public) | | | | Level 2 data (professionals) | | | Conclusion |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Na-ion | Research only | yes, better at higher level such as module. | yes, like Li-ion | no | yes | yes | unknown | no, research currently | currently not: research | yes | No family marking symbol. |

### 2.4.4. Requirements on the remaining three topics

The remaining three topics are:

- The traceability of battery modules and packs
- Carbon footprint information and the option for a threshold
- Minimum battery pack design and construction requirements

For these criteria no specific issues are supposed for the proposed requirements. There is no difference between Li-ion modules and other battery modules for the possibility to add identification like a QR code. Module and pack design differ from Li-ion counterparts especially if gas release is possible (lead-acid) or increased internal temperature is used (NaS, $NaNiCl_2$). Nevertheless, other battery modules and packs than Li-ion ones have no additional constraints in pack design that would hinder repair, re-use and recyclability.

Carbon footprint information can only be given if a PEFCR exists. This is given in Table 2-7.

## 2.5. Conclusion on technology neutral policy

### 2.5.1. The potential need and rational for performance concessions for other chemistries

Hereafter we will focus on grid energy storage applications (ESS) because for these applications there were new chemistries identified.

New chemistries can potentially not meet those requirements (see conclusions per policy requirement in section 2.4) and hereafter are two rationales and methods discussed for granting concessions. The idea would be that concessions can be granted to particular chemistries because the carbon footprint (GWP([$CO_2$eq]) is lower and/or fewer gross energy (GER[MJ]) is required. Note: GER is a parameter that stems from the MEErP but not included in the PEF CR.

#### 2.5.1.1. A correction factor based on carbon footprint

A first rationale for a concession could be a lower carbon footprint of the particular battery chemistry. Usually such an ESS is used in conjunction with renewable energy to reduce the carbon footprint of electricity generation. However, for example, battery systems with a lower efficiency can still provide a similar service over its full life cycle when their manufacturing carbon footprint is relatively lower. Therefore, a concession can be granted on efficiency, based on their carbon footprint for manufacturing.

The preparatory study did found a GWP for production and distribution of 61 g$CO_2$eq per kWh functional unit ($GWP_{FU}$) or 155 kg$CO_2$eq per kWh declared storage capacity($GWP_{CAP}$) for the residential ESS base case, see Table 7-5.

#### 2.5.1.2. A correction factor based on Gross Energy Requirements

A second rationale to consider is the Gross Energy Requirements (GER) for manufacturing batteries which is related to the Primary Energy; this parameter is available from the MEErP. Therefore, the preparatory study proposed the newly defined capacity Energy Efficiency Index (cEEI). This capacity Energy Efficiency Index (cEEI) refers to the ratio of declared storage capacity relative to the embodied primary or gross energy requirement (GER) for manufacturing. It was defined in Task 7 of the preparatory study, section 7.1.2.5. It is a metric that shows how much energy the manufacturing a battery system requires compared to its storage capacity. A cEEI value of 890 was calculated for the residential base case ESS, see Table 7-5 in the Task 7 report of the preparatory study. Using the cEEI as a rationale can also be justified by the idea that the lifetime of a battery product must be sufficiently longer otherwise the embodied energy in the battery manufacturing is the primary energy supply to the system.

Note: the GER and the primary energy are currently not included in the PEF CR. Therefore, the MEErP is needed to calculate the cEEI. The GER is e.g. used in the Ecodesign study on PV systems[12]. The energy needed to produce substances from raw materials are not given in the PEF CR, but in the MEErP.

This capacity Energy Efficiency Index (cEEI) is defined as:

$$\mathrm{cEEI} = \frac{\text{Gross Energy Requirement (GER) according to the MEErP[MJ]}}{\text{declared storage capacity [MJ]} \times \frac{\text{DOD from cycle life test [\%]}}{100}}$$

GER: the discussion on how to calculate the Gross Energy Requirement (GER) for the cEEI is part of WP3 and eventually later standardization work.

Declared capacity: the declared capacity was defined in section 7.1.2.1 in task7 of the preparatory study. This capacity is not necessarily the initial capacity of the battery. In this way the effect of a possible quick initial capacity fade before entering a steady capacity reduction over time can be taken into account by setting the declared capacity lower than the initial capacity.

DOD from cycle life test: the DOD that is used for the cycle life test and reported in the level 2 data (data available to third party accredited professionals) of the proposed European database (section 7.1.2.3 in the preparatory study). Almost no battery types are allowed to be discharged 100% to reach a long cycle life. This is shown in Table 2-4. For Li-ion batteries this DOD is in general 80%. However, most of the battery types accept only a 50% DOD for a long life. This means that double the capacity must be installed. This must thus be taken into account in the cEEI.

The preparatory study did find a typical cEEI of 890 for a lithium battery used for the residential ESS base case, see Table 7.5. Including the DOD from cycle life test, and assuming that it is 80% for a Li-ion battery, then it becomes now 1110 MJ.

### 2.5.2. Rationale and method for potential concessions on remaining capacity versus lifetime in policy requirements

The current LiB policy proposal for LiB required for ESS a remaining capacity of 90 % after 2000 test cycles before the product can brought on the market.

12 https://susproc.jrc.ec.europa.eu/solar_photovoltaics/docs/20191220%20Solar%20PV%20Preparatory%20Study_Task%207_Final%20following%20consultation.pdf

Furthermore, it required a warranty of 12 years minimum calendar life or 2000x (Declared Capacity) in kWh functional unit. Herein the functional unit is the total measured delivered energy at the output of the battery over its lifetime.

In general, we believe that whichever cEEI, a minimum functional lifetime on capacity fade might be needed before such a storage is useful, in our opinion 1000 test cycles or 50 % and 6 years of warranty.

We recommend not to propose stronger requirements (2000 cycles) for new chemistries, preventing them from the market, which could justify to cap the requirements at the current proposal.

Therefore, it is proposed to apply the following correction factor (Kcycle) on the 2000 proposed cycles and on the warranty period of 12 years:

$K_{cycle}$[%] = 100 x cEEI/1110 [%] when 1110/2< cEEI < 1100

$K_{cycle}$[%] = 50 % when 1110/2< cEEI

$K_{cycle}$[%] = 100 % when cEEI ≥ 1110

For example, in the best case if renewable energy is used during manufacturing then the cEEI is below 445. In that case a 50% reduce factor can be used, i.e. 1000 cycles at midlife and 6 years warranty period.

According to Table 2-4, 2000 cycles at full life can be satisfied by all chemistries, except LiS up to our knowledge. The minimum warranty period of 6 years is for most chemistries possible. For lithium metal and lithium sulphur data lacks currently. For most lead-acid batteries this period is challenging, but there are solar type lead-acid batteries for which it is feasible.

Note that alternatively $GWP_{CAP}$ [$kgCO_2eq/kWh$] / 155 [$kgCO_2eq/kWh$], this approach is applied in the subsequent section.

### 2.5.3. Rationale and method for remaining round trip efficiency versus lifetime in policy requirements

The current LiB policy proposal a minimum remaining round trip efficiency versus lifetime for LiB, however here those thresholds cannot be met for other chemistries used in ESS (see Table 2-4).

A rationale for a concession can be found in the lower carbon footprint of the battery system involved. Usually such an ESS is used in conjunction with renewable energy to address Global Warming and reduce the carbon footprint of electricity. Battery systems with a lower efficiency can still provide a similar service to store renewables over its lifetime when the manufacturing carbon footprint is lower and therefore a concession can be granted on efficiency based on their carbon footprint. The study found GWP for production and distribution of 61 $gCO_2eq$ per kWh functional unit ($GWP_{FU}$) or 155 $kgCO_2eq$ per kWh declared storage capacity ($GWP_{CAP}$) for the residential ESS base case, see Table 7-5.

In general, we believe that an efficiency below 80% mid-life is unacceptable, therefore the corrections can be capped.

Therefore, it is proposed to apply the following correction factor ($K_{eff}$) on the 2000 proposed cycles:

$K_{eff}[\%] = \max(100 \times GWP_{CAP}[kgCO_2eq/kWh]/155[kgCO_2eq/kWh], 75)\ [\%]$

when $GWP_{CAP} < 155\ kgCO_2eq/kWh$

$K_{eff}[\%] = 100\ \%$ when $GWP_{CAP} \geq 155\ kgCO_2eq/kWh$

Note: the discussion on how to calculate the carbon footprint of production and distribution is part of WP3 and possible later standardization work.

As example, Na-ion batteries have $GWP_{CAP}$ of 140 $kgCO_2eq$ per kWh[13]. The decreased roundtrip efficiency therefore can be 140/155x94% = 85% (at mid-life). For new batteries, which have always better efficiency than at mid-life, 85% seems not reachable for: NiFe and NaS. For the hybrid ion type the characteristic efficiency is 85% at the beginning of life, and therefore 85% at midlife is not possible currently without changing the battery design. For LMP, $NaNiCl_2$, and LiS characteristic efficiencies are unknown.

If the excluded batteries are manufactured with help of renewable energy, $GWP_{CAP}$ decreases, resulting in a lower efficiency threshold, creating a possibility.

[13] Fig. 3 in https://pubs.rsc.org/en/content/articlepdf/2016/ee/c6ee00640j

## ANNEX:OVERVIEW OF STANDARDS ON BATTERY PERFORMANCE

*Table 2-8: Identification of battery standards related to performance and classified per application and battery chemistry.*

**Performance tests**

| Application | Battery type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Agnostic | Li-ion | Li-metal | Pb | NiMH | NiFe | NaNiCl2 | NaS | Flow battery | hybrid-ion | LiS | Na-ion |
| Stationary | | | | | | | | | | | | |
| Stationary in general | IEC 62933-2-1<br>*Batt. appl. system* | | | IEC 60896 series<br>*Cell &Module* | IEC 63115-1<br>*Cell to battery system* | | IEC 62984-3<br>*Battery system* | IEC 62984-3<br>*Battery system* | IEC 62932-2-1<br>*Battery system&<br>Batt.appl.system* | | | |
| residential ESS (BC6) | IEC 61427-2<br>*Battery system* | BVES Effizienzleitfaden für PV Speichersysteme<br>*Batt. appl. system* | | | | | | | | | | |
| Grid ESS (BC7) | „<br>„ | IEC 62620<br>*cell to battery system* | IEC 62620<br>*cell to battery system* | | | | | | | | | |
| Other | IEC 61427-1<br>*Battery system* | | | | | | | | | | | |
| Light EV | | | | | | | | | | | | |
| LEV in general | | | | | | | | | | | | |
| scooters | | | | | | | | | | | | |
| bicycles | | | | | | | | | | | | |
| mopeds & motorcycles | ISO 13064-1& 2<br>*Batt. appl. system* | ISO/DIS 18243<br>*Battery system* | | IEC 63193<br>*Modules& packs* | | | | | | | | |
| Industrial LEV | | IEC 62620<br>*Cell to battery system* | IEC 62620<br>*Cell to battery system* | IEC 63193<br>*Modules& packs* | | | | | | | | |
| Industrial | | | | | | | | | | | | |
| mobility to stationary | | IEC 62620<br>*cell to battery system* | IEC 62620<br>*Cell to battery system* | | IEC 63115-1<br>*Cell to battery system*<br>IEC 62675<br>*Cells* | | | | | | | |
| Portable | | | | | | | | | | | | |
| Portable | | IEC 61960-3& 4<br>*Cell to battery system*<br>ANSI C.18.2M-1<br>*Cell to battery system* | IEC 61960-3& 4<br>*Cell to battery system* | | IEC 61951-2<br>*Cell to battery system*<br>ANSI C.18.2M-1<br>*Cell to battery system* | | | | | | | |

**Performance tests**

| Application | Battery type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Agnostic | Li-ion | Li-metal | Pb | NiMH | NiFe | NaNiCl2 | NaS | Flow battery | hybrid-ion | LiS | Na-ion |
| EV | | | | | | | | | | | | |
| Mobility in general | SAE 2288<br>*Modules*<br>SAE J1798<br>*Modules* | | | IEC 60254-1<br>*Cell & module* | | | IEC 62984-3<br>*Battery system* | IEC 62984-2<br>*Battery system* | | | | |
| cars | DOE-INL/EXT-15-34184<br>*all levels*<br>DOE-INL/EXT-07-12536<br>*all levels*<br>DOE-INL/EXT-12-27920<br>*Battery system* | IEC 62660-1<br>*Cells*<br>ISO 12405-4<br>*Packs to battery system* | | IEC 61982<br>*Cells to battery system* | IEC 61982<br>*Cells to battery system* | | IEC 61982<br>*Cells to battery system* | | | | | |
| Trucks | | | | | | | | | | | | |
| Busses | UITP E-SORT<br>*vehicle* | | | | | | | | | | | |
| Off road (incl. industrial& ships) | | | | | | | | | | | | |
| Other | | | | | | | | | | | | |
| Vehicle auxiliary power | | IEC 63118<br>*Modules to battery system* | IEC 63118<br>*Modules to battery system* | EN 50342 series<br>*Modules* | | | | | | | | |
| Aircraft | | | | IEC 60952-1<br>*Modules* | | | | | | | | |
| Ships | | IEC 62620<br>*Cell to battery system* | IEC 62620<br>*Cell to battery system* | | | | | | | | | |
| Light electric rail | | IEC 62620<br>*Cell to battery system* | IEC 62620<br>*Cell to battery system* | | | | | | | | | |
| Repurposing | ANSI/CAN/UL 1974<br>*Cells to pack* | | | | | | | | | | | |
| General (not application dependent) | | White Paper on Test methods for improved battery cell understanding<br>*Cells* | | IEC 61056 series<br>*Cells to modules* | | | | | | | | |

Levels:

- Cell
- Module (monobloc)
- Pack
- Battery system
- Batt.appl.system (ESS)
- Vehicle