H2020 Work Programme "Smart, green and integrated transport"
GV-06-2017 – Physical integration of hybrid and electric vehicle batteries at pack level aiming at increased energy density and efficiency

D2.2 - Comparison of suitable high energy density cells for automotive applications

Lead Contractor: [RESCOLL]

Author(s): B.PALOMO (RSC), M. LE GOFF (RSC), I. CENDOYA (CID)

Date: 22-12-2017

This document summarizes the methodology according to which the most suitable cells references have been selected as well as how Ecodesign approach has been defined and applied in the analysis and selection of cells for automobile applications in the frame of iModBatt project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770054.

Document History

Date	Version	Name	Changes
18-12-2017	1	BP, MLG (RSC)	Version 1
19-12-2017	2	IC (CID)	Overall overview
22-12-2017	3	BP, MLG (RSC)	Final version

TABLE OF CONTENTS

1 Introduction

The aim of this three months task is to discuss cell brands and chemistries between partners from all points of view: technical, safety, availability, recyclability and any other. This discussion has not been based on a testing activity, but on the overall background of each expert when working with specific commercial cells.

The second main objective of this task is to select 5-7 references of cells in order to purchase them to accomplish their analysis in T2.3. It is estimated that 6 cells per reference would be necessary (approximately 40 cells).

Although the official decision on the cells to be analysed for the selected EVs should be taken by M3, another objective of the task 2.2 is to update commercial cells availability until M24. In fact, if during the life of the project, any other promising chemistry reaches the market, some effort could be transferred to briefly launch a comparative study on the performance of the new chemistry, even if it is done just at cell level due to the project deadline.

On the other hand, in task 2.2 a discussion will be also launched on the advantages and disadvantages of hybrid BPs made of different brands, chemistries or cell shapes. Since flexibility is one of the targets of this project, it is worth to analyse if these three parameters could be combined in order to get and optimum product and optimum components availability.

This deliverable D2.2 is focused mainly on the two first points mentioned above. Thus, the methodology applied to compare cells is presented in the following section. Afterwards, the Eco-design approach will be explained. The main results obtained so far are presented in section 3. Finally we will find a conclusion on work performed during these three first months.

2 Work performed

2.1 Methodology to compare suitable high energy density cells for automotive applications

Conference Call the 31st October 2017: for this meeting some cell's references and data had been given by partners involved in T2.2. Some conclusions emerged from this meeting:

- All partners agree on the preference for 21700 cells. If not possible, 18650 cells will be taken into account. This means that prismatic cells are discarded.
- Just high energy cells are suitable for the EV application.
- Once cell's selection established, cell sourcing is guaranteed thanks to the relation of partners with cell manufacturers.

Then, and in order to make the cell's comparison easier, RSC created a table gathering the main cell's technical parameters from partners.

A first discussion on the first version fulfilled table took place the 13th November between CID and RSC. A second discussion took place with the most part of T2.2 partners the 29th November during a Conference Call organized by RSC. During this meeting, RSC presented some elements of the Eco-design approach, preliminary indicators and first main conclusions from literature review. The cell's comparison table fulfilled at that date was also shared. Furthermore, a fruitful discussion between all partners took place. The main conclusions that emerged from this meeting are listed below:

- RSC will explain and apply Eco-design approach in the analysis and selection of cells.
- In order to reduce the number of cell's and make feasible the final selection, partners agree on the fact that the parameters Energy and Volumetric energy density could be retained as first main technical criterion. Although, the cell's characteristics must also match our OEMs requirements.
- All partners also agree that there will be little information available (by manufacturers) on specific chemical data (different stoichiometry for example). This means that it will be difficult to evaluate precisely indicators based on chemistry data. The comparison will be done taken in account some considerations based on available data (LCA public databases, literature…)
- Regarding hybrid BPs, partners prefer to go to one specific cell. Any type of hybridization is almost discarded by partners. Even if the same chemistry type (e.g. generically NMC) would be used, partners estimate that it would make the BMS too complex and see no benefit.

Taken into account all these preliminary conclusions, the following methodology to make final cell's selection has been defined and is being applied:

1. Every partner fulfil columns regarding **Gravimetric** and **Volumetric Energy density on the cell's comparison table and send this information to RSC**[1]**.**

2. OEMs analyse separately this information and choose the better cell for their application (10 cells by each one ➔ a **list of X references of cells should be retained at the end of this process**). In this choice, the criterion of **availability and cost** must be also taken into account (It has to be possible of purchase thousands of cells by reference for the final BP). Additionally OEMs will be asked to define and weight the additional technical parameters taken into account for their cell final selection.

3. Once cell candidate list will be reduced based on technical, availability and cost parameters, the final filtering will be done according to **eco-design** and **recyclability rules**.

[1] PS: *Energy density data has been included in the cell comparison table. As the supply of these data depends on the brand, the feedback to the table has been obtained as indicated here below:*
   - *Gravimetric energy density = Capacity [Ah] * V nominal [V] / Weight [kg].*
   - *Volumetric energy density = Capacity [Ah] * V nominal [V] / Volume [l]* ➔ *preferred parameter by OEMS, since space is even more critical than weight.*
   - *Weight [g]* ➔ *if we have this data, and on the other hand we have the capacity and voltage, gravimetric energy density can be easily calculated.*

2.2 Eco design indicators definition

2.2.1 Definition of the EcoDesign approach

In the literature surrounding the eco-design research area, different definitions exist because some authors expand the idea by adding a characteristic or a specific viewpoint (Environmental Product Development – EPD, green design, environmental design, Design For the Environment – DfE, life cycle thinking...) (Dufrene, 2015). Whatever the standard ISO/TR 14062 defines eco-design as the "integration of environmental aspects into product design and development". Five keys factors are essential to follow for a successful eco-design approach as illustrated in the Figure 1 below:

- ✓ integration of the environmental aspects in the **early stages of a product design process**,
- ✓ consideration of the entire **product life cycle**,
- ✓ consideration of a **multi-criteria approach**,
- ✓ consideration of the **functionality**,
- ✓ minimization of product's environmental impact **without compromising** other essential product criteria such as **performance and cost**.

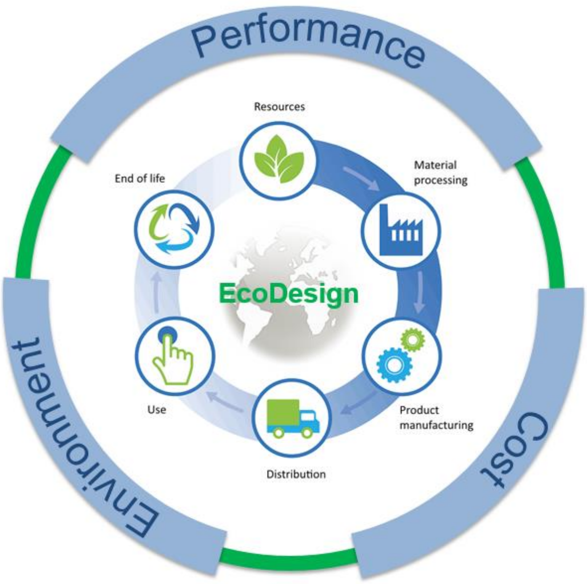


Figure 1 - Ecodesign approach along the life cycle with performance/cost/environment considerations.

During past years, many methods and tools for eco-design were developed. The aim of this section is not to draw up an exhaustive list but we can classify three main categories: quantitative environmental assessments, qualitative tools such as guidelines and in-house flow indicators. Life Cycle Assessment (**LCA**) is a standardized (**ISO 14040 series**) quantitative methodology that was developed for the evaluation of environmental impacts of systems along their life cycle. This multi-criteria methodology is well-recognized and indispensable to evaluate environmental impacts. However LCA has some **limitations**: time and resources consuming, inventory data collection often outside companies boundaries, no consensus about some methodology of environmental impacts calculation, heterogeneity of modelling methodologies/hypotheses and finally uncertainty of results.

2.2.2 Literature review about environmental assessment of li-ion batteries

Peters and al. reviewed exhaustively publications on Life Cycle Assessment (LCA) of LIB production from 2000 to 2016 and compared exhaustively thirty-six LCA that provide sufficient detailed results (Peters, 2016). Assessed cathode chemistries include lithium iron phosphate (LFP), lithium cobalt oxide (LCO), manganese spinel oxide (LMO) and composite oxides (LCN, NCM and NCA). The most assessed battery chemistries are LFP (nineteen studies) and NCM (eighteen studies), while only few studies deal with LCN and NCA type batteries (two and eight respectively). It is considered that anode material are almost exclusively carbon, normally in the form of graphite. Only three studies also assess anodes based on the lithium salt of titanium oxide (lithium titanate, LTO type), two in combination with LFP and one with an LCN cathode. Another three studies deal with a silicone-graphite anode, all in combination with NCM cathodes. Finally, one single study focuses explicitly on a lithium-metal anode. Studies focusing only on cathode materials or still in a very early laboratory development phase are excluded of the comparison with conventional LIB.

The following table shows the average results by LIB chemistries of the six most frequently assessed environmental indicators as far as possible (only based on LIB manufacturing step): Global Warming Potential (GWP), Abiotic Depletion Potential (ADP), Acidification Potential (AP), Eutrophisation Potential (EP), Ozone Depletion Potential (ODP) and Human Toxicity Potential (HTP). For all studies, the keys assumptions and the obtained results are extracted and recalculated for 1Wh of energy storage capacity.

Environmental indicators	LFP	LFP-LTO	LCO	LMO	NCM	NCA
GWP (kg CO2/Wh)	1,61E-01	1,85E-01	5,60E-02	5,50E-02	1,60E-01	1,16E-01
ADP (kg Sbeq/Wh)	1,00E-03	*nd*	*nd*	4,22E-04	8,86E-04	*nd*
AP (kg SO2ep/Wh)	1,29E-03	*nd*	1,50E-03	5,36E-04	2,03E-03	*nd*
EP (kg Neq/Wh)	2,72E-04	*nd*	*nd*	1,22E-05	1,52E-04	*nd*
ODP (kg CFCeq/Wh)	1,14E-06	*nd*	*nd*	4,68E-09	6,72E-07	*nd*
HTP (kg 1.4-DCBeq/Wh)	2,60E-01	1,60E-01	2,40E-01	2,50E-01	4,82E-01	2,78E-01

Table 1 - Environmental impacts /Wh for manufacturing step of several LIB chemistries.

It is was observed that studies often rely on the inventory data of previous publications (seven studies used own primary LCI data, eight re-used these LCI partially and twenty-two based completely on the LCI of previous studies), differ significantly in scope and system boundaries (some only assessed manufacturing step whereas others assessed all the life cycle steps), and use fundamentally different technical assumptions. Moreover, majority of existing studies focuses only on one or two types of batteries and all apply their own impact assessment methodology. Use and end of life steps were not considered in the comparison although they might have a considerable influence on the results. Thus, it is difficult to get an impartial comparison of the environmental performance of each LIB chemistry.

Some technical **key parameters** based on LIB performance are found to be **equally relevant** for the environmental life cycle footprint:

- ✓ **Cycle life**: associated to calendric and cyclic lifetime parameters which are determined by different phenomena of degradation in the cell over time and cycles and depend of depth of discharge (DoD), charging-rate, operation temperature... A LIB is usually considered to be at its end of life when its usable energy reached 80% of the initial value.
- ✓ **Battery efficiency**: associated to the amount of energy lost in every charge/discharge cycle due to internal resistance. Several parameters can influence LIF efficiency as charging rate, temperature and the used Battery Management System (BMS).
- ✓ **Energy density:** associated to the capacity of active material and the amount of additional passive components contained in the battery.

2.2.3 Selection of EcoDesign indicators

Considering **confidentiality** aspects and **uncertainty** about decision-making presented in the previous paragraph, it was assumed that **eco-design indicators selection is based on regulation and technical indicators**. The table 2 shows priority and secondary eco-design indicators with the procedure to follow for cells selection and associated uncertainty. **Priority indicators** are the main **quantitative** indicators to consider for cells selection, whereas **secondary indicators** are **qualitative** indicators to validate a choice.

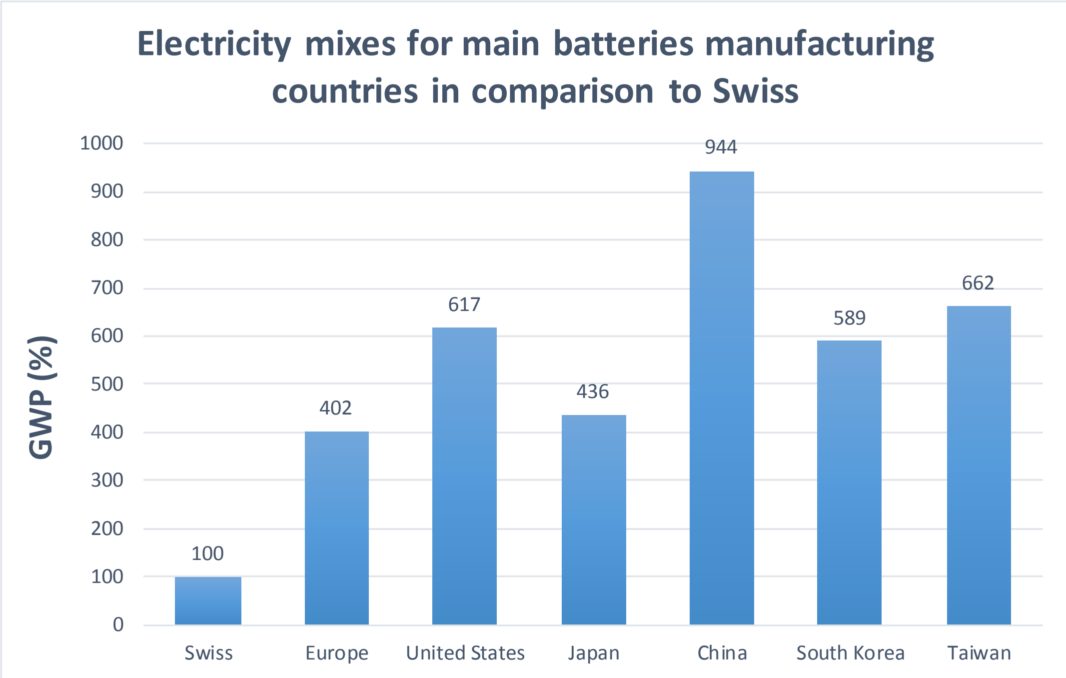
	Category	Procedure	Uncertainty
1) Priority Eco-design indicators			
Cycle lifetime (cycles)	Technical performance	Checking of datasheets or request additional information from the manufacturer if not available. The highest values will be preferred for the following indicators: cycle lifetime, calendar lifetime and gravimetric energy density. On the contrary, lowest values will be preferred for internal resistance indicator.	Average (dependent of availability, no consensus on datasheets for different cells comparison)
Calendar lifetime (days)	Technical performance		Average (dependent of availability, no consensus on datasheets for different cells comparison)
Internal resistance (mΩ)	Technical performance		Average (dependent of availability)
Gravimetric energy density (Wh/kg)	Technical performance		Low (generally available or calculable)
2) Secondary Eco-design indicators			
REACH	EU regulation	Inventory of chemicals substances as possible (MSDS, manufacturer...) and qualitative comparison with the list of candidate substances.	High (poor accessibility of data)
Recyclability	EU regulation	Inventory of chemicals substances / materials (MSDS, manufacturer...), and calculation* of recyclability** (wt%) if possible otherwise qualitative interpretation (evaluation with ACCUREC partner knowledge).	High (poor accessibility of data)
Cell's manufacturing country	Other	Checking of datasheets/literature or request additional information from the manufacturer if not available. Consideration of the comparison of electricity mixes showed in the Figure 2 and best GWP impact as possible.	Average (dependent of availability)

** according to EBRA guidance document on the calculation of recycling efficiencies for spent batteries and accumulators.*

***as reminder battery back must be recycled at least 50 wt% according to EU Directive 2006/66/EC.*

Table 2 - List of priority and secondary eco-design indicators for cells choice according to eco-design approach.

The graph of figure 2 shows a comparison of electricity mixes of main li-ion batteries manufacturing countries in comparison to that of Swiss country.



Note:
Data based on electricity mixes from Ecoinvent database (except electricity mixes for Taiwan and South Korea modelled by RESCOLL from literature) and calculated for the Global Warming Potential (GWP) according to ILCD recommendations with GaBi 6 software. The GWP impact of Swiss was fixed to 100% and the evolutions were calculated in percentage for others countries.

Figure 2 – Comparison of electricity mixes of main li-ion batteries manufacturing countries in comparison to that of Swiss country.

3 Results and discussion

As a result of the scheduled working roadmap:

- The cell's comparison table is updated with feedback from partners on Gravimetric & Volumetric Energy density;
- RSC sent this table to OEMs;
- Feedback from OEMs has been received

The three partners did a selection according to several criteria which is presented here below:

Partner A's criteria are the following:

- 18650 or 21700 format
- Wh/kg > *confidential value*
- Number of cycles > *confidential value* Cy
- Vnominal around *confidential value* V
- R < *confidential value* mOhm

After applying the above criteria, the best cells have been selected by A in terms of the maximum Volumetric Energy density.

As a result of applying above criteria, seven references of cells have been selected from four different brands.

For partner B the main criteria for the selection are the following ones:

- Availability from three different big cell's manufacturers
- Cell size 18650 or 21700
- Charging time between 1 and 3 hour
- Gravimetric energy density> *confidential value* Wh / kg
- Volumic energy density> *confidential value* Wh / L

As a result of applying above criteria, eight references of cells have been selected from three different brands.

Regarding partner C criteria, as their aim is building an affordable but reliable car, their highest interest is a tradeoff in the best cost / energy density value compared to the lifecycle of at least 8 years.

Based on these criteria and available information on the fulfilled table, C selected seven cells from different brands.

To summarize and if we take into account the "common" selected cells by the three partners, the last update version of the cell's comparison table **gathers fifteen references** (from the initial table gathering fifty four references)

Therefore, next actions regard:

Next steps	Deadlines	Responsible
Eco design indicators will be applied in order to justify final choice (between 5-7 references of cells)	1st W of January 2018	RSC
Final filtering and discussion will be done according to eco-design and recyclability rules too.	2nd W of January 2018	All
Launch purchase of about 40 cells	3rd W of January	OEMs

3.1 Eco-design indicators application

Regarding Eco-design indicators application, the procedure described in the table 2.2 of the section 2.2.3 will be applied on the fifteen selected cell's references.

The first step will consist in applying Priority Eco-design indicators

Regarding the application of priority Eco-design indicators, RSC will check datasheets and/or request additional information from the manufacturer/partners if not still available on the table regarding cycle lifetime, calendar lifetime, internal resistance, gravimetric energy density. The highest values will be preferred for the following indicators: cycle lifetime, calendar lifetime and gravimetric energy density. On the contrary, lowest values will be preferred for internal resistance indicator.

Regarding the application of secondary Eco-design indicators, the procedure presented in the table 2 will be applied regarding the three concerned indicators: Reach, Recyclability and cell's manufacturing country. As the uncertainty of these three indicators is higher than for Priority Eco-design indicators, they will be used to validate the choice after a first filter with priority Eco-design indicators.

4 Conclusions

This task has been useful to share the experience, advantages and disadvantages found by each developer (OEM, SME and RTD) with respect to automotive cells.

The main results/conclusions of the work performed are summarized here below:

- A database of cells (about 50 references) has been constructed in order to easily compare the cells with respect to each parameter with the collaboration of all involved partners.
- Priority criteria (cf section 3) for cell's selection have been defined and applied in order to reduce the number of cells (about 15 references)
- An Eco-design approach has been defined and explained (cf section 2 & 3) and is being applied on the retained cells

Regarding milestone linked to this Deliverable:

MS	MS header	Description of executed activity
MS2	Set of advantages and disadvantages per selected cell	Each partner involved in this task has contributed with data, advice, advantages and disadvantages of different types of commercial cells and from different criteria (technical, safety, availability, cost, and environment impact) A database of a cell has been constructed in order to easily compare the cells with respect to each parameter

5 Bibliography

Dufrene. (2015). *A methodological framework to support integrated ecodesign for companies : requirements and conceptualization towards a software platform (thesis).* Université de Grenoble.

Peters. (2016). The environmental impact of li-ion batteries and the role of key parameters - a review. Renewable and Sustainable Energy reviews 67 (491-506).