High specific energy rechargeable batteries used as a main source of energy for mobile application

Definition of scope

Definition of the representative product

Description of the model for the PEF screening study

Title of the Study: High specific energy rechargeable batteries used as a main source of energy for mobile application – Definition of Scope, representative product and description of the model for the PEF screening study

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Acronyms

GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
GWP	Global Warming Potential
PCR	Product Category Rules
LCA	Life Cycle Assessment
ICT	Information and communication technology
IEC	International Electrochemical Commission
HEV	Hybrid Electric Vehicle
PEHV	Plug-In Hybrid Electric Vehicle
NiMH	Nickel Metal Hydride
Li	Lithium
Wh	Watt-hour
UPS	Uninterruptible power supply
SLI	Starting-Lighting-Ignition-battery

1 Introduction

The European Commission has selected RECHARGE in September 2013 to develop the Product Environment Footprint for rechargeable batteries in an advanced pilot project.

Out of 90 proposals, RECHARGE's proposal has been retained with other projects that will be part of the first set.

Initiated by the European Commission, the Product Environmental Footprint (PEF) is a Life Cycle Assessment (LCA) based method to evaluate the environmental performance of a product. Through this project, RECHARGE aims to develop the applicable criteria to the environmental performance of batteries in selected applications. RECHARGE intends to develop the methodology of the environmental impact evaluation for rechargeable batteries based on the PEF guidance document, as well as selected Environmental Performance Criteria which are based on information accepted and recognised on an international basis by the battery industry and other stakeholders. Finally, the PEF pilot phase provides an opportunity to harmonise the rules for environmental labelling of the batteries.

RECHARGE's mission is to promote Advanced Rechargeable Batteries as a technology that will contribute to a Sustainable Society, a Resource and Energy Efficiency policy and to the achievement of a Green Circular Economy.

The membership of RECHARGE includes suppliers of primary and secondary raw materials to the battery industry, rechargeable battery manufacturers, original equipment manufacturers, logistics partners and battery recyclers.

RECHARGE is following the continuously changing regulatory and legislative environment for rechargeable batteries and is a recognized expertise centre for advanced portable and industrial rechargeable battery technologies.

2 Scope

According to the Product Environmental Footprint (PEF) Guide [PEF Guide] and the Guidance Product [Guidance Products], defining the Scope of a Product Environmental Footprint study, shall include:

- Unit of analysis and reference flow
- System boundaries
- Environmental Footprint impact categories
- Assumption/Limitations

This section describes the unit of analysis and the reference flow. The Environmental Footprint impact categories as well as the assumptions and limitations will be addressed and communicated to the stakeholders as part of the Screening PEF exercise.

2.1 Global Definition

Global definition of the function of a rechargeable battery is to supply electrical current at a desired voltage range from an on-board rechargeable battery with a high specific energy, which is the main source of energy for a mobile application, during a given service life.

There are three fields of application focused on, in the scope:

- high specific energy batteries for e-mobility (e.g. e-bikes, EV, PHEV, cars, bus/trucks)
- ICT (tablets and phones, computers, cameras, games, …)
- Cordless power tools

The property of high specific energy (Wh/kg) is enabling the considered application to be successful in the market: i.e. cellular phones have known a large success linked to the lightweight of their batteries (high specific energy batteries have a low weight for a given energy contend). Another example is the portable computers: these products have permanently been using the higher specific energy battery technology available on the market during the past years, moving from Ni-Cd to Ni-MH and then to Li-ion.

Other applications include different relevant criteria for battery performance, such as the service time of the battery, the power, the weight etc. Therefore, batteries used in such applications cannot be evaluated and considered in this screening study and PEFCR.

Some examples of such excluded applications are:

- Stationary power stations, back-up power systems (for train, aircrafts, UPS, etc.): the main function is the service time of the back-up availability. The unit of analysis is not the total energy delivered, but total service time. In addition, for most of the stationary applications, the weight of the battery is not a key factor: high specific energy is not required.

- SLI batteries: the main function is the minimum power for cold cranking performance1. The functional unit is the power delivered.
- Batteries with different expected quality and/or additional function (for example forklift batteries are selected for their total energy over lifetime, but counterweight is often used in the application as an additional function). The maximum specific energy, which is clearly a major characteristic of the function definition in our scope, is not a primary requirement for these applications. Consequently, the batteries used in applications such as forklifts, golf-carts, wheelchairs, ... will not be considered in this study.
- Non- rechargeable batteries fulfil the same function only for one discharge. The total service life (cumulative energy delivered over service life) can be obtained with many products, each one being discharged only once. Supporting this approach, we have not identified significant markets shares corresponding to applications in our scope, where primary batteries are the energy source of reference. In addition, no charging system is required, thus creating a difference with rechargeable batteries in the PEFCR boundaries.

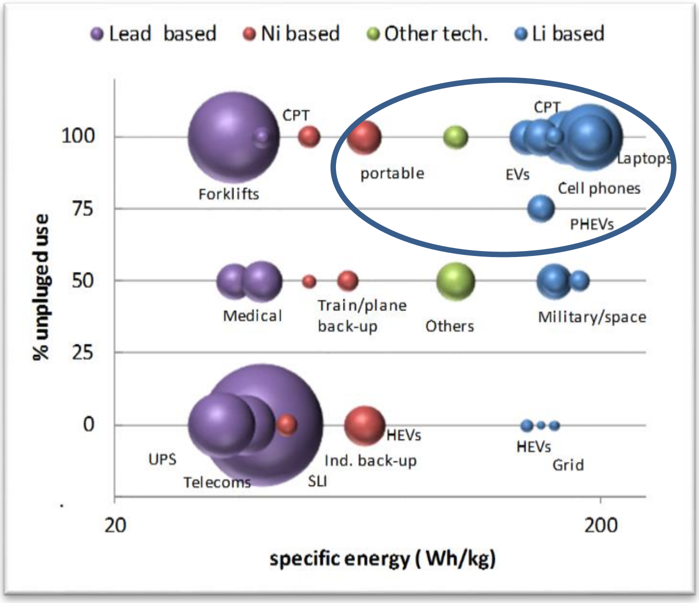

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Figure 2-1: Battery markets according to specific energy (Wh/kg) and unplugged use (%)[2]

The different markets for rechargeable batteries have been reported on the chart here above, according their specific energy (Wh/Kg) and a scale representing their usage: bat-

[1] The cranking performance is the discharge current (Is) which a battery can supply at -18°C in case of class A and B for 60s to a minimum voltage of 8.4volts. The SAE cold cranking current is defined as the current a battery at a temperature of -18°C can deliver for 30 seconds while maintaining a voltage of greater than or equal to 7.20V.

[2] Data source treatment: the data published by Avicenne are covering the worldwide market, and all type of technologies and applications. The data presented here have been recalculated for Europe only.

teries designed to be used as permanently plugged have 0% usage unplugged, batteries designed for mobile systems have 100% usage unplugged. Several markets where the usage is mixed or undefined have been attributed a 50%. The size of the markets ($) is represented with the size of each ball point.

On this chart, the applications identified as homogeneous according the definition are circled on the top right. It is clear that the scope of the project do not cover all rechargeable batteries markets. It appears that the type of battery in the scope of the PEFCR is only part of all batteries identified under the mentioned CPA code: 27.20.23

2.2 Unit of Analysis and Reference flow

The scientific unit of measure for the electrical energy is Watt-hour (Wh). In the case of rechargeable batteries, the total service provided can be measured by the total Watt- hour delivered over life. Consequently, the unit of analysis considered is the Total Watt-hours, over service life. It is defined according to the following criteria, described in the Product Environmental Footprint (PEF) Guide [PEF Guide]:

1. **The function(s) / service(s) provided: "what"**
    - electrical energy, measured in Wh (current and voltage during a unit of time)
2. **The magnitude of the function or service: "how much"**
    - Amount of delivered energy by a fully charged battery (quantity of Wh, associated to the size of the battery)
3. **The amount of service provided over the life time: "how long/ how often[3]"**
    - Amount of cumulative energy delivered over service life (quantity of Wh, obtained from the number of cycles multiplied by the amount of delivered energy over each cycle)
4. **The expected level of quality: "how well"**
    - Maximum specific energy (measured in Wh/kg),

In the applications covered in this PEF pilot project, maximum specific energy (measured in Wh/kg) is a primary requirement for the battery to fulfil, and so is therefore used as a measurement of the expected level of quality. Other criteria (maximum Wh/l, W/kg, W/l, external jacket, safety properties, temperature range) can be considered as secondary properties in this study. In other applications not covered by this pilot, different primary measures of "level of quality" required from the battery may be relevant. This should be assessed on a case by case basis.

[3] The purpose of rechargeable batteries is to be used several times. The number of use cycles is a key feature of the product. This is the reason why "how often" has been added to this criteria.

After careful analysis of the battery function, it has been concluded that time, or life-time, was not a correct description, but service life expressed in total Wh was. For example: depending on the user need, a battery having a life cycle of 500 cycles can be used during 1,3 year for a user charging once a day, but 4 years for a user charging each 3 day.

Reference flow: in our case, it is the output of the process required to produce a battery delivering the requested total Wh over service life, identified as the functional unit.

This definition allows to clearly differentiate the quality of batteries regarding the PEF:

High quality batteries may be defined as enduring a larger number of cycles than the minimum specified in the standard, providing then more total Wh over service life, for a given size. Consequently, in order to achieve the functional unit service, the size of such type of battery can be reduced, according the manufacturer specification, allowing a reduced reference flow. This may of course reduce the environmental footprint of the product.

In the same way, for a given application, the number of functional units required to provide the expected service may be reduce for high specific energy batteries: for example in case of EV, the electrical energy used to move the vehicle will be reduced if the vehicle is lighter. Consequently, the total amount of energy required by the vehicle for a given number of km will be reduced in case of use of high specific energy batteries.

2.3 System boundaries

The figures below describe the general system boundaries. In chapter 3.3 a detailed description of the system boundaries of Li-Ion and Ni-MH processes is described.

The blue box regards the upstream data. It encompasses the extraction and processing of the raw materials required for the various components of the battery. The data included here takes into account all the efforts and impacts associated with the generation of the requisite materials until they are in a state ready to be used in the manufacturing of the battery.

The red box illustrates the efforts associated with manufacturing of the various components of the cell using the aforementioned raw materials. The quantity of raw materials sourced, and thereby the associated impacts from the upstream data depend on the quantity of materials required for the manufacture of cell components.

The process “Battery Modul”, on the right, represents the assembly of the components to produce the battery. The efforts and impacts associated with the assembly represent the final step in the production stage of the battery.

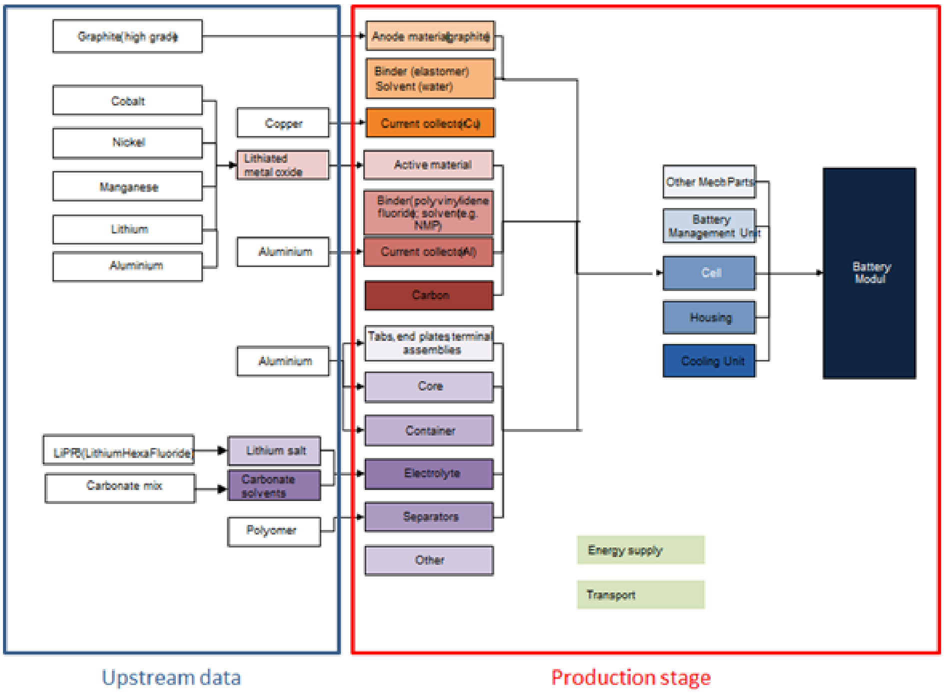

Figure 2-2: Manufacturing stage

Energy supply as well as transportation of raw materials to the manufacturing site are included in the system boundaries.

The use-stage of the battery follows the manufacturing stage. This stage depends on the application where the battery is used.

This PEFCR is function oriented, not application oriented. Due to the multiplicity of application of the batteries in the scope, the battery has been considered as a final product providing a service to the application: the source of energy. As the OEM specification and usage can change according each application (and also inside each application), it will be considered as part of the use stage to define the conditions of use, and include the battery environment in use (charge, BMS, cooling systems,...) (see Figure 2-3).

The charge management system includes the manufacturing of the charge tool of the battery.

In case a cooling system is required for the correct functioning of the battery, the impacts associated have to be considered.

The battery management system includes the electronics parts required to fulfil the required application.

The energy consumption to charge the battery is an essential part of the battery performance: charging system efficiency and battery charging efficiency will be included inside the boundaries of the study.

A scenario involving reuse of batteries has been excluded from the system due to unavailability of adequate data. For the present time, a lack of regulation (EPR, product liability) and technical practice (refurbishment process, warranty,…) reduce the possibility to assess the impact of battery second life. On the contrary, the "second-hand" batteries usage is part of the service life).

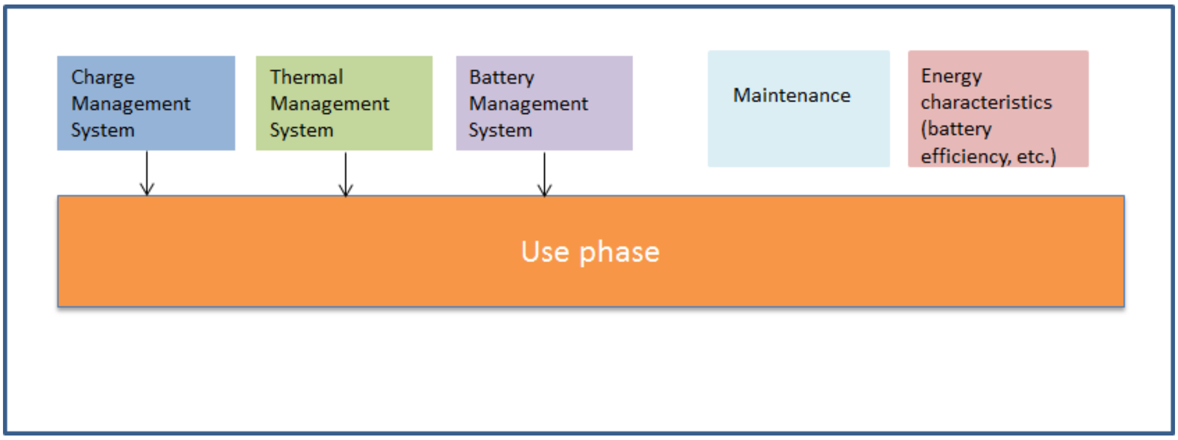

Figure 2-3: Use stage of battery

The end of life scenario takes into consideration the collection rate and recycling process. In the case of batteries, these processes have regulated objectives, according the directive EC2006/66/EC /2006/66/EC/ and the regulation EU 493/2012 /EU 493/2012/.

According to these documents, the collection rate for portable batteries has to be at 45% minimum, and the collection of industrial batteries has to be close to 100%. It seems reasonable to use these legal minimum values as a reference in our study.

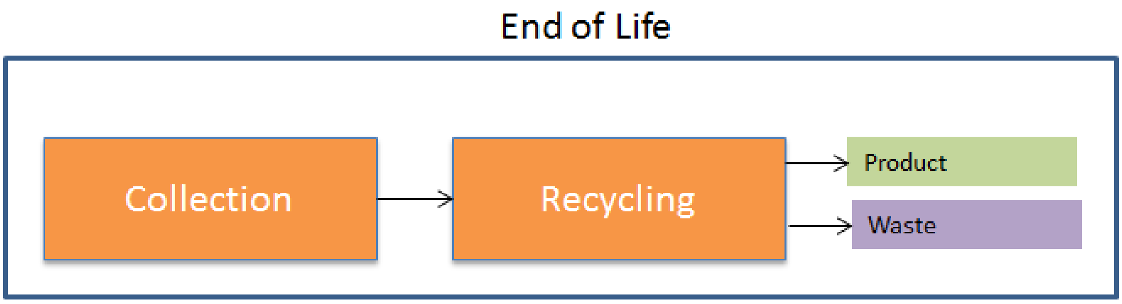

Figure 2-4: End of Life of a battery

The recycling process depends on the chemistry of the battery. According the type of battery technologies considered (see chapter 3.1), primary data concerning the output of the recycling process will be collected with the major European battery recycling companies. This will include the recycled materials as well as the by-products generated by the reference processes. Dismantling and pretreatment are taken in account in the global "recycling" process.

3 Representative Product

According to the Product Environmental Footprint (PEF) Guide [PEF Guide] and the Guidance Product [Guidance Products], the “representative product” model report should include the following elements:

- Bill of materials (BOM) or if more suitable, ingredients;
- A flow diagram (system boundaries) covering the entire life cycle;
- Assumptions related to transportation systems;
- Assumptions related to use scenario (if relevant);
- Assumptions related to End of Life (if relevant).

3.1 Description of representative Product

The “representative product” chosen for the PEF Screening, represents the unit product to be evaluated. It is a virtual product which can be calculated based on the typical characteristics and composition of the different products available on the market. Nevertheless, considering the very different applications, and very different size of batteries, it is proposed to evaluate the PEFCR using one representative product per application. As the number of applications is quite large, this pilot will test the robustness of the model using 3 to 4 representative products: one for cordless power tools, one for cellular phones and one or two for e-mobility (large electric vehicle battery and/or ebikes-escooters). This approach offers the required flexibility to assess the quality of the representative product model during the screening phase, based on specific representative product per application. The assessment of the representativeness of a virtual product merging all applications of the scope will also be tested in a second step for comparison..

1. **Option A:** for each application, a single product can be evaluated which represents the technologies used. Such a virtual product, encompassing the market for all technologies, would represent an average rechargeable battery.

   This average is calculated on the basis of market shares. The market share averages have been evaluated using weighting of the different technologies on the basis of the dollar-value (value of sales referencing 2012 data) on the market (source Avicenne, Batteries 2013 Congress, Oct 14-16th 2013, Nice)[4]

[4] Data source treatment: the data published by Avicenne are covering the worldwide market, and all type of technologies and applications. The data presented here have been recalculated for Europe only, and for the applications considered only.

Table 3-1: Market share (dollar value) per technology and application

% of market share ($) per technology and market									
		Li CoO2	Li NMC	Li PO4	Li Mn	Ni-Cd	Ni-MH	Pb acid	**Grand Total**
Mobility		**0,7**	**5,8**	**3,5**	**6,8**	**-**	**-**	**0,4**	**17**
	electric bicycles	0,7	2,1	3,5	0,7	-	-	0,4	**8**
	EV	-	0,3	-	5,7	-	-	-	**6**
	PHEV	-	3,4	-	0,4	-	-	-	**4**
ICT + Consumer products		**26,7**	**27,7**	**0,7**	**2,4**	**-**	**6,5**	**1,2**	**65**
	cameras/games	0,9	6,0	-	1,7	-	-	-	**9**
	cell phones	9,9	4,6	-	-	-	-	-	**14**
	laptops	15,9	6,7	-	-	-	0,5	-	**23**
	others portable	0,1	0,3	0,7	0,7	-	6,0	1,2	**9**
	tablets	-	10,2	-	-	-	-	-	**10**
cordless power tools		**-**	**6,7**	**-**	**-**	**2,0**	**0,3**	**2,1**	**11**
	Cordless power too	-	6,7	-	-	2,0	0,3	2,1	**11**
Others		**6,4**	**-**	**-**	**-**	**-**	**-**	**-**	**6**
	Medical	6,4	-	-	-	-	-	-	**6**
Grand Total		**34**	**40**	**4**	**9**	**2**	**7**	**4**	**100**

Source: Avicenne, Batteries 2013 Congress, Oct 14-16th 2013, Nice (see footnote 4)

Red is used to highlight individual figures larger than 5%. Blue lines are for (sub)total.

In the case of the application "ICT and consumer products" , an option B will be evaluated:

2**. Option B**: the two technologies of Li-ion and Ni-MH could be evaluated separately and two representative products could be defined: one average Li-ion battery and one Ni-MH battery, In this case, market shares of each technology would be discounted and the batteries would be evaluated individually.

The choice among Options A and B is to be made in the course of the PEF screening.

A large number of battery technologies is existing on the market. Some are existing since years, but due to their specific properties, their usage is limited to niche markets, representing small quantities of products placed on the market. Some others are emerging technologies, with manufacturing process still not mature, in start-up or SME's structure. In both cases, the data concerning the manufacturing stage and use stage are specific, and their availability is limited or not existent. Consequently, the need of a cut-off decision at some level of market share is unavoidable. A test scenario will be made with Li PO4 included in the calculation, to validate that the result of the impact assessment of the representative product is not significantly changed by the integration of a different technology with less than 5% market share. Based on this result, the proposal to exclude all chemistries which are not representing more than 5% of the market will be confirmed.

Consequently, the representative product will not take into account LiFePO4, Ni-Cd or Pb-acid batteries owing to the fact that **their market shares are lower than 5% for the considered applications**,

The sum of the 4 chemistries considered is more than 75% of market.

As described in chapter 2.2, the functional unit is defined to be 'watt-hour'. Therefore, the representative product is based on the quantity of watt-hour delivered to the market (see Table 5-1).

The proportion is according the following figure, in the case of a product representing all applications: (recalculated without HEV)

Li CoO2	Li Mn	Li NMC	Ni-MH
40%	47%	5%	8%

Figure 3-1: Market share of the different battery chemistry considered in the representative product

3.2 Bill of Materials

The bill of materials contains the quantity of raw materials, sub-components and intermediates needed to manufacture the end product. The generic bills of materials for Li-Ion and Ni-MH according to literature (see footnotes) are displayed in Table 3-2 and Table 3-3.

Table 3-2: Bill of Materials for Li-Ion Batteries (Total Mass 10-12kg)[5]

Component	Material	Percent Mass (%)
Anode		**15 - 24**
	Copper foil (collector)	1 - 12
	Battery grade graphite/carbon	8 -13
	Polymer	<1 - 0
	Auxiliary solvent	<1 - 6
Cathode		**29 - 39**
	Aluminium (collector)	4 - 9
	Lithium-ion material*	22 - 31
	Polymer / other	<1 - 3
	Auxiliary solvent	<1 - 11
Separator		**2 - 3**
	Polymer	2 - 3
Cell Casing		**3 - 20**
	Aluminium casing and polymer pouch	
Electrolyte		**8 - 15**
	Carbonate solvents	7 - 13
	Lithium hexafluorophosphate	1 - 2

[5] EPA (Report) – LCA to Nanoscale Technology on Li-Ion Batteries for vehicles

BMU		**2**
	Copper wiring	1
	Steel	1
	Printed wire board	<1
Battery Pack Casing/Housing		**17 - 23**
	Polypropylene/polyethylene terephthalate/steel	17 - 23
Passive Cooling System		**17 - 20**
	Steel and aluminium	17 - 20

** The different chemical compositions of lithium ion materials for the representative product will be weighted in accordance with market share, expressed in watt-hours delivered, when calculating a weighted average (see Figure 2 2). The following battery chemistries will be taken into consideration:* $LiCoO_2$*, LiMn, and LiNMC.*

Table 3-3: Bill of Materials of NiMH battery[6]

Component	Material	Percent Mass (%)
Active Component (Anode and Cathode)*		**43 - 64**
	Nickel	30 - 40
	Cobalt	2 - 4
	Rare earths	7 - 10
	Aluminium	2 - 4
	Copper	2 - 6
Separator		**9 - 15**
	Polypropylene / PE	9 - 15
Cell Casing		**3 - 14**
	Steel	3 - 14
Electrolyte		**20 - 25**
	Alkaline mix	20 - 25

** The active component includes active mass, additives and current collection grid.*

3.3 System boundaries

The system boundaries for the representative products correspond to the flow diagram displayed in Figure 3-1 and Figure 3-2. As described in chapter 3.1, there are two options for the representative product. The final decision will be taken after the PEF Screening.

3.3.1 Manufacturing stage of Lithium Ion Battery

The Figure 3-1 describes the production of Li-Ion battery.

[6] Saft Battery Information Sheet for Industrial Nickel-Metal Hydride cells, modules and battery systems, November 2013

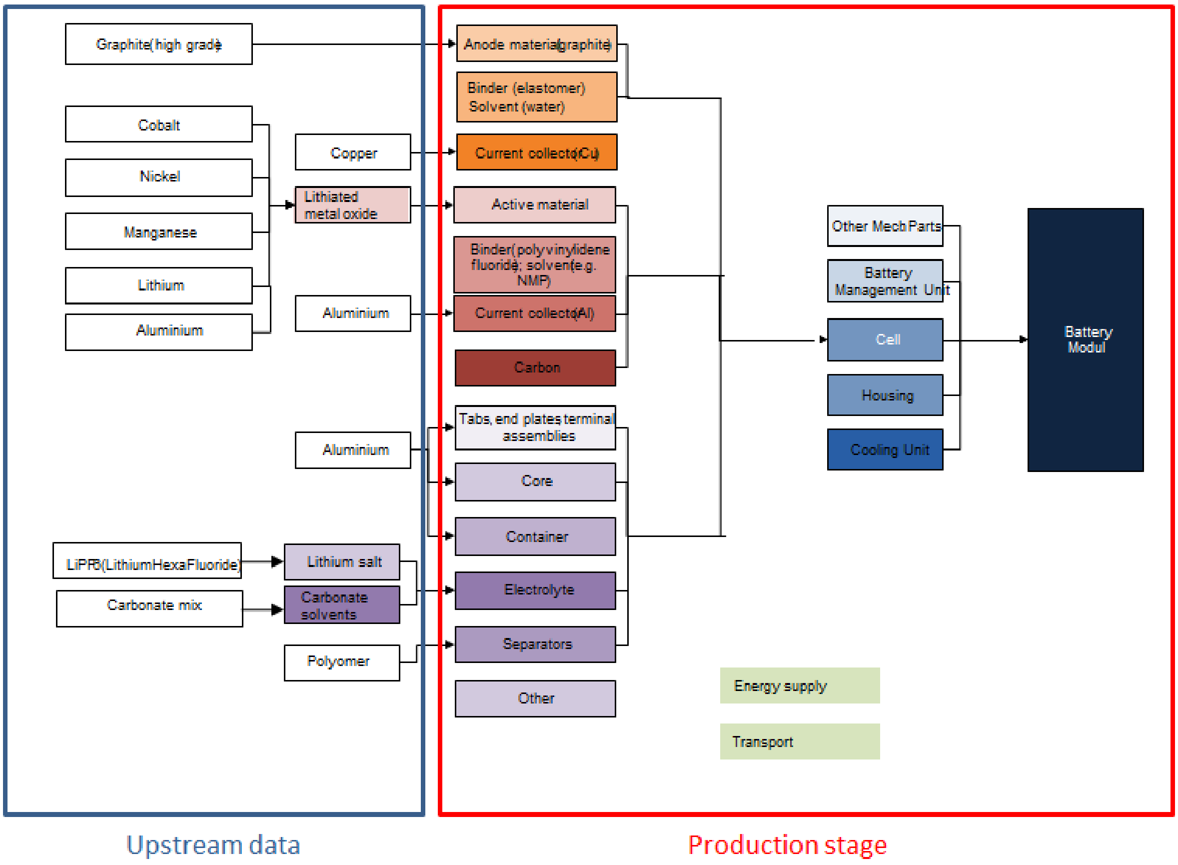

Figure 3-1: Cradle to gate of Li-Ion battery

Energy supply as well as transportation of raw materials to the manufacturing site are included in the system boundaries.

A description of the main process steps of the Li-Ion battery manufacturing follows:

Raw material preparation:

The ink manufacturing process needs to dry some of the raw material powders using a drier. After accurate weighing the powders are transferred to the mixer. Air aspiration is kept during the powder distribution. The air is dust filtered.

Ink preparation:

Two different inks:

• The negative ink is an aqueous stage preparation (water + mix of elastomers such as NBR/SBR/CMC)

• The positive ink is an organic stage preparation (NMP + PVDF)

Coating:

The ink is distributed towards the coating line to obtain a thin coat on the coils (aluminium for the positive electrode, cupper for the negative electrode): the active strip. The coated coils go through the drier with several regulated heat zone.

Calendaring and slitting:

These operations are done in dry room (dew point < - 40°C). The objective of calendaring is to reach certain porosity for the active strip. After calendaring, the calibrated strip is slit to obtain the final dimension of the electrodes.

Winding and cell assembly:

These operations are done in dry room (dew point < - 40°C). The positive and negative electrodes are winded insulated by a separator. Connexions and terminals are welded before insertion in the can. The cell assembly is ended by welding of the cover. A sealing test is applied before the next operation.

Electrical Formation:

Few electrical cycles are performed to control cell performance.

3.3.2 Manufacturing stage of Nickel Metal Hydride battery

The battery manufacturing and assembly stages of Nickel Metal hydride (NiMH) can be organized in a similar scheme to the Lithium battery. It follows a general description of the main production steps.

Active material mixing:

Positive and negative active materials are mixed together with additives, binder and sol-vent.

Coating:

These active positive and negative mixes are then coated on a collector foil/strip and the coated strips are dried in an oven.

Calendaring and slitting:

In order to achieve the targeted porosity, the coated strips are then calendared and slit at the adequate electrode dimensions.

Cell assembly:

A positive electrode, a separator and a negative electrode are assembled together with connectors. This dry cell is filled with electrolyte, and then closed.

Electrical Formation:

Few electrical cycles are performed to control cell performance

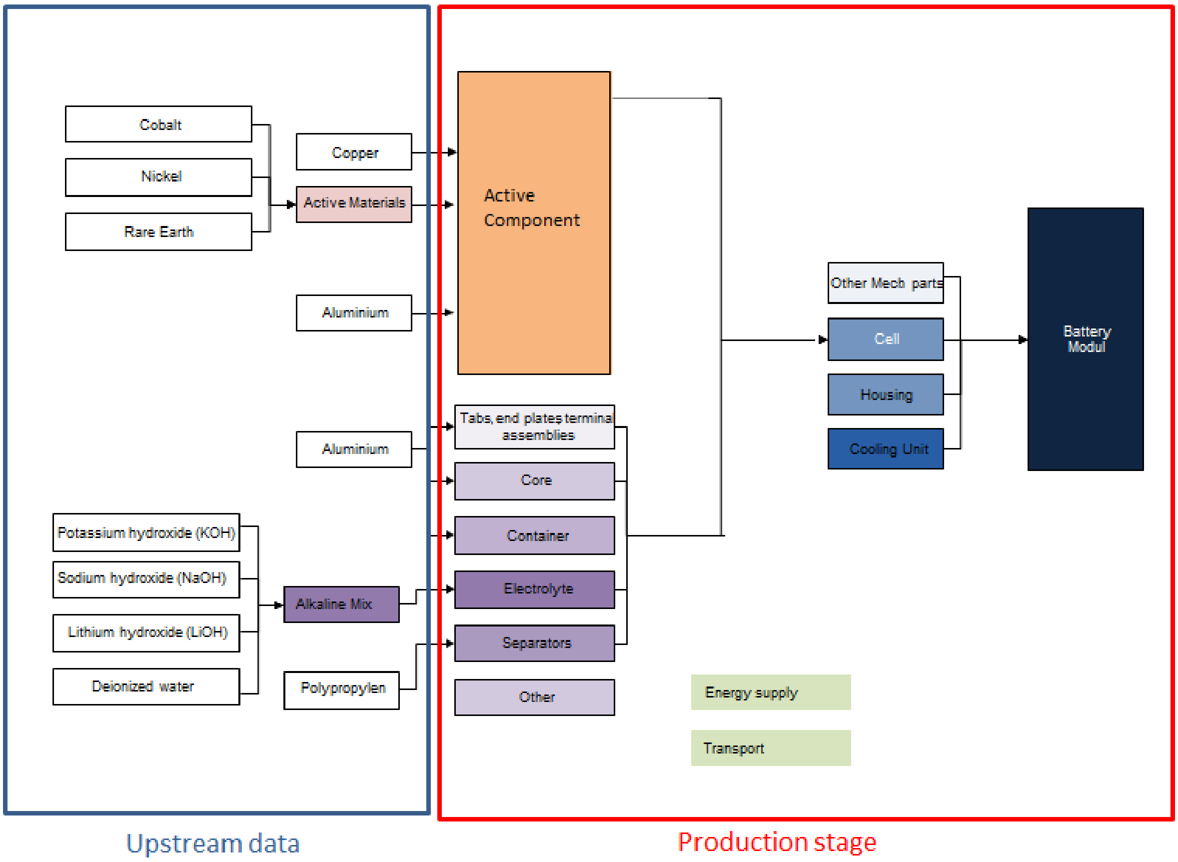

Figure 3-2: Cradle to gate of Ni-MH battery

Energy supply as well as transportation of raw materials to the manufacturing site are included in the system boundaries.

3.3.3 Use stage of Lithium Ion battery and Nickel Metal Hydride battery

As mention in chapter 2.3 the use stage depends on the application of battery. The general flow chart is illustrated below.

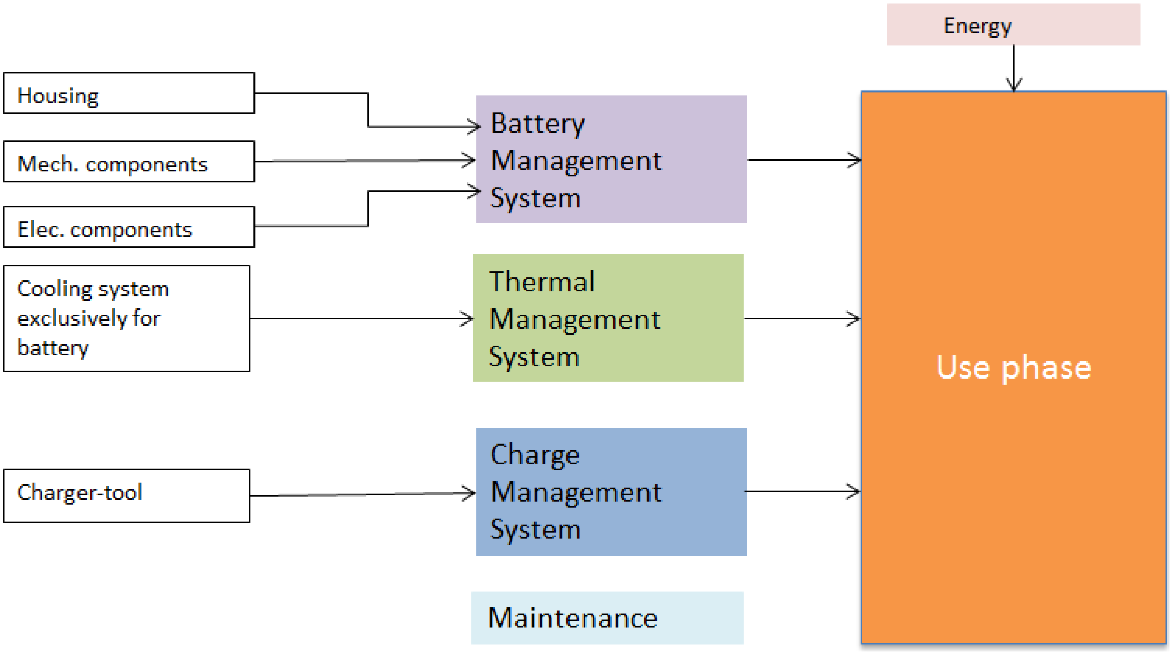

Figure 3-3: Use stage of a Li-Ion and Ni-MH battery

3.3.4 End of Life of Lithium Ion battery and Nickel Metal Hydride battery

The recycling stage for the batteries starts in general with a "preparation to recycling" step. During this step, some components like casings, cooling systems, plastics and other parts can be separated from the battery before the recycling process is applied.

<u>End of Life of Lithium Ion battery</u>

For Li-ion batteries, the representative recycling process is pyro-metallurgical, but other process exists, such as hydro-metallurgical treatment.

The main output of the recycling is a metallic fraction, containing metals from the battery and the slag. The metallic fraction can be refined to extract valuable metals or alloys such as Co in case of Li-Cobalt or Li NMC based batteries.

The slag can be used in the construction sector. In case of batteries containing manganese, the manganese is not recovered because the recovery process would be too energy and cost intensive. The manganese therefore remains in the slag.

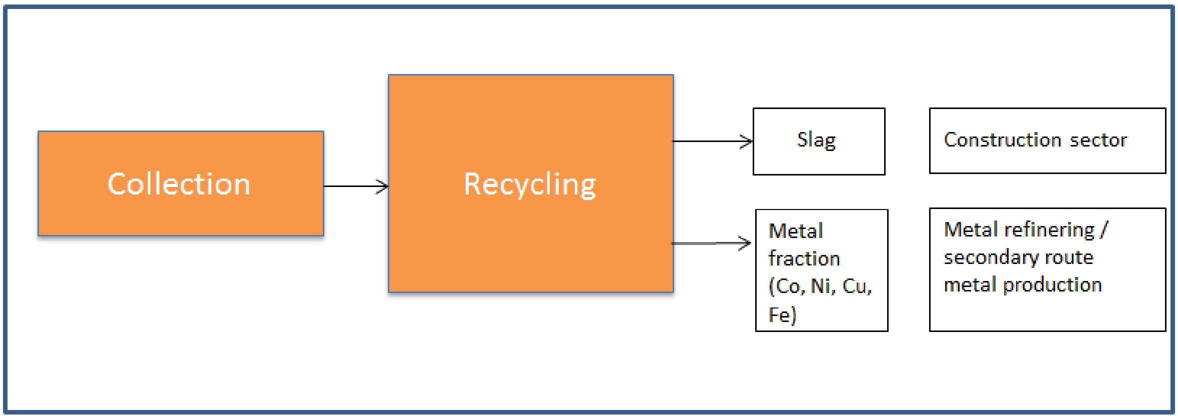

Figure 3-4: End of Life of Li-Ion battery

End of Life of NiMH battery

In case of Ni-MH batteries, most recyclers use a pyro-metallurgical process. The output of this process are metals such as a Fe-Ni-alloy, which is used as input material for the stainless steel industry, residues with concentrated rare earth content, that can be further refined.

Depending on the preparations for recycling steps and the different applications, casings and others components may be separately recycled.

3.4 Assumptions related to Transportation

The impact of transport on the overall environmental profile of e.g. the metal products is usually found to be negligible in LCAs. It is, however, a point to be addressed in the PEF Screening and a sensitivity analysis based on average distance data will be provided, to prove the insignificance to the overall results.

3.5 Assumption related to use scenario

The use stage is defined by the specific application, see also chapter 2.3. For the Screening exercise, a scenario based on the minimum performance expected for the batteries placed on the market will be applied. This total energy delivered over life (in Wh) can be calculated using the IEC standards describing the minimum life cycle performance:

For the Li-ion batteries, the standard IEC 61960 /IEC 61960/ will be considered. This standard describes in paragraph 7.5 the procedure to test the endurance in life cycles through permanent charge and discharge process. The test stops when the delivered energy in one cycle drops below 60% of the initial energy. The minimum number of cycles required is 400.

For the Ni-MH batteries, the standard IEC standard 61951-2 /IEC 61951-2 / will be considered. In a similar way to the Li-ion batteries standard, a testing procedure is described for the endurance in life cycle. The test is terminated when the delivered energy in one cycle drops below 60% of initial. The minimum number of cycle required is 500 (for most type of considered technologies).

Due to specific differences in the charging/discharging conditions for each chemistry, both standards will be used to describe these cycling test conditions. Nevertheless, the criteria used to define the end of life for the battery (end of the cycling test) can be unified. The criteria used in the Li-ion standard will be applied for both technologies: as it is fixed in Li-ion standard at 400 cycles/60% of capacity, and at 500 cycles/60% of capacity in the Ni-MH standard, the calculated minimum total energy delivered by the battery can be guaranteed in both cases. This single value for the minimum total energy delivered will represent an energy equal to the value of the battery single discharge energy mutiplied by 400 cycles and multipled by 80% (representing the total energy for a battery having a linear decrease of capacity between 100% and 60% of initial capacity).

On the Fig 3-5 is presented the minimum energy per cycles according the IEC standard, compared to a typical energy per cycle of a battery selected as an example.

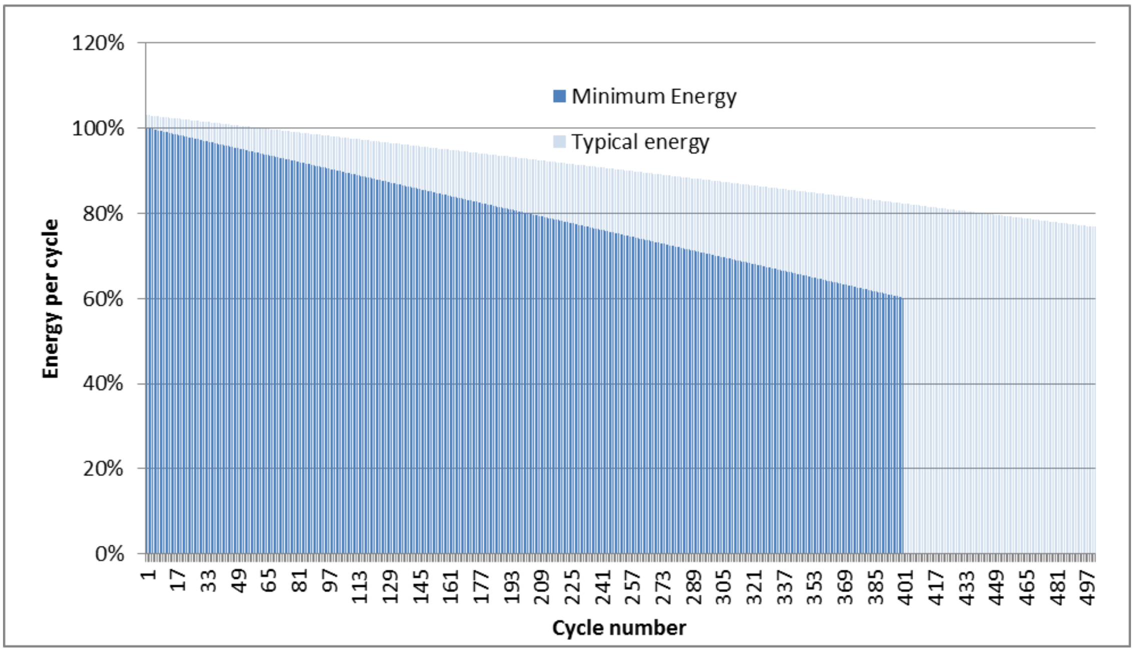

Figure 3-5: Energy per cycle during IEC cycle life testing standard.

It is clear that the minimum cycle life required by the IEC standard will not represent a typical average of the product service. Nevertheless, this fixed reference point enables any comparison. Applications specific benchmark will be tested in case an accepted reference of use phase standard is available

For example, the use phase for the battery of a cordless power tools has been defined in the LCA study supported by the industry and the Commission (http://ec.europa.eu/environment/waste/batteries/pdf/report_12.pdf). In this case, the use phase for the battery was described as similar to the one of the power tool: End of life after 165 h in use, representing 1375 usages with an energy delivered of 43,2 Wh. The tool being sold typically with 2 batteries, this represents an energy of 29,7 kWh supplied by each battery over the life. This value can be compared to the value obtained with the IEC standard, in this case 14,4 kWh. Consequently, the reference flow would be 2,6 for a battery providing only the minimum standard life duration, considering an equivalent life duration in the standard cycling test and the operation usage. A reduced reference flow could be used with a battery proved to have a better life cycle duration.

Another example can be provided based on the LCA of an e-bike realized by EMPA (ref Eurobike 2011,Friedrichshafen, 2. September 2011,Andrea Del Duce). In this analysis, the use phase is described as follows: the e-bike is expected to be used during 15000 km, the energy consumption being 10 Wh/km. This represents a total energy requirement of 150 kWh. It is indicated that the number of li-ion batteries (2,6kg each) required for the life is 2.75. Each battery having a energy content of 400 Wh, the total energy required for each battery is 54,5 kWh, This requirement is lower than the value calculated using the IEC standard (128 kWh), considering an equivalent life duration in the standard cycling test and the operation usage. Consequently, the reference flow for a battery providing the minimum energy according the IEC should be 150kWh/128 kWh= 1,17 batteries, instead of 2,75 has proposed in this study. This result underlines the interest to refer to a common standard for the description of the expected service of the battery.

It appears that in many applications, due to the various use phase conditions description, the total energy required by application cannot be easily assessed: for example, a study on the LCA realized for ICT applications indicates a broad range of total energy usage during the use phase, in a proportion of 1 to 2,5 (Anders S. G. Andrae & Otto Andersen , Int J Life Cycle Assess (2010) 15:827–836, DOI 10.1007/s11367-010-0206-1).

3.6 Assumption related to End-of-Life

Credits or Burdens occurring at end-of-life of the representative product will be:

- Calculated according to the formula[7] provided by the European Commission (EC) [PEF Guide]
- Calculated according to an alternative formula[8] provided by the EC [Guidance Products]
- Possibly calculated according to industry data
- Possibly calculated according the Declaration of the Metals Industry on Recycling Principles [METAL INDUSTRY]
- Possibly calculated according to suggestion of stakeholders (After Stakeholder consultation)

[7] PEF Guide, p. 118: Dealing with Multi-functionality in Recycling Situations

[8] Guidance Products, p. 26: End of Life (EoL) formula

For the moment, the close loop is not considered, as it doesn't correspond to any industrial reality. The available data for metals used do not include secondary raw materials.

4 Description of the model for PEF screening

The LCA model will be created using the GaBi 6 software system for life cycle engineering, developed by PE INTERNATIONAL AG. The GaBi 2013 LCI database [GaBi 6] provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

In the Screening Stage, the general model will be created for Li-Ion and Ni-MH batteries based on the bill of materials described in chapter 3.2. In addition to that, the specific companies will test the models for real products with their specific and confidential data.

The background data for upstream processes will be used from the GaBi 6 database. All processes are documented.

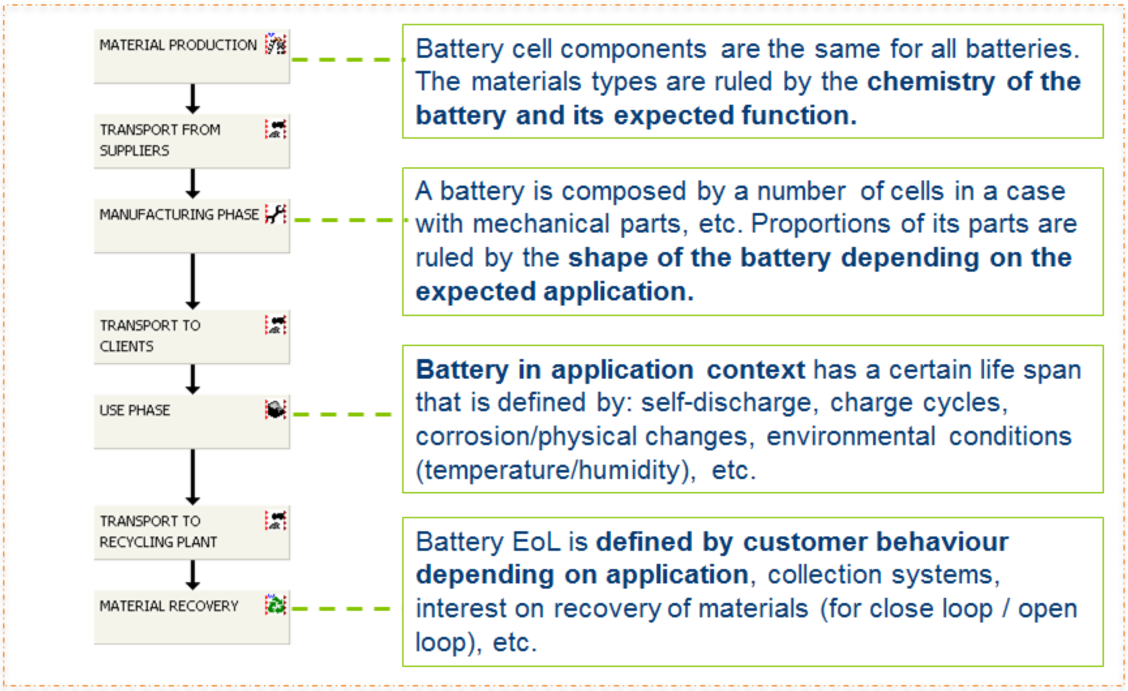

Figure 4-1: Gabi 6 Screenshot with explanations

For each product, an individual “Plan system” (see left side of the screenshot) in form of a flow diagram will be built up in GaBi 6 Software, taking into consideration the specific production of both batteries. The same procedure will be repeated for the rest of the Life Cycle steps.

5 Composition of the representative product

According to the market share evaluation (Table 3-1) the composition for the representative products would be as follow:

Option A:

For the case of representative product per application, the choice of representative product as global weighted average, based on table 3-1. The typical energy per unit for each application is provided in the table 5-1 below.

The minimum total energy (Wh) over service life can be directly calculated , as explained in prag. 3.5: it is equal to the value of the battery single discharge energy mutiplied by 400 cycles and multipled by 80% (representing the total energy for a battery having a linear decrease of capacity between 100% and 60% of initial capacity)

In the case of a global representative product, the choice of representative product as global weighted average for Li-ion and NiMH batteries.

MinimumTotal Watt-hours (Wh) over service life: **502 kWh**

Weight of the battery: **9,5 kg**

Option B: Considering separately Li-Ion and Ni-MH for the :

Li-Ion

Minimum Total Watt-hours (Wh) over service life: **552 kWh**

Weight of the battery: **9,9 kg**

Ni-Mh

Total Watt-hours (Wh) over service life: **0,7 kWh**

Weight of the battery: **0,03 kg**

Option C: The choice of representative product as global weighted average for Li-ion, including LiFePO4, and NiMH batteries. This case will be used to analyse (comparing to option A) the consequences on the PEFCR of the inclusion of a technology having less than 5% marketshare.

MinimumTotal Watt-hours (Wh) over service life: **534 kWh**

Weight of the battery: **9,24 kg**

The different chemistry mix (Co, Ni, Mn, etc) in the Li-Ion material of the cathode will be considered. The weighting factor will be based on the application share in Wh.

The bill of materials for the representative products will be calculated based on the selected chemistries and the market share ratio presented in the table below.

Table 5-1: Calculation of composition representative product

	Li-ion			Ni-MH			Li-ion+Ni-M
	Wh/unit	Market share		Wh/unit	Market share		
Mobility		**9,3%**			**0,0%**		
electric bicycles	400	2,4%			0		
PHEV	10000	1,9%			0		
EV	25000	5,1%			0		
representative energy	13694			1100			13694
representative weight	81			16			81
Wh/kg	170			70			170
ICT+ consumer products	**Wh/Unit**	**61,1%**			**7,5%**		
cell phones	5	9,9%			0,0%		
others portable	15	1,7%		2,2	7,1%		
laptops	54	31,2%			0,4%		
tablets	25	8,4%			0,0%		
cameras/games	10	8,4%			0,0%		
representative energy	34			2,2			30
representative weight	0,19			0,031			0,19
Wh/kg	175			70			164
Power tools		**5,0%**			**0,0%**		
Power tools	45	5,0%			0,0%		
Grand Total		**75,4%**			**7,5%**		
representative energy	1724			2,2			1569
representative weight	9,9			0,03			9,51
Wh/kg	174			70			165

6 Comments of the Steering Committee and consequent adaptations.

The minutes of the Steering Committee are reported here below:

- **Pilot on batteries**

The Technical Secretariat presented the document on scope and the representative product. (See PowerPoint presentation) The chosen scope definition is function oriented. The representative product is a virtual product and the PEFCR will be evaluated with one representative product per application. The impact of transportation is usually found negligible but still it will be looked at the PEF screening. For the Screening exercise, a scenario based on the minimum performance expected for the batteries placed on the market will be applied. In response to comments, it was clarified that all types of recycling options will be considered but recycling rates will not be country specific but an EU average will be used. Non-rechargeable batteries and Ni-containing batteries for vehicles will not be included.
The Steering Committee approved the document with 30 "yes" votes, one abstention (EEB) and no vote against.

Consequent adaptations:

There will be a representative product for each application considered: it will be a virtual product with a composition calculated according the market share presented in table 3.1.

For each application, a use phase scenario will be based on the minimum performance of the battery according the IEC standard 61960. In addition, this minimum performance will be compared to a typical application requirement.

Concerning the scope, the non-rechargeable batteries and Ni-containing have been removed from the study: see Fig. 2.1.

7 References

EN ISO 14040	EN ISO 14040:2009-11 Environmental management - Life cycle assessment - Principles and framework
EN ISO 14044	EN ISO 14044:2006-10 Environmental management - Life cycle assessment - Requirements and guidelines
GaBi 6	GaBi 6 dataset documentation for the software-system and databases, LBP, University of Stuttgart and PE INTERNATIONAL AG, Leinfelden-Echterdingen, 2012 (http://documentation.gabi-software.com/)
GHG Protocol	World Resource Institute, wbcsd, Product Life Cycle Accounting and Reporting Standard. September 2011; http://www.ghgprotocol.org/standards/product-standard
PEF Guide	Official Journal of the European Union L124: Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations – Annex II: PRODUCT ENVIRONMENTAL FOOTPRINT (PEF) GUIDE, May 4th 2013
Guidance Products	European Commission (EC): Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) pilot phase, Version 3.4, January 2014
PCR Overview	Compiled Overview of Existing PCRs for portable batteries, Excel Document, February 2014
EPA	Application of Life-Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles, April 24th 2013
2006/66/EC	Directive 2006/66/EC of the European Parliament and the Council on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, Version 6; September 2006
EU 493/2012	Commission Regulation laying down, pursuant to Directive 2006/66/EC of the European Parliament and of the Council, detailed rules regarding the calculation of recycling efficiencies of the recycling processes of waste batteries and accumulators
IEC 61960	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications, Version 2.0, June 2011
IEC 61951-2	Ni-MH batteries performance.
METAL INDUSTRY	Declaration by the Metals Industry on Recycling Principles, Internationa Council on Mining & Metal, November 2006