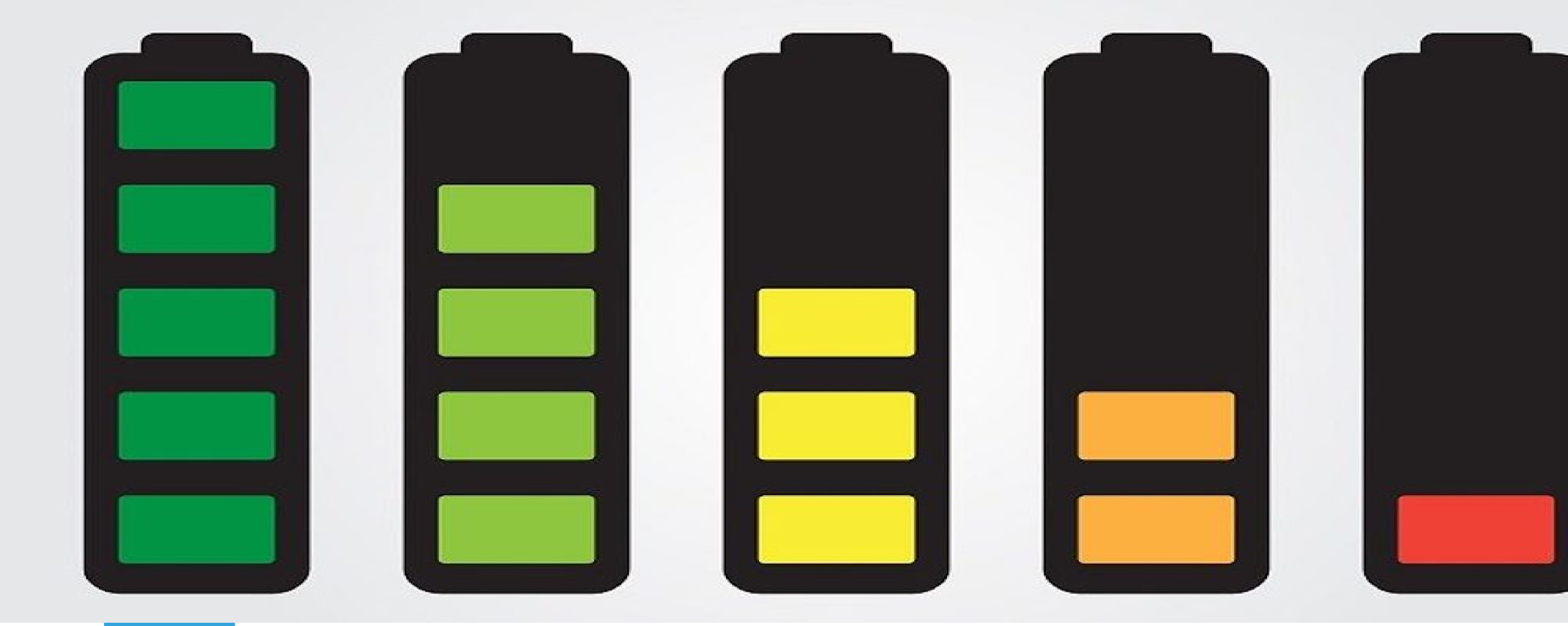


ECODESIGN BATTERIES – 1. STAKEHOLDER MEETING PRESENTATION OF TASK 4

Tim Hettesheimer, Antoine Durand

December 20, 2018 – Brussels

AGENDA

- ***Purpose of task 4***
- ***Subtask 4.1 - Technical product description***
  - *Description of a battery systems key components* → **Input for PEF: 3.2 Representative products**
  - *Technical improvement: BAT and BNAT according to literature*
  - *Definition of design options*
- ***Subtask 4.2 - Production, distribution and end-of-life****
  - *Product weight and Bills-of-Materials (BOMs)* → **Input for PEF: 6.1 Raw material acquisition**
  - *Materials flow and collection effort at end-of-life (secondary waste)*
    - *Second life*
    - *Recycling* → **Input for PEF: 6.6 End of life**

*Production stage and EOL also considered in PEF (for mobile applications, also in the following), as well as Use stage (see task 3)

PURPOSE OF TASK 4- TECHNOLOGIES

- Task 4 provides a **technological description** of the products in scope of the study.
- It serves two different purposes:
  - **inform the policymakers** and stakeholders about the product and its components from a technical perspective,
  - it serves to define the Base Cases and also works towards the **definition of Best Available Technologies (BAT)** and state-of-the-art **Best Not-yet Available Technologies (BNAT).**

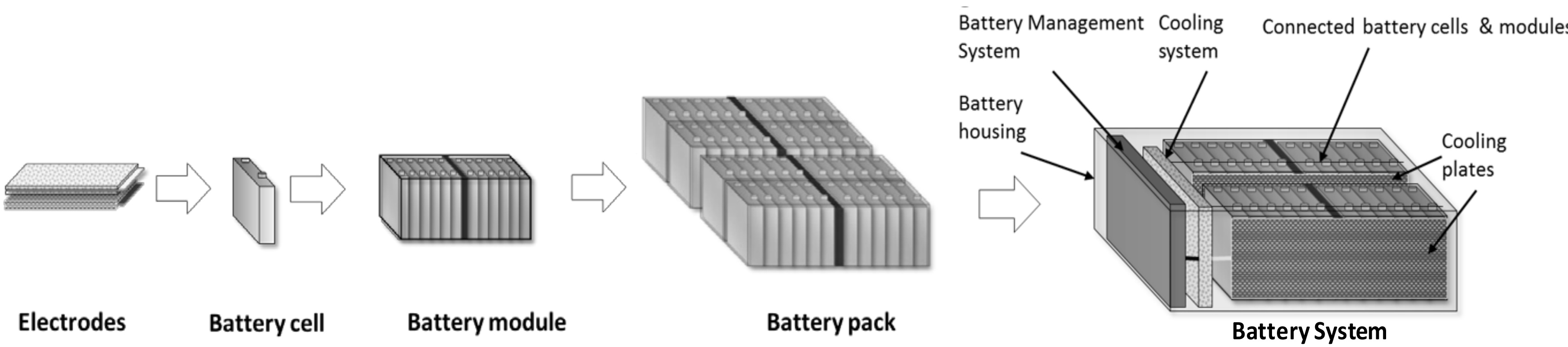
- While the **Base Case** represents an average product on the market today
- The **Best Available Technology (BAT)** represents the best commercially available product with the lowest resources use and/or emissions.
- The **Best Not yet Available Technology (BNAT)** represents an experimentally proven technology that is not yet brought to market, e.g. it is still at the stage of field-tests or official approval.

- The assessment of the BAT and BNAT provides the **input for the identification of the improvement potentials in Task 6**. The data for the base cases will serve as **input for Task 5**.

SUBTASK 4.1 - TECHNICAL PRODUCT DESCRIPTION

KEY COMPONENTS- SUBTASK 4.1 - TECHNICAL PRODUCT DESCRIPTION

Description of the key components of a battery system



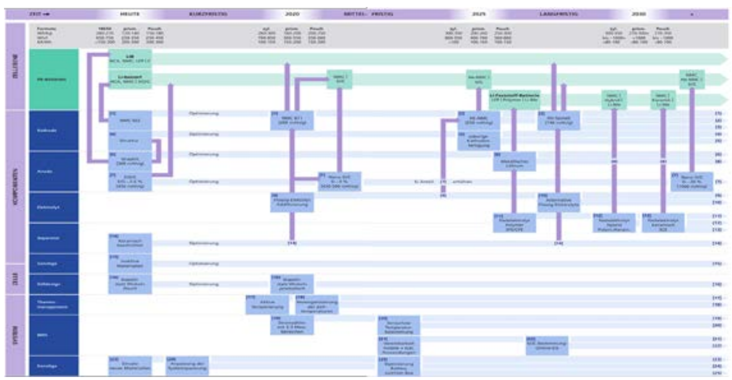
→ Input for PEF: 3.2 Representative products

Source: Hettesheimer 2017: Strategische Produktionsplanung in jungen Märkten. Ein systemdynamischer Ansatz zur Konzeption und dynamischen Bewertung von Produktionsstrategien am Beispiel der Lithium-Ionen-Traktionsbatterie. Stuttgart: Fraunhofer Verlag.

BAT & BNAT - SUBTASK 4.1 - TECHNICAL PRODUCT DESCRIPTION

Technical improvement: BAT and BNAT according to literature

- The procedure differs from MEErP in which sections on standard improvement, BAT and BNAT are usually described in sequence.
- BAT and BNAT by means of future development prospective of the different battery components.



		Today (BAT)	2020 (BNAT)	Until 2025 (BNAT)	From 2025 (out of time scope)
Cathode	Nickel-rich materials				
	High-energy NMCs				
	High-voltage spinels				
	Layer thickness				
	Aqueous cathode production				
Anode	Graphite				
	Si/C composites	2–5 % SiO	Si/C >5 %		Si/C --> 20 %
	Lithium metal				
Electrolyte	Additivation				
	Alternative liquid electrolytes				
	Polymer electrolyte SPE/CPE				
Separator	Stable separators				
Cell design and cell formats	Stacking instead of winding				
	Optimization of inactive materials				
Battery management system (BMS)	Electricity meter with 2-3 physical measuring ranges				
	Sensorless temperature measurement				
	Compatibility of electronics for automotive and stationary applications				
Thermal management	Battery temperature control during fast charging				
	Homogenization of temperature				

Please provide further input on improvement options and if they can be considered as BAT or BNAT.

Source: Thielmann, Axel; Neef, Christoph; Hettesheimer, Tim; Döscher, Henning; Wietschel, Martin; Tübke, Jens (2017): Energiespeicher-Roadmap (Update 2017). Hochenergie-Batterien 2030+ und Perspektiven zukünftiger Batterietechnologien. Karlsruhe.

DESIGN OPTIONS - SUBTASK 4.1 - TECHNICAL PRODUCT DESCRIPTION

Definition of design options: Exemplarily for base case 1

Name	BC 1	EE	CRM	DUR	Ext	REP	EES
Full Name	PC - BEV_BC	PC - BEV_EE	PC - BEV_CRM	PC - BEV_DUR	PC - BEV_Ext	PC - BEV_REP	PC - BEV_EES
Main strategy	Base Case	Higher Efficiency of the battery	Better CRM recycling	Higher durability of the battery	User profile changed: after 1st lifetime, range is limited	High repairability	1st life: like BC ⇨ 2nd life: as ESS (repurposing)
Description		Optimized BMS and thermal manangement	Substitution of weldings and adhesives by e.g. screws/ Substitution of composites by metals	Increased durability due to better cooling and dimensioning of cell and system	After EoL used e.g. for short ranged city car	Possibility to exchange e.g. a damaged module and thus to delay EoL	Use of battery for 2nd life application Caracteristics/parameters of 2nd life application not here
Positive influence on:		Higher FU due to higher system efficiency Lower installed capacity	Better recyclability	FU by longer lifetime	Increased lifetime beyond 80% SoH Increased FU due to lifetime	Increased lifetime Increased FU due to lifetime	Increased FU due to lifetime (side effect): improved information for 2nd hand EV (increased trust from customers)
Negative influence on:			Higher volume and weight (e.g. switch from composites to ... Lower lifetime (recyclability vs. lifetime) Lower quantity of FU	System efficiency (e.g. cooling) ... Energy density	... 2nd life)	Higher weight ...olume ...se of ...n for replacements -> Lower energy density	System compatibility

Any options missing or not applicable?

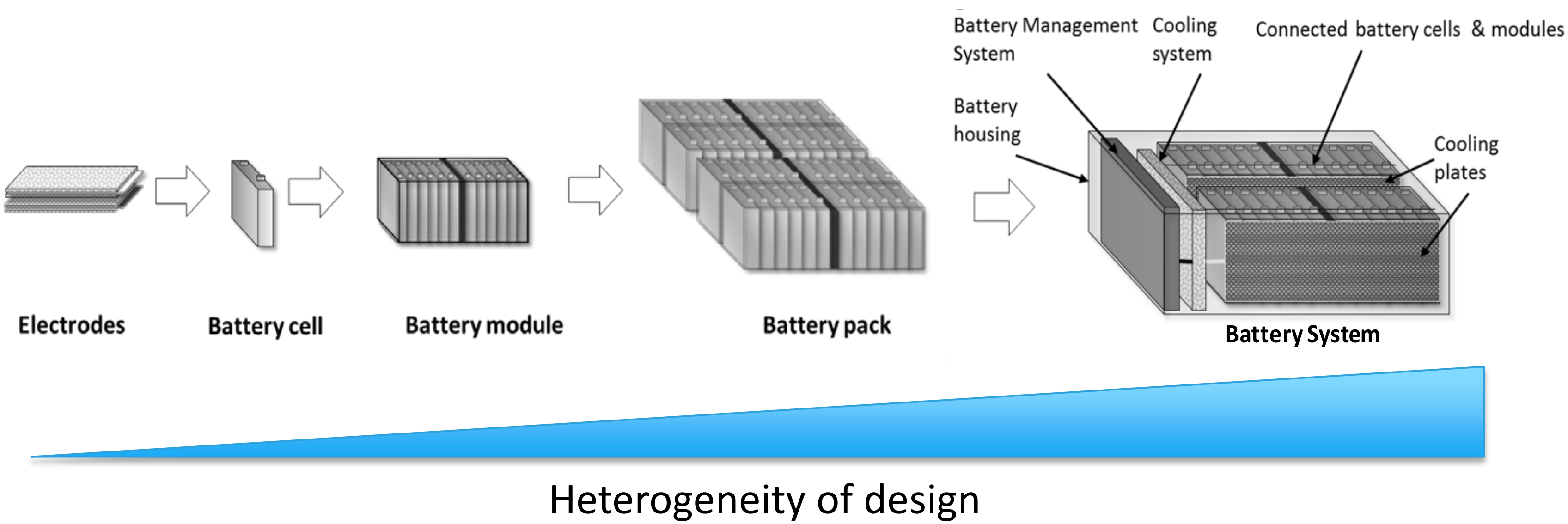
SUBTASK 4.2 - PRODUCT WEIGHT AND BILLS-OF-MATERIALS (BOMS)

Calculation of the BOM for the base cases

Product weight and Bills-of-Materials (BOMs) – Main barriers for defining the BOM for a BC

Calculation of BoM on battery system level for all base cases, but:

- Up to now, there is no representative product in the market, which could be used as a base case
- Products, even on cell level, differ regarding cell chemistry and cell format
- The heterogeneity of possible designs and products increases strongly when reaching the module and system level.



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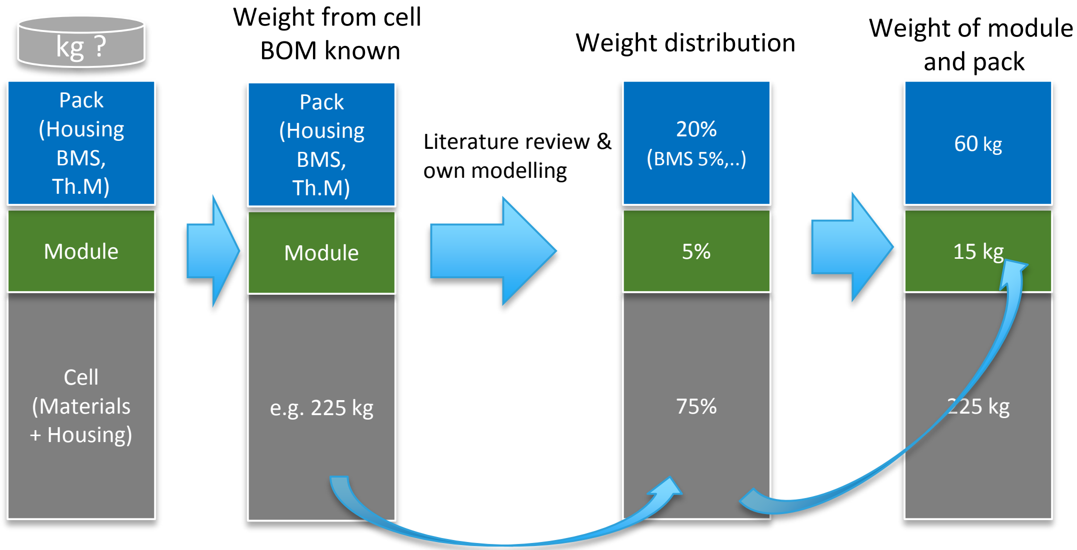
APPROACH BOM - SUBTASK 4.2 - PRODUCT WEIGHT AND BILLS-OF-MATERIALS (BOMS)

Summary of approach for defining the BOM for a base case



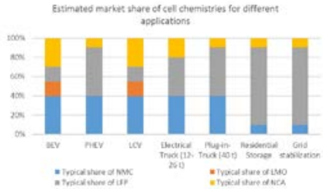
- BOM on battery system level (top-down)

1. Calculation of battery system and - modules weight by means of typical share of cell mass.
2. Calculation of the BOM for the module considering the cell format of the common cell
3. Calculation of the BOM for the pack considering different applications
4. Calculation of BMS and Thermal management weight and the BOM
5. Calculation of BOM for virtual product (system level) under consideration of the different share of cell chemistry per application

BOM ON CELL LEVEL- SUBTASK 4.2 - PRODUCT WEIGHT AND BILLS-OF-MATERIALS (BOMS)

Product weight and Bills-of-Materials (BOMs) – Cell level

- 5 common cells on the market
- Considering to cover most cell chemistries and to cover all three cell formats
- Calculation of the BOM on cell level for different applications under consideration of the share of each cell chemistry
- ➢ BOM for a virtual product for each base case



		LGC Bolt	LGC Volt (Gen2)	SDI BMW i3	Panasonic 18650	BYD 200Ah for e6/k9
General Information	**Format**	**Pouch**	**Pouch**	**Prismatic**	**Cylindrical**	**Prismatic**
		NCM 622	**NCM424/NCM111/LMO -**	**NCM523/NCA(80/15/5)/LM**	**NCA (82/15/3)**	
	Chem.		**(6/2/2 assumed)**	**O - (Share 6/2/2)**		**LFP**
	Ah	59	25,9	60	3,18	250
	Wh	212,4	96	222	11,45	875
	V	3,6	3,7	3,7	3,6	3,2
	W/mm	305	171	173	18,25	410
	H/mm	100	233	125	65,1	146
	T/mm	13,5	7,5	45		58

			Material	**per cell in g**	**Material**	**per cell in g**	**Material**	**per cell in g**	**Material**	**per cell in g**	**Material**	**per cell in g**
BOM Cell level	Kathode	Cathode active material		346	**NCM424/NCM**	200,7	NCM523/NCA	552	NCA (82/15/3)	16,46	LFP	1400
		Cathode active material 1	Fe	0	Fe	0	Fe	0	Fe	0,0	Fe	496
		Cathode active material 2	Co	39	Co	21	Co	22	Co	1,4	Co	0
		Cathode active material 3	Ni	117	Ni	29	Ni	75	Ni	7,5	Ni	0
		Cathode active material 4	Mn	37	Mn	64	Mn	223	Mn	0,0	Mn	0
		Cathode active material 5	Al	0	Al	0	Al	1	Al	0,2	Al	0
		Cathode active material 6	Li	46	Li	21	Li	42	Li	2,2	Li	62
		Cathode active material 7	P	0	P	0	P	0	P	0,0	P	275
		Cathode active material 8	O	107	O	66	O	188	O	5,1	O	568
		Cathode conductor	Carbon	9	Carbon	10,6	Carbon	25,23	Carbon	0,22	boron modifie	200
		Cathode binder	PVDF	9	PVDF	9,49	PVDF	23,43	PVDF	0,15	PVDF	66,67
		Cathode additives	ZrO2	4	ZrO2		ZrO2		ZrO2		ZrO2	
		Cathode collector	Al foil	23		29,2	Al foil	67,2	Al foil	1,62	Al foil	295,2
		Total cathode		390		250		668		18		1962
	Anode	Anode active material	Graphite	199	Graphite (MP(	106	Graphite (MP(	244,41	Graphit (MAG	11,64	Graphit	1000
		Anode binder 1	SBR	3	AAS?	4,42	SBR	6,57	SBR	0,19	SBR	26,3
		Anode binder 2	CMC	3	CMC		CMC	6,57	CMC	0,19	CMC	26,3
		Anode collector	Cu foil	55	Cu foil	53,2	Cu foil	162,4	Cu foil	4,06	Cu foil	640,8
		Anode heatresistnt layer	Al		Al		Al	42,24	Al		Al	
		Total anode		261		163,62		462,19		16,08		1693,4
	Electrolyte	Formulated electrolyte	Total	128	Total	76,9	Total	313,13	Total	4,7	Total	1100
		Fluid	LiPF6	12	LiPF	9,8432	LiPF	40,08064	LiPF	0,6016	LiPF	140,8
		Fluid	LiFSI	6	LiFSI		LiFSI		LiFSI		LiFSI	
		Solvents	EC	26	EC	24,608	EC	100,2016	EC	1,504	EC	352
		Solvents	DMC	0	DMC	24,608	DMC	100,2016	DMC	1,504	DMC	352
		Solvents	EMC	72	EMC	17,687	EMC	72,0199	EMC	1,081	EMC	253
		Solvents	PC	12	PC		PC		PC		PC	
		Total electrolyte		128		76,7462		312,50374		4,6906		1097,8
	Separator	Separator	PE 10 µm+AL	24	PE 10 µm+AL	-	PE 10 µm+AL	-	PE 10 µm+AL	-	PE 10 µm+AL	-
		Separator	PP 15 µm + A	-	PP 15 µm + A	18,0	PP 15 µm + A	-	PP 15 µm + A	-	PP 15 µm + A	-
		Separator	PP/PE/PP		PP/PE/PP		PP/PE/PP	61,96	PP/PE/PP		PP/PE/PP	215,04
		Separator	PE-Al2O3		PE-Al2O3		PE-Al2O3		PE-Al2O3	1,05	PE-Al2O3	
		Total separator		23,6		17,9832		61,96		1,05		215,04
	Cell Packaging	Tab with film	Al Tab	5	Al Tab	5	Al Tab		Al Tab		Al Tab	
			Ni Tab	16	Ni Tab	16	Ni Tab		Ni Tab		Ni Tab	
		Exterior covering	PET/Ny/Al/PF	17	PET/Ny/Al/PF	19,21	PET/Ny/Al/PF	-	PET/Ny/Al/PF	-	PET/Ny/Al/PF	-
		Collector parts	Al leads		Al leads		Al leads	3,8	Al leads		Al leads	15
		Collector parts	Cu leads		Cu leads		Cu leads	10,4	Cu leads		Cu leads	45
		Collector parts	Plastic fasten	-	Plastic fasten	-	Plastic fasten	16	Plastic fasten	-	Plastic fasten	20
		Cover	Valve, rivet te	-	Valve, rivet te	-	Valve, rivet te	112	Valve, rivet te	1,86	Valve, rivet te	100
		Case	Al		Al		Al	150,5	Al		Al	800
		Case	Ni plating Iron		Ni plating Iron		Ni plating Iron		Ni plating Iron	5,93	Ni plating Iron	
		Total cell packaging		38		40		293		8		980

Source: Takeshita et al. 2016, 2018

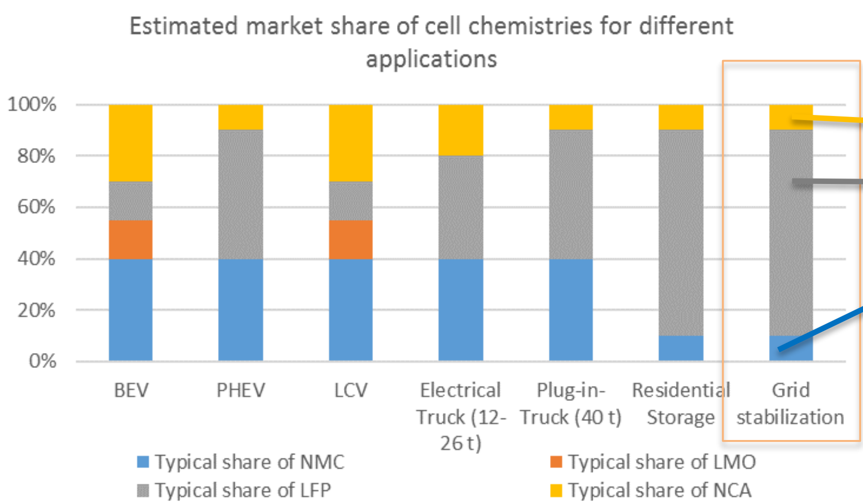
Product weight and Bills-of-Materials (BOMs) – Cell level

Calculation of BoM on battery system level for all base cases, but:

- Up to now, there is no representative product in the market, which could be used as a base case

→ Calculation of a virtual product,
  - → based on different cell chemistries and
  - → their market share in the different applications
  - → 5 common cells on the market

BOM Virtual product „Grid stabilisation"
= 10% BOM NCM + BOM 80% LFP + BOM 10% NCA



	LGC Bolt Cell	LGC Volt (Gen2)	SDI BMW i3	Panasonic 18650	BYD for e6/k9
Format	Pouch	Pouch	Prismatic	Cylindrical	Prismatic
Chem	NCM 622	NCM424/NCM 111/LMO	NCM523/NCA (80/15/5)/LMO - 6/2/2	NCA (82/15/3)	LFP
Ah	59	25,9	60	3,18	200
Wh	212,4	96	222	11,45	640
V	3,6	3,7	3,7	3,6	3,2
W/mm	305	171	173	18,25	410
H/mm	100	233	125	65,1	146
T/mm	13,5	7,5	45		58

Same battery chemistries as in PEF: NMC (LiNixMnyCozO2), LiMn (LiMnO2), LFP (LiFePO4)
Difference to PEF: NCA instead of LCO

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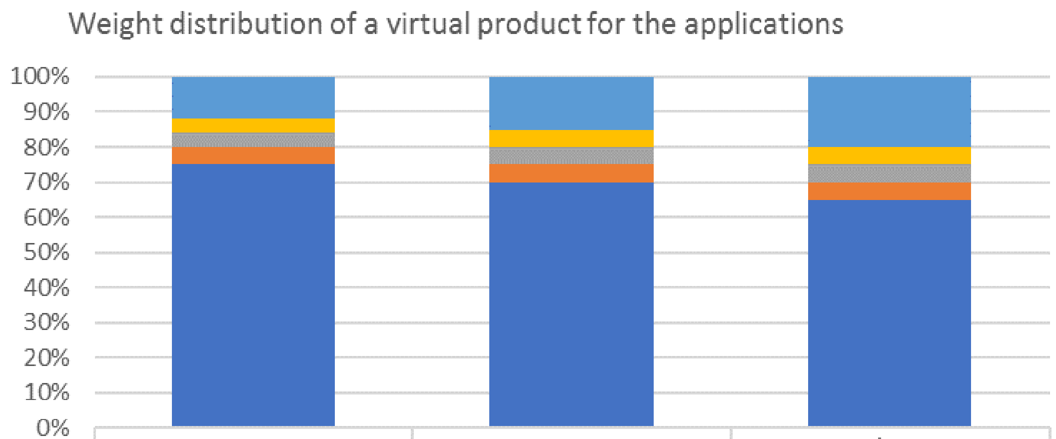
Module and System level – Definition of module and systems weight

- OEM are designing their own modules and systems
- Bottum-up approach not feasible
- Weight of the different systems components needed
- Thus considering the results of the literature review and the modelling the following weight distributions are defined for the applications:



	BEV	PHEV	Stationary
Packaging	12	15	20
Therm. Man.	4	5	5
BMS	4	5	5
Modules	5	5	5
Cells	75	70	65

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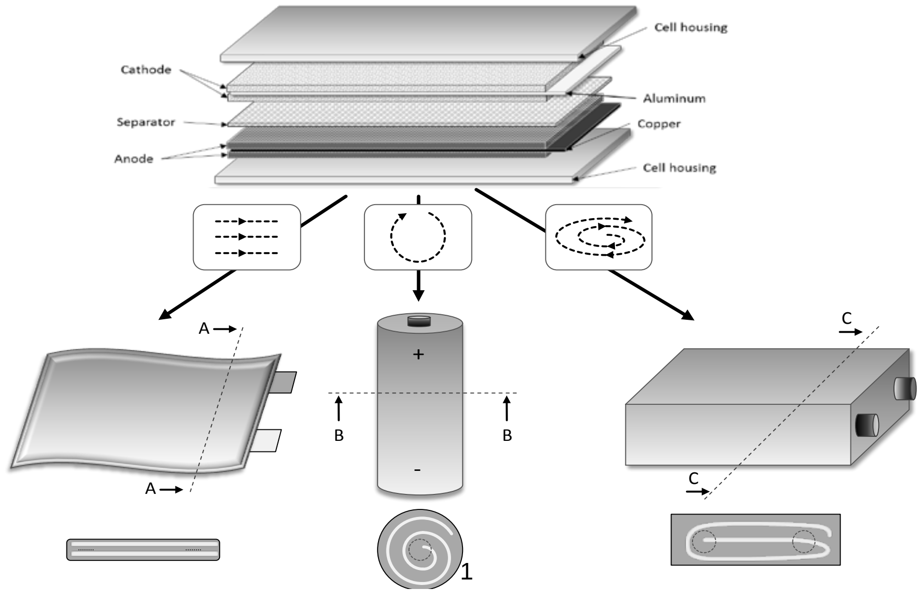
Product weight and Bills-of-Materials (BOMs) – Module and System level

- Definition of share of materials for modules
- Same for all applications
- Higher share of PP/PE for pouch compared to prism. due to necessity of cell frames
- High share of PP/PE for cylindrical due to cell holders, lid,..

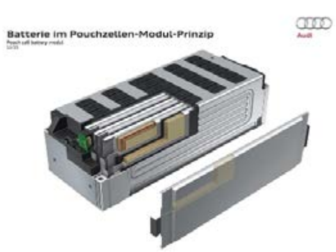


Pouch cell | **Cylindrical cell** | **Prismatic cell**

Pouch format (Source: Audi)

Cylindrical format (Source: Panasonic

Prismatic format (Source: Audi)



Product weight and Bills-of-Materic

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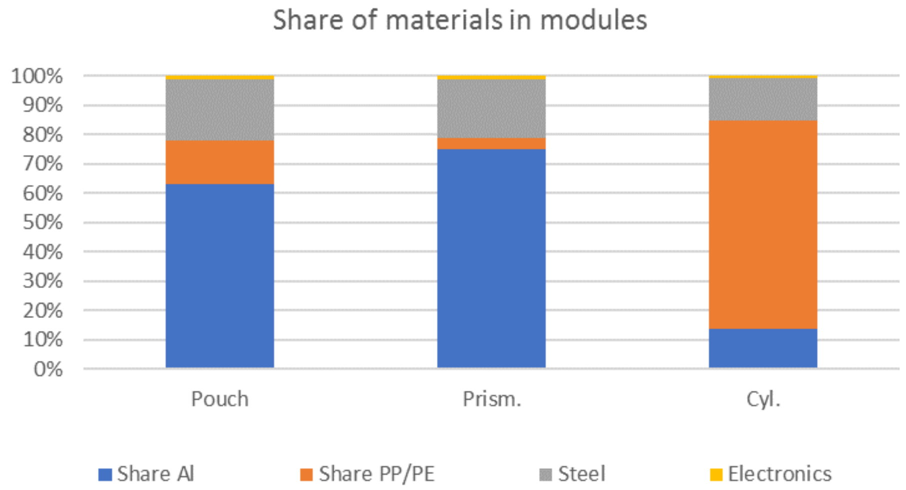


Pouch cell

Pouch format (Source: Audi)

Cylindrical cell

Cylindrical format (Source: Panasonic

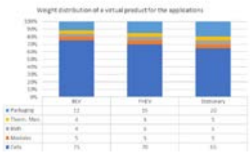
Prismatic cell

Prismatic format (Source: Audi)

SUBTASK 4.2 - PRODUCT WEIGHT AND BILLS-OF-MATERIALS (BOMS)

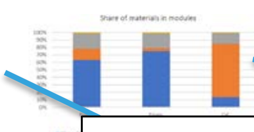
BOM for the base cases

- BOM on cell level already given based on common cells → **cell weight known**
- Calculation of the components weight, based on the cell weight and the specific share of weight of the components



Relative weight of components

- Calculation of the materials of the module (excl. cells) , the system housing, BMS,.. based on the shown assumptions.



- Following the PEF, … included

Relative share of materials in the components

			PC BEV	PC PHEV	LCV BEV	Truck BEV	Truck PHEV	Res. Storage	Grid stab.
System Level	Component	Material	40.000	12.000	35.000	45.000	20.000	10.000	10.000
Cell	Cathode	Fe		3.399	2.974	10.196	5.664	4.531	4.531
		Co		561	4.407	4.439	936	308	308
		Ni		2.302	16.393	15.852	3.837	1.208	1.208
		Mn		3.883	7.697	3.103	6.471	172	172
		Al		49	223	170	82	19	19
		Li		1.441	6.448	6.933	2.401	975	975
		P		1.885	1.649	5.654	3.141	2.513	2.513
		O		7.841	19.586	24.747	13.069	6.142	6.142
		Carbon		1.924	2.563	5.013	3.207	1.888	1.888
		PVDF		947	1.682	2.248	1.579	665	665
		ZrO2		-	242	311	-	17	17
		Al foil		3.654	6.349	9.278	6.090	2.948	2.948
	Anode	Graphite		13.377	35.597	46.619	22.295	11.098	11.098
		SBR		421	702	966	702	272	272
		CMC		200	702	966	334	272	272
		Cu foil		7.480	15.029	21.029	12.466	6.472	6.472
		Al		-	999	-	-	-	-
		LiPF6	75 %	1.521	3.137	4.388	2.534	1.396	1.396
				-	422	542	-	30	30
				3.802	7.547	10.591	6.336	3.470	3.470
				3.802	5.861	8.423	6.336	3.350	3.350
				2.732	8.934	12.125	4.554	2.745	2.745
		PC		-	793	1.019	-	57	57
	Separator	PE 10 micron		-	1.556	2.000	-	111	111
		PP 15 micron		899	-	-	1.499	-	-
		PP/PE/PP		1.475	2.756	4.424	2.458	1.966	1.966
		PE-Al2O3		110	963	825	183	92	92
	Cell Packaging	Al Tab		250	330	424	417	24	24
		Ni Tab		800	1.055	1.356	1.333	75	75
		PET/Ny/Al/PP		961	1.107	1.424	1.601	79	79
		Al leads		103	180	309	171	137	137
		Cu leads		309	516	926	514	411	411
		Plastic fasten		137	498	411	229	183	183
		Al, Steel, Va		881	4.954	3.519	1.468	1.077	1.077
		Al		5.486	8.359	16.457	9.143	7.314	7.314
		Ni plating Iron		621	5.438	4.661	1.036	518	518
		Al		3.120	6.015	8.503	5.199	2.947	2.947
						3.807	1.720	869	869
						2.959	1.714	946	946
						154	87	48	48
						4.935	3.488	1.924	1.924
	BMS	Copper	4 %	2.616	4.737	6.169	4.360	2.405	2.405
		Printed circuit		523	947	1.234	872	481	481
System	management	Al	4 %	4.709	8.527	11.105	7.848	4.329	4.329
		Steel		523	947	1.234	872	481	481
	Packaging	Al	12 %	10.988	19.896	25.911	18.313	3.848	3.848
		PP/PE		785	1.421	1.851	1.308	2.886	2.886
		Steel		3.139	5.685	7.403	5.232	11.545	11.545
		WEEE		785	1.421	1.851	1.308	962	962

Any major comments on the approach?

→ Input for PEF: 6.1 Raw material acquisition and pre-processing

SUBTASK 4.2: MATERIALS FLOW AND COLLECTION EFFORT AT END-OF-LIFE

2nd life batteries

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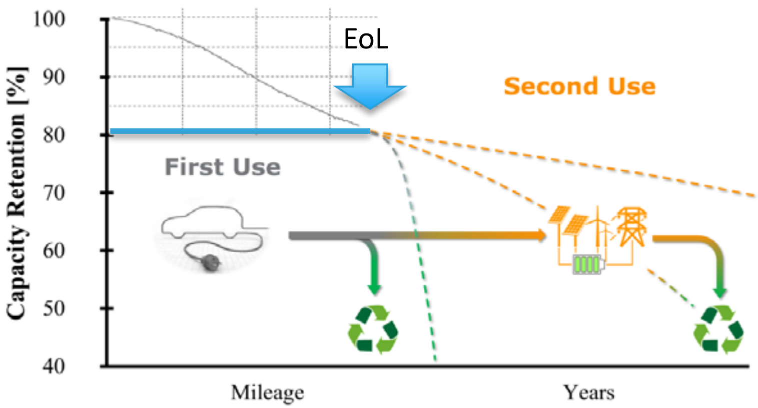
Second life applications

- The performance of a battery cells and battery systems **decreases in the course of t**ime due to cycling, elevated temperature and time-calendar aging.
- The battery system of an EV usually reaches its **End of Life when the remaining capacity falls below 80% SoHCap***. Automotive lithium-ion batteries offer the possibility of second use.
- Second life has the potential to **reduce the environmental footprint**.
- Second life is not foreseen in the PEF.

* from the PEF



- Role of second life in the future: some expect very few batteries to have a second life, considering that prices for lithium-ion batteries will further drop in the future, while others expect most batteries to have a second life before recycling.

Source: Bobba, Silvia; Cusenza, Maria Anna; Podias, Andreas;; Messagie, Maarten; Mathieux, Fabrice; Di Persio, Franco et al. (2018): Sustainability Assessment of Second Life Application of Automotive Batteries (SASLAB). Luxembourg, 2018.

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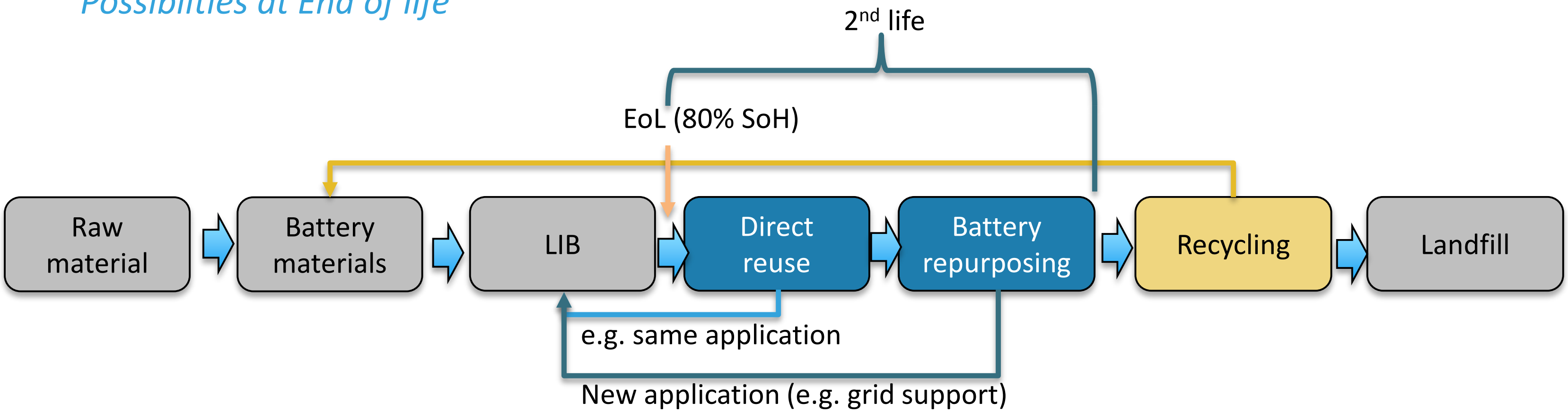
Possiblities at End of life



Source: Electric vehicles from life cycle and circular economy perspectives TERM 2018: Transport and Environment Reporting Mechanism (TERM) report

In terms of **repurposing** it can be distinguished between two different strategies:

1) **Direct reuse**: The battery system is **not dismantled, tested and directly reused**

2) **Battery repurposing**: The battery system is **dismantled at module level** and a new battery system is created by **repackaging**

Barriers of second life applications

- "**Design for disassembly**" is a relevant issue (e.g. connection of structural components) for 2nd use
- **Automation** to manage large amounts in an economical way → But the large variety of battery cells and battery system systems is a major challenge for automated dismantling
- Enable the **storage of all important data** from the operational history of the battery pack at individual battery cell level → Find suitable application for each cell, module or system
- The **access to this data** has to be enabled.
- The **design of electronics for use in automobiles and in stationary** applications would make it possible to move the battery to its second use without making any major concessions with regard to the required performance

Possibility to integrate 2nd life as a base case

- EV batteries reaching EoL (80 % SoHcap) ➔ repurposed for stationary application (ESS)

Application	EV Passenger Car	Stationary
Life-time of the installed system [year]	10	15
Battery system capacity [kWh]	40	32 (= 40 x 80%)
SoH @ EoL	80%	50%*
Quantity of functional units (QFU)	43 200	216 000

*Non-critical application

- **Main advantage:** Quantity of FU increased by far ➔ environmental impacts / QFU get improved
- Few examples over the world

EoL of EV batteries

	Challenges	Possible solutions
Mechanical	Facilitate the operations of repair, remanufacture and repurpose	Use of physical features of the product (battery) that enable assembly/disassembly
Information	Quality of the modules, in particular: determination of the State of Health (SoH) of a used battery	Data storage and access to some data stored in the BMS to facilitate the determination of the State of Health (SoH)

The data stored during the life of the battery in the BMS may include the following parameters (at pack, battery pack and sub-pack levels):

- remaining capacity;
- battery temperature profile;
- overall kilometres (pack level);
- load and charge profile of each battery pack/module/cell

This might also increase information transparency and there the trust of customers in 2nd hand EV car

Two fold approach in theory possible

- **Specific measures** targeting 1st life EV battery systems to **prepare / facilitate repurposing**
- **Specific measures targeting** ESS battery systems manufactured with 2nd life battery components **to push such a market**.

  Otherwise: such batteries systems might have to fulfill same requirements as ESS battery systems manufactured with brand new battery components

SUBTASK 4.2: MATERIALS FLOW AND COLLECTION EFFORT AT END-OF-LIFE

Recycling

Recycling

- Currently recycling processes focus on the recovery of the most valuable materials **Ni and Co.** Next to the high commodity prices for these materials, expect future shortage due to the increasing production of lithium-ion batteries
- **Recycling** of Li-ion batteries is **currently low**, due to:
  - very small battery volumes reaching end of life
  - poor knowledge of battery design;
  - a lack of proper pack and cell marking.

- Recycling processes for LIB are a combination of different individual processes:
- The **deactivation** can be done by discharging the entire battery system
- The **pyrometallurgical** process involves the recovery of metal from the electrode materials with the help of thermal processes
  - Bind **heavy metals cobalt, copper and nickel in a melt**,
  - other metal components are completely slagged and could be deposited in a landfill.
- The **hydrometallurgical** uses leaching and some preparation processes
- enables direct recovery of metals as **cobalt, nickel, manganese and lithium** and extraction of Al and Li from the slag of pyrometallurgical processes.

Recycling efficiency

- The efficiency of battery recycling is a combination of the collection rate and the recycling efficiency.
- The collection and recycling of batteries is regulated under the Directive 2006/66/EC, which is currently under revision (the PEF assumes 95% collection rate for emobility)
- The recycling efficiency differs according to the processes used.

	Combination of pyrom. & hydrom. processes - NMC and LFP [%]	Purely hydrometallurgical process - NMC only [%]	Purely hydrometallurgical process - LFP only [%]
Lithium	57	94	81
Nickel	95	97	NA
Manganese	0	~100	NA
Cobalt	94	~100	NA
Iron	0	NA	0
Phosphate	0	NA	0
Natural graphite	0	0	0

→ Input for PEF: 6.6 End of life

Please review and provide further input on the extra cost/energy required for lithium and natural graphite recycling in different processes, which will be useful in Task 6.

Source: Lebedeva, Natalia; Di Persio, Franco; Boon-Brett, Lois (2016): Lithium ion battery value chain and related opportunities for Europe. In: European Commission, Petten.

Next steps

Today

- Introduction of the data sources
- Warmly invited to review and provide input
- Spreadsheet will be shared after the meeting via email

After the stakeholder Meeting:

- We kindly ask for your feedback until: 20. January 2018

THANKS FOR YOUR ATTENTION

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