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**BeyondBattRec –**

**BEYOND STATE-OF-THE-ART BATTERY RECYCLING**

**BY INCREASING THE SELECTIVITY AND SPECIFICITY**

**OF EFFICIENT PRE-PROCESSING TECHNOLOGIES**

**Work Package 5**

Deliverable 5.1

Definition of specifications and requirements for cell integration

Date: 14th February 2025

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Acronyms and Abbreviations

|  |  |
| --- | --- |
| ABBREVIATIONS | Description |
| EC | European Commission |
| GP | General Public |
| PM | Policy Makers |
| SC | Scientific Community |
| WP | Work Package |
| LIB | Lithium-Ion-Battery |
| LCO | Lithium Cobalt oxide (LiCoO2) |
| NMC | Lithium Nickel Manganese Cobalt oxide (Li(NixMnyCoz)O2) |
| NCA | Lithium Nickel Cobalt Aluminium oxide (Li(NixCoyAlz)O2) |
| LMO | Lithium Manganese oxide (LiMnO2) |
| LFP | Lithium Iron phosphate (LiFePO4) |
|  |  |

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Executive Summary

Work package 5 is to create an understanding of the benefits in terms of the Life cycle of battery materials and environmental and economic impacts. As a first task a definition of batteries with state-of-the-art specification is done. VARTA has figured out two different types of cells for different possible applications – a small cell for typical portable electronics applications and a larger cell for mobile and stationary applications. Cell designs, properties and materials set-ups are tuned for the special requirements of the intended applications. Interesting materials in terms of recycling are discussed and basic requirements for implementation of them into typical cells are defined as well.

Introduction

* 1. Methodology for defining parameters

Battery cells, especially Lithium Ion Cells, have a wide usage range in state-of-the-art electronic devices. Each use case of a cell defines its own requirements onto the cell properties and parameters. In addition, the development cycle of Lithium-Ion-Batteries is still very high and there are a lot of new designs and materials which are entering the market currently. Not obvious but ongoing are developments in respect to manufacturing processes of battery cells which define their own requirements on the materials. According to this basic statement it is almost impossible to define a material and cell design as well a specification list to cover up each type of cell and application.

A more general approach now is to devide the parameter list into several groups and to balance requirements to applications, needs and impacts.

* 1. Selection of the materials

In Lithium-Ion batteries there are different materials as active materials common.

On the anode side the most popular material is graphite. For graphite artificial as well as natural source possible. Mixtures of them or pure application is common, and the properties of the graphite fit to the requirements of the cell and its use. More and more upcoming but with only little market penetration is an anode material which contains Silicon or mixtures of it together with carbon materials.

For cathode active materials a wider range is common which have very different properties, and which essentially define the final cell properties. Based on their specifications the application of the cells can be selected.   
Very often used for small or mid-size cells in consumer electronics devices are LCO – Lithium Cobalt oxide, NMC – Lithium (Nickel, Manganese, Cobalt) oxide or NCA – Lithium (Nickel, Cobalt, Aluminium) oxide. These materials provide best-in-class energy densities combined with good cycling stability. NMC itself is a group of materials which can have different compositions depending on the amount of Nickel, Cobalt and Manganese. Its use range includes very often automotive applications as well as storage systems, too. The highest energy densities together with sufficient cycle life show NMC-811 materials which have an atomic composition for the metal atoms of more than 80% Nickel and 5 – 10% Cobalt and 5 – 10 % Manganese.

Another very common material is LMO – Lithium Manganese oxide. It is used for low price but high rate and moderate safety applications – often found in electric driven bicycles and scooters.

The third popular cathode material on the market is LFP – Lithium iron phosphate. The material provides moderate energy density combined with a long cycling performance and is mostly used for storage systems as well as for the power trains in cars.

The following Table 1 summarizes some of the main properties of the materials to select them for recycling.

Table 1. Summarizing overview about active materials for LIB

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Application | Cost | Criticalness |
| Artificial graphite | All applications | Mid – High | - Raw material not critical  - Production mainly in Asia |
| Natural graphite | All applications | Low – Mid | - Raw material critical  - Production mostly in Asia, N-America |
| LCO | Consumer electronics | Very High | - Raw material critical  - Production mostly in Asia |
| NMC | Consumer electronics; Automotive, Stationary | High | - Raw material critical  - Production mostly in Asia, Europe, N-America |
| NCA | Consumer electronics | Very High | - Raw material critical  - Production mostly in Asia |
| LMO | Mobile application (low cost) | Low | - Raw material not critical  - Production in Asia |
| LFP | Stationary, Automotive | Very low | - Raw material not critical  - Production in Asia, Europe |

In the previously shown Table 1 active materials of high or very high costs as well as of limited availability of their raw materials are marked with red colours. Such materials draw much more attention on recycling than materials of low costs and / or high availability. Concluding to that the graphite material are interesting to recycle but much more pressure is on the reuse of LCO, NCA or NMC materials from the cathode side.

Defining specifications and requirements (S&R)

* 1. Specifications of the Battery cells and electrodes

LCO and NMC materials are widely used in consumer electronics batteries as well as stationary and mobile applications. To address both use cases VARTA has defined to scenarios of cell which cover as much as possible typical cell parameter in that fields. A very small cell like the CoinPower cell is used in a hundreds of millions pieces per year range for high portable small devices in a growing market. The 21700 cell are widely used in several applications like home and gardening, professional electrical tools, mobile applications as well as independent energy storage systems. The global market far exceeds the billion cells mark.

Table 2. Cell and electrode parameter for CoinPower and 21700 LIB

|  |  |  |
| --- | --- | --- |
| Specified Parameter | CP1254 type | 21700 type |
| Cell specifications | | |
| Capacity | 84 mAh | 3.9 Ah |
| Voltage range | 3.0 V – 4.45 V | 2.5 V – 4.2 V |
| Rate capability  Discharge cont. / pulse | 1.5 C / 7.0 C (> 10s @ SOC50) | 2.5 C / 10.0 C (> 10s @ SOC50) |
| Rate capability  Charge cont. / pulse | 1.0 C / 5.0 C (> 10s @ SOC50) | 1.0 C / 5.0 C (> 10s @ SOC50) |
| Cycling stability | > 1000 Cycle (1C/1C, rt) | > 1000 Cycle (1C/1C, rt) |
| Temperature range cycling | 15 °C – 40 °C | 15 °C – 40 °C |
| Temperature range storage (SOC30) | 0 °C – 45 °C | 0 °C – 45 °C |
| HTHH (60°C; 90% rH; SOC30 / SOC100; 28 d) | **SOC30**:   Recovery > 25%  retention > 90%  **SOC100**:  Recovery > 75%  retention > 85% | **SOC30**:   Recovery > 25%  retention > 90%  **SOC100**:  Recovery > 80%  retention > 90% |
| Safety | UN38.3; IEC62133-2 | UN38.3; IEC62133-2 |
| Electrode specifications | | |
| AAM | 96.0 – 97.0 % Graphite | 96.0 – 97.0 % Graphite |
| CAM | 96.5 – 97.5 % **LCO** | 96.5 – 97.5 % **NMC-811 (Ni80+)** |
| Area specific capacity cathode | 3.2 mAh/cm² | 3.05 mAh/cm² |
| N/P ratio | 1.07 | 1.12 |
| Electrode film density anode | 1.65 g/cm³ | 1.65 g/cm³ |
| Electrode film density cathode | 4.1 g/cm³ | 3.5 g/cm³ |

Table 2 shows an overview about typical target specifications for the described type of cells. These target parameters are basic state-of-the-art values and aren’t suitable for new product developments. But nevertheless, there is a broad market for this kind of cells and there is a wide use of them.

* 1. Used proportion of recycled materials

Materials for Lithium-Ion-Batteries are almost high sophisticated compounds with optimized material properties and a high sensitivity against impurities and changes in morphology and other particle properties. Recycled materials often loose such properties and suffering on catching up impurities. Regarding that fact it is necessary to define basic material values and a reasonable portion of material what can be used in cells.

Table 3. Basic material properties for a use in LIBs

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Low portion | Mid portion | Pure |
| Artificial graphite | Spec. Cap\*.: > 250 mAh/g  FCE: > 85%  Particle size: 4 – 40 µm  Tap density: > 0.8 g/cm³ | Spec. Cap\*.: > 330 mAh/g  FCE: > 88%  Particle size: 7 – 35 µm  Tap density: > 0.9 g/cm³ | Spec. Cap\*.: > 355 mAh/g  FCE: > 92%  Particle size: 7 – 30 µm  Tap density: > 0.95 g/cm³ |
| Natural graphite | Spec. Cap\*.: > 250 mAh/g  FCE: > 85%  Particle size: 4 – 35 µm  Tap density: > 0.8 g/cm³ | Spec. Cap\*.: > 330 mAh/g  FCE: > 88%  Particle size: 7 – 35 µm  Tap density: > 0.9 g/cm³ | Spec. Cap\*.: > 355 mAh/g  FCE: > 92%  Particle size: 7 – 30 µm  Tap density: > 0.95 g/cm³ |
| LCO | Spec. Cap\*.: > 150 mAh/g  FCE: > 85%  Particle size: 4 – 50 µm | Spec. Cap\*.: > 160 mAh/g  FCE: > 88%  Particle size: 7 – 45 µm | Spec. Cap\*.: > 168 mAh/g  FCE: > 92%  Particle size: 7 – 40 µm |
| NMC-811 (Ni80+) | Spec. Cap\*.: > 165 mAh/g  FCE: > 82%  Particle size\*\*: 4 – 40 µm | Spec. Cap\*.: > 172 mAh/g  FCE: > 85%  Particle size\*\*: 4 – 30 µm | Spec. Cap\*.: > 185 mAh/g  FCE: > 88%  Particle size\*\*: 4 – 20 µm |
| NCA | Spec. Cap\*.: > 160 mAh/g  FCE: > 82%  Particle size: 4 – 50 µm | Spec. Cap\*.: > 160 mAh/g  FCE: > 88%  Particle size: 7 – 40 µm | Spec. Cap\*.: > 168 mAh/g  FCE: > 92%  Particle size: 7 – 30 µm |

\* - Full cell data @ C/5 discharge rate  
\*\* - Single crystalline material 4 – 8 µm; Poly crystalline material > 8 µm

To integrate the recycled materials 3 different scenarios are depicted. The Table 3 includes the basic requirements for them. Following that approach the different qualities of recycled material can be used either as a mixture with fresh or as pure product when it shows similar data. The following portions can be defined as suitable:

* **Low portion**: 5 – 15 % recycled material mixed with 85 – 95% fresh material
* **Mid portion**: 35 – 70 % recycled material mixed with 30 – 65 % fresh material
* **Pure**: 100% recycled material can be used directly

Conclusion

Recycling of active materials of LIBs is an upcoming request for a sustainable cell production. The most interesting materials to recycle have a wide use range, high price and use raw materials from critical sources. This approach shows up that Graphite materials both artificial and natural Graphite as well as LCO, NMC and NCA are the most interesting types of the broad range of LIB materials. The known constraints of recycled materials will be considered by generating mixtures with freshly produced. The definition of minimum values for the single materials guarantees the compatibility with known materials and opens the door for implementation into standard designs.

References

1. **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **DMP**=Data Management Plan [↑](#footnote-ref-2)
2. **PU**=Public, **SEN**=Sensitive [↑](#footnote-ref-3)