Investigating Possible Applications and Business Models of Second-Life Batteries from Electric Scooters

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Investigating Possible Applications and Business Models of Second-Life Batteries from Electric Scooters

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Abstract

The surge in electrification across the transport, industry and residential sector, has sparked a high demand for batteries. While batteries from the electric vehicle sector are already being repurposed for second-life applications, the rapidly growing micromobility market, particularly in shared electric scooters, lacks an efficient solution for end-of-life battery management. The research objectives are therefore to establish knowledge of the second life market for scooter batteries and suitable applications with associated circular business models. Through an extensive literature review, industry interviews, expert-oriented workshops and case studies, the research presented results in the form of applications and business models as well as challenges and opportunities for the future SLM for scooter batteries. Early findings that shaped the research revolved around the current design of scooter batteries, which are potted through the use of glue between the cells, making the disassembly, refurbishment and recycling of these packs very difficult. The study identified suitable applications at both cell and pack levels for repurposing scooter batteries. Cells within scooter packs, typically of high quality, can be utilized in various applications such as power banks and solar street lights, which use cylindrical 18650 cells. However, scalability and feasibility pose challenges due to the labor-intensive and costly manual disassembly process. Pack-level applications include portable battery energy storage systems and solar street lights. The research found that safety concerns associated with scooter batteries are paramount in their reuse. The feasibility of using scooter batteries in second life applications is contingent upon the adhesive use within the packs. Looking ahead, regulations and design for circularity can alter the design of scooter batteries, making their contents much more attractive on the second life market.

Keywords: second-life application, electric scooter batteries, circular business model, circularity, regulation

Sammanfattning

Ökningen av elektrifiering inom transport-, industri- och bostadssektorn har lett till en hög efterfrågan på batterier. Samtidigt som batterier från fordonssektorn redan återanvänds för andra ändamål, saknar den snabbt växande marknaden för mikromobilitet, särskilt el-sparkcyklar, en effektiv lösning för hantering av uttjänta batterier. Forskningsmålen är därför att etablera kunskap om second-life marknaden för el-sparkcykelbatterier och lämpliga applikationer med tillhörande cirkulära affärsmodeller. Genom en omfattande litteraturstudie, branschintervjuer, workshops med experthjälp och fallstudier, presenteras forskningsresultaten i form av möjliga applikationer och affärsmodeller, samt de utmaningar och möjligheter som finns för framtida hantering av uttjänta el-sparkcykelbatterier. Tidiga resultat som påverkade forskningen var relaterade till den nuvarande designen av el-sparkcykelbatterier, där användningen av lim mellan cellerna gör demontering, lagning och återvinning av dessa batterier mycket svårt. Studien identifierade lämpliga applikationer både på cell- och packnivå för återanvändning av el-sparkcykelbatterier. De enskilda cellerna i el-sparkcykelbatterier, som vanligtvis håller hög kvalitet, kan användas i olika tillämpningar som powerbanks och solcellsdriven gatubelysning, vilka använder cylindriska 18650-celler. Dock utgör skalbarhet och genomförbarhet betydande utmaningar på grund av den arbetsintensiva och kostsamma manuella demonteringsprocessen. Tillämpningar på packnivå inkluderar bärbara batterilagringsystem och gatlyktor med solceller. Forskningen visade att säkerhetsaspekter förknippade med el-sparkcykelbatterier är avgörande för deras återanvändning. Möjligheten att använda el-sparkcykelbatterier i second-life applikationer beror i stor utsträckning på om lim används inom batteripacken. I framtiden kan regleringar och design för cirkularitet bidra till förändringar i designen av el-sparkcykelbatterier, vilket skulle göra deras komponenter betydligt mer attraktiva på andrahandsmarknaden.

Nyckelord: second-life applikation, el-sparkcykelbatterier, cirkulära affärsmodeller, cirkularitet, regelverk

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To adventure beyond horizons, to explore off the beaten path, to take lead.
To trust in our significance in this world and our power to change it.
To risk. For the potential of prosperity. For fairness. For the unknown.
That is the way of Cling.

Stockholm, May 2024

Ruben Renmarker & Felix Mårtensson

Nomenclature

ASEAN: Association of SouthEast Asian Nations
BESS: Battery Energy Storage System
BM: Business Model
BMS: Battery Management System
C&I: Commercial & Industrial
CAM: Circular Asset Management
CB: Certificate Body
CBM: Circular Business Model
DoD: Depth of Discharge
EoL: End of Life
EoCUL: End of Current Usage Loop
EPA: Environmental Protection Agency
EPR: Extended Producer Responsibility
ESaaS: Energy System as a Service
ESS: Energy Storage System
EV: Electric Vehicle
HDV: Heavy Duty Vehicles
HEV: Hybrid-Electric Vehicles
IECEE: International Electromechanical Commission for Electric Equipment
ILAC: International Laboratory Accreditation Cooperation
La: Lead-acid
LCO: Lithium Cobalt Oxide
LFP: Lithium Iron Phosphate
LiB: Lithium-ion Battery
LMO: Lithium Manganese Oxide
LMT: Light Means of Transport
NCA: Nickel Cobalt Aluminum
NDA: Non Disclosure Agreement
NMC: Nickel Manganese Cobalt
NMH: Nickel-Metal Hydride
OEM: Original Equipment Manager
PAR: Participation Action Research
PBEV: Passenger Battery Electric Vehicle
PHEV: Plug-in Hybrid Electric Vehicle
R&D: Research & Development
RV: Recreational Vehicle
RUL: Remaining Useful Life
ROI: Return of Investment
RoR: Reason of Retirement
RQ: Research Question
SEI: Solid Electrolyte Interface
SLA: Second Life Application

SLB: Second Life Battery
SLBESS: Second Life Battery Energy Storage System
SLBM: Second Life Battery Market
SLM: Second Life Market
SoC: State of Charge
SoH: State of Health
Wh: Watt-hours

1. Introduction

Facing the development of electric means of transportation and an expected continuously increasing market of electric scooters (Grand View Research, 2023) in particular, means facing an unknown future for their batteries. A future where the market for recycling and possible new applications by reusing second-life batteries (SLBs), are still uncertain and developing. This allows for a future with opportunities for new actors within the battery market to find innovative, circular business models that are centered around the increasing importance of the Extended Producer Responsibility (EPR) (Yates & Schreiber, 2023).

The concept of EPR stems from Thomas Lindhqvist, associate professor at Lunds University, which refers to the strategy of adding the estimated environmental costs related to a product throughout its whole lifecycle, to the market price (Multi-Material Stewardship Western, n.d). The purpose of the concept is to illustrate the importance of producers acknowledging their products´ environmental impact. The awareness of EPR can in many cases be seen as an obstacle from a producers´ perspective. However, the EPR can also be seen as an opportunity for the producers themselves, or secondary actors, to find *new possibilities* to contribute to a sustainable future. As the market and production of battery-driven transports increase, so does the production of batteries that today do not have a clear End of Life (EoL) use.

When batteries reach their EoL, they can still be *useful* in other applications that have other criterias on whether the batteries are considered useless or not. There are examples of application areas, especially for electric car batteries, where a majority of batteries are considered EoL while still having a capacity of 70-80% (de Guia, 2021). This means that the greater part of the initial capacity is still available, and energy is going to waste if nothing is done with them. There are start-up companies today, constructing their whole business idea on identifying solutions to opportunities of finding a second life for batteries taken out of use; actors that are contributing to sustainable change and a circular economy. Cling systems is one of those companies and has assigned the authors of this report with the task to investigate one of these opportunities further.

This report will touch on the subject of SLBs from electric scooters, what challenges and possibilities this sector faces and what the future holds. More in detail, the authors will investigate possible applications for the SLBs from electric scooters and what business model that could be applicable for a company like Cling to use for them.

1.1 Problem

In the contemporary market, a large number of electric vehicle (EV) batteries are prematurely retired despite retaining a majority of its capacity. Instead of sending these batteries directly to recycling, which is neither economically sustainable nor environmentally friendly given the remaining capacity, they can be utilized in a second life. Several emerging companies, such as B2U, Zenobe and Rebaba to mention a few, have initiated efforts to address this issue by developing battery energy storage systems (BESS) to enable the reuse of batteries specifically extracted from EVs. Despite these efforts, a recent increase in the volume of smaller electric transports, such as bicycles and scooters, are causing great challenges. Particularly, none of the mentioned actors have yet ventured into repurposing batteries from these smaller electric transports, intensifying the issue at hand. This situation is compounded by the large volume of units in circulation and the common perception that the cost associated with recycling or reusing these batteries, outweighs the disposal option. Consequently, a significant quantity of batteries with remaining functional capabilities, suitable for alternative applications, are wasted. Addressing this challenge is essential for establishing sustainable practices that optimize the use of valuable resources in the electric mobility sector.

Cling systems is a company that specializes in EoL management solutions, offering a full service system for proper reuse, repurposing and recycling of batteries. Integration of Clings´ EoL expertise presents an opportunity to increase battery value while reducing the administrative and compliance costs for its customers through their digital platform. Noticing an increase of electric scooter batteries on the Second Life Market (SLM), the company wanted to investigate the business opportunities of working with them. Cling is uncertain what to do with the batteries and wanted to investigate the possibilities for a second-life application of them and associated business model. Although relatively much Research & Development (R&D) has been done on applications for SLBs from EVs, little is yet found on electric scooters which is why the authors were asked to conduct the research.

1.2 Purpose

The purpose of this thesis is - *To explore alternative applications for SLBs from electric scooters and devise a business strategy for Cling, considering both technical and business-related constraints with electric scooter batteries.*

1.3 Research Questions and Goals

The market for SLBs is growing as more batteries from EVs, including scooters, reach their EoL (Niese et al, 2020). As Cling currently has this great potential at its hands, the task for the project is to make the best use of this opportunity. To achieve this, the goal is to create a better understanding of the scooter battery, second-life as a concept and the SLM of electric scooters while utilizing Cling's position as a provider of full system battery EOL management solutions. As the purpose is twofold, encompassing both technical feasibility and business viability, the research questions have been expressed as the following:

RQ1: What applications are most suitable for second-life batteries from electric scooters?

RQ2: What business strategies are most applicable concerning the state of second-life batteries from electric scooters and Clings's business model?

The goal of the thesis is realized through these research questions by systematically exploring the technical possibilities of SLBs from electric scooters and translating these insights into alternative applications. This approach ensures a comprehensive understanding of both the potential uses and the market strategies necessary for Cling to capitalize on these batteries, aligning with the overall purpose of the research.

1.4 Delimitations

In this research, a limitation will be the number of batteries that the researchers can use data from. Since Cling do not have their own testing facilities, the batteries that they have test results from were done at a third party facility. Further, the test results used in this research will be limited to the ones done beforehand, as well as the ones eventually gathered during the project. Additionally, the batteries that will be handled in this report are not limited to one specific type. Rather, the batteries included will be determined by the market supply during the research period.

The research will be limited to the batteries used in electric scooters from the micromobility companies. Which means, if nothing else is stated in that specific occasion, when the authors use the words electric scooters, they refer to the ones owned by the rental kick-scooter fleets.

Lastly, given the complexity and the timing of the project in the nature of the SLM, the research will be structured in a holistic perspective and should be seen as a preliminary study. Concerning the complexity of the subject matter and the amount of time the researchers have, some areas will have to be prioritized over others in order to complete the research. For example, the actual concept- and product development processes of potential applications will be presented on an idea stage since there will be more focus on analyzing the possibilities seen from both technical- and business perspectives. The work will be more of a mapping of the market of SLBs from electric scooters, a market that more or less is non-existent as for now.

2. Methodology and Approach

From the problem formulation and research questions presented in the previous chapter, the authors decided that a qualitative research approach was the best fit for the project and paper, compared to a quantitative approach. According to Chism, Elliot & Hilson (2008), quantitative research is in general concerned with identifying relationships between variables and generalizing results, whereas qualitative research aims to understand phenomena in depth and within certain contexts. As the purpose of the paper involves determining suitable applications for scooter batteries, the research looked to understand phenomena, (applications and business models) within a context (scooter batteries).

The design characteristics of qualitative research have a naturalistic orientation meaning they are conducted in the natural setting. For this paper, this implied carrying out the study at the company Cling as well as with their clients. Qualitative research is aimed at understanding and not primarily at prediction, control or generalization, which was true for the authors of this paper. Furthermore, the researchers were a part of the study and their presence was seen as an asset to the study and valuable for the result, compared to quantitative methods where the researcher is primarily detached. The study has an inductive approach meaning that it is exploratory rather than confirmatory, and therefore no explicit hypotheses exist to be tested. Qualitative researchers find new paths along the study, not remaining fixed to a certain data collection method for example, but rather having provisional plans that allow for an emerging design. (Chism, Elliot & Hilson 2008)

An inherent strength of qualitative research is the flexibility that the researchers obtain throughout the study, using tools, strategies and methods at hand to further the research. However, within qualitative research, many research strategies exist, which helps a researcher design a study with guidelines that are in line with accepted qualitative research practices. A particular study does not have to identify a single strategy used throughout, but can rather incorporate characteristics of more than one approach, per Denzin & Lincoln (1994). Denzin and Lincoln list eight different qualitative research strategies:

- Case study
- Ethnography/participant observation/performance ethnography
- Phenomenology/ethnomethodology
- Grounded theory
- Life history
- Historical method
- Action and applied research
- Clinical research

Ethnography aims to study the cultural aspects of a group, not limited to ethnicity or religion, but in engineering rather to an institution or organization. With this strategy it is suitable for the researcher to immerse herself in the group being studied, being called a “participant-observer”. Data collection methods involve interviews, collection of documents and also observations. This strategy was applied by the authors due to the nature of the project being pursued in a specific organization’s environment, sharing their culture. To truly identify a study as ethnography, six features are listed by Punch (1998):

1. The behavior of the group is understood by understanding the culturally shared meanings within the group.
2. The study is conducted to understand meanings from the perspective of the people in the group.
3. The group is studied in its natural setting.
4. The design evolves during the study, rather than being pre-defined.
5. A variety of data collection techniques are used within a single study.
6. Data collection occurs over a long period of time.

Another relevant research strategy that the authors pursued was a case study. Such a strategy is selected when one wants to study a specific situation in depth. Within this strategy there are several approaches that can be taken. Chism, Elliot & Hilson (2008) name three different approaches to this strategy. Firstly, an intrinsic case study can be performed for solely one, particular case. Second, The instrumental case study can shed light on a more general occurrence, due to it being representative of its field, or being unusual and therefore offering a valuable point of comparison to the norm. Third, the collective case study encompasses several different cases that give insight to the greater phenomenon. In this paper, case studies were conducted with customers of Cling, to gain knowledge specifically for applications of scooter batteries and better understanding of associated business models. The case study looked at a currently marginalized sector of the second life industry, namely scooter batteries which are overshadowed by the more attractive source, EV batteries. This, more unusual sector within the second life market aims to contribute to a new perspective of smaller batteries for repurposing, yielding a point of comparison to the norm.

At the beginning of the research, neither of the authors had any experience nor knowledge about the SLM of batteries and the batteries themselves. This led to them initiating an extensive literature review in order to both gain knowledge within the subject of matter as well as the areas around it. The objective of the literature was to gain more knowledge of the subject and get a better understanding of the actual problem the authors were going to try to solve.

When beginning the literature review, the authors, together with their supervisor at Cling, began structuring what chapters they had to cover. Because of the little knowledge the authors had about the area, together with the fact that they were informed that their chosen RQs were investigating a somewhat unexploited industry, they decided to set up the strategy of beginning wide to then narrow it down. A structure at the beginning of a literature review is crucial for the result. Examples of some structures that can be used are presented below:

- Chronologically
- By sector
- By development of ideas

Or by combination of some of the above. What structure that is used can vary a lot and can be individual for each project. The importance is to establish one that will best fit the story that is being told throughout the thesis (University of Leicester, 2009). For the case of this thesis, the wide-to-narrow strategy was applied since it became obvious that the problem with the use of SLBs from scooters was part of a much bigger problem. The authors also felt that it would be easier to narrow it down along the project rather than the other way around, especially due to the lack of knowledge initially. The gained knowledge from the literature did not only paint the picture of the current state of the SLM of batteries and electric scooters. It also created the theoretical framework that allowed the authors to conduct better interviews for the qualitative research.

2.1 Chosen research method

When deciding on data collection strategies, it is important to have the study's research questions and goals as a header throughout the process, to ensure that the data collection is acting towards fulfilling the aim of the study. For qualitative research, the most commonly used data collection methods include interviews, observations as well as documents and materials (Chism, Elliot & Hilson 2008).

First of all, data collection through observation was fundamental in the study presented in this paper due to the study being carried out primarily at the company, Cling. The type of observation can be classified as "participant observation" since the researchers were involved in the problem-solving associated with the research questions and project as a whole, as well as part of the Cling team, with everything it entailed. With that said, the common critique of observational data collection is that the researchers cannot remain completely objective, since they are often related to the findings when immersed in the group that is being studied (Chism, Elliot & Hilson 2008). However, for the research in this paper, this contamination of objectivity was not an issue since the goal was working to further enhance the understanding of a submarket of a timely important area, the second life battery market and scooter batteries in specific, while contributing to Cling's business.

The research began with an extensive literature review followed by three types of analyses that all contributed with different perspectives and findings for the final discussion. These methods are discussed in more detail in the following chapters. Figure 1 presents a schematic overview of the chosen strategy for the methodology applied and how the interconnect.

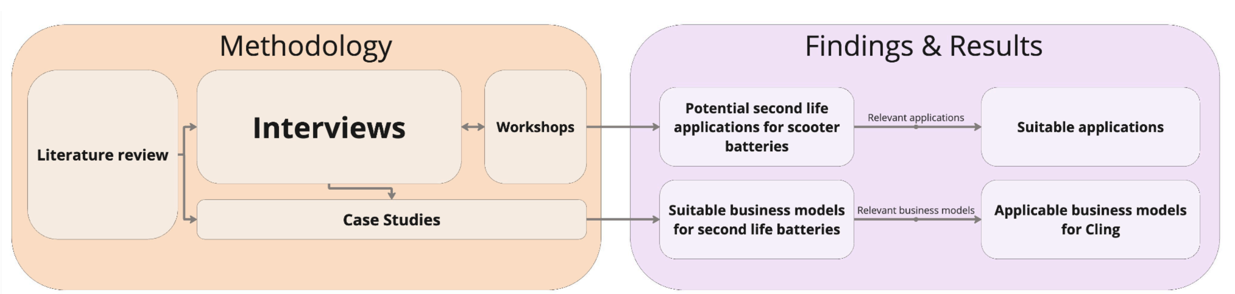

Figure 1. Schematic overview of the methodology used in this research

2.1.1 Literature review

The use of documents and other materials was a necessary data collection method for this research to understand the existing knowledge on the subject of second-life batteries, especially from electric scooters. This subject has gained interest over the last years and the amount of research and information available is steadily increasing. The subchapters in the theory section all needed to be researched through documents and other online materials, for the authors to understand their current states. Primary and secondary sources were used, meaning information straight from the source as well as analyses, interpretations and summaries of these primary sources (Chism, Elliot & Hilson 2008).

The strategy for the literature review began with gaining a broad understanding of the battery market and focusing specifically on SLM. This was achieved through internal seminars and onboarding sessions at Cling, as well as research using Google Scholar. Initial searches included terms such as “Lithium-ion batteries,” “Second life market,” and “Second life batteries.” Further, the market lead at Cling as well as the supervisor from the Department of Design Sciences, provided valuable articles, enhancing the foundational knowledge. As the understanding deepened, the focus of the searches became more specific, targeting electric scooters, their market, and related battery operations such as “Repurposing,” “Recycling,” and “Dismantling.” This evolving knowledge also led to exploring additional areas like “Battery degradation,” “Battery regulations,” and “Battery certifications”.

The primary databases used were Google Scholar, ScienceDirect, and general Google searches. To decide which literature to read and use, the authors first reviewed the abstracts of more extensive works. For shorter articles, they typically read a few in full and then discussed which provided the most valuable information for the report. This collaborative approach ensured that the selected literature was both relevant and informative. The results of these searches were comprehensive and provided a strong foundation for both the researchers and future readers to understand the outcomes of the analysis better.

2.1.2 Interviews

Interviews played a central role in data collection to understand different areas of interest within the sector. The reference list with a total of 27 interviews held is presented in table 1. The areas were “market” - including players in all areas of the battery value chain, BESS manufacturers, dismantlers/testers, recyclers, battery sales specialists and companies working directly with scooter batteries. The interviews were different depending on the interviewees’ relevant area. The interviews were of the semi-structured type, meaning that they had pre-determined, open-ended questions with flexibility to explore spontaneous topics that arose during the interview (Chism, Elliot & Hilson 2008). By keeping the interviews semi-structured, the authors could adapt the questions and the interview strategy as more knowledge was gained along the way.

The interviews were structured in the way that both authors attended them and could ask the questions in order to keep the interviews as unbiased as possible. Further, the authors divided the tasks during the interviews as one being the leading interviewer, asking the majority of questions by following the interview guide. The other had the responsibility to take notes during the interviews as well as asking spontaneous questions that arose. The interview guide was prepared for each different interview area, acting as a template for the different interviews. The questions were kept standardized within each area to have some structure and provide grounds for analysis. The format of the interviews began with open-ended, broad questions about the area in which the interviewee operated, so called “grand-tour” questions (Chism, Elliot & Hilson 2008). Each question then had follow-up or probing questions within the broader one. The structures of the interviews were chosen in order to keep them formal while still allowing open discussions which could lead to the interviewee sharing knowledge valuable for the research. Nevertheless, some specific questions were prepared before each interview based on the reference´s area of expertise. The interview templates were living documents during the research in order to align with the strategy of being flexible. This was vital since important knowledge was gained along the interviews that contributed to the authors being able to ask more relevant questions to the subject of matter. After each interview was conducted, key takeaways were annotated while the information was still fresh. Transcriptions were performed through two different tools, Microsoft Words' transcribe function and Klang.AI.

A few of the interviews referenced in the list are marked with N/A, since these were held via e-mail contact. Data collection through interviews amounted to 25 live and 2 through email. The average duration of the interviews was 35 minutes and 39 seconds.

Sector	Date	Duration	Reference
Market			
Consultancy company from Germany	1/2-2024	0:39:24	I.1
Representative from Naturvårdsverket in Sweden	21/2-2024	0:37:02	I.2
Consultant within battery market	28/2-2024	0:36:51	I.3
Market lead at Swedish battery circularity company	26/3-2024	0:39:28	I.4
Applications			
Battery engineer in Swedish ESS building company	7/2-2024	0:42:30	I.5
The founders of Swedish ESS bulding company	13/2-2024	1:00:54	I.6
CEO of ESS building company from Sweden but with production in Portugal	20/2-2024	0:53:53	I.7
CEO of ESS building company from Netherlands, building on batteries from e-scooters and e-bikes	27/2-2024	0:34:01	I.8
Manager of business development of a ESS building company from Netherlands	4/3-2024	0:43:01	I.9
Founder of an Australian company building applications on both batteries from scooters and EVs as well as dismantle inhouse	6/3-2024	0:51:24	I.10
Co-founder of a Swiss company builidng applications batteries from both scooters and EVs as well as dismantle inhouse	7/3-2024	0:31:41	I.11
Research institute and ESS builder from Spain	8/3-2024	0:35:27	I.12
Co-founder of a French e-mobility charging station company	18/3-2024	0:24:44	I.13
CEO of a Polish repurposing/retrofitting company	28/3-2024	0:42:25	I.14
CEO of Rwandan BESS company for telecom	3/4-2024	0:23:12	I.15
Battery sales specialists			
Battery procurement specialist at Swedish battery circularity company	13/3-2024	0:30:28	I.16
Battery circularity specialist at Swedish battery circularity company	13/3-2024	0:38:13	I.17
Battery circularity specialist & Sustainable lead at Swedish battery circularity company	19/3-2024	0:27:43	I.18
Scooter companies			
Operation manager from a global scooter company in Sweden	8/2-2024	0:38:57	I.19
Project manager from an Italian scooter company	19/2-2024	0:27:22	I.20
Electric engineer from a global scooter company in Netherlands	22/2-2024	0:29:07	I.21
Founder of a Swedish scooter company	29/2-2024	0:26:19	I.22
Head of corporate development from a Turkish scooter company	8/3-2024	0:34:06	I.23
Testers/Dismantlers			
CEO & founder of a Finish battery testing company	29/2-2024	N/A	I.24
Dismantler of scooter batteries at an Italian repurposing company	20/3-2024	N/A	I.25
Recyclers			
Managing director at a german recycling company	12/3-2024	0:35:03	I.26
Product Area Manager for Batteries at a Swedish recycling company	14/3-2024	0:36:14	I.27

Table 1. Reference list of interviews held

2.1.3 Workshops

Using workshops as a part of a research methodology is on one hand, authentic, as it aims to fulfill participants´ expectations to achieve something related to their own interests. On the other hand, the workshop is specifically designed to fulfill a research purpose: to produce reliable and valid data about the domain in question (Ørngreen & Levinsen, 2017, p.70-81). In the case of this research, the authors used the workshops as another research tool for analyzing the possible applications that could be suitable for second life batteries from scooters. The reason for using this detached analysis method was not to get a finite result of an application to suggest. Rather, the aim was to get a more technical, objective perspective of what is possible to do by utilizing the knowledge from the company where the authors conducted their research. The goal with the workshop study was to end up with 1-3 possible applications that could be compared with the results and patterns gathered during the qualitative parts of the research, i.e interviews, case studies as well as the literature studies.

The workshop analysis was at first meant to be divided into two workshops. However, after the first workshop, the authors decided that one additional workshop was needed. This means this analysis was done in three steps over a course of three workshops where the participants were the authors and the battery engineer at Cling systems. Before the workshops, the battery engineer was given information about the workshops, how they should be carried out, what was expected from him as well as the milestones with each workshop together with the main goal. The results from them are presented later in the report for the convenience of the reader.

2.1.4 Case Studies

The authors decided to call this chapter “Case studies”, which were actual business cases that the researchers engaged in. It is also possible to see the similarities to Participation Action Research (PAR), a form of action research in which the authors combine the roles of researcher and manager themselves. Action research is described to solve a problem for the client and to contribute to science (Ottosson, 2003), which is also one of eight qualitative research methods listed in earlier literature (Denzin & Lincoln 1994). As a participator, the critical daily steps and details of a project can be made aware by personally managing it. PAR involves using research findings and putting them into practical use to obtain faster feedback which results in better and deeper learning for all involved in the process (Ottosson, 2003). The business cases that the authors participated in were both internal and external cases. The internal ones were cases where employees at Cling asked the authors to do smaller research projects that would help the company with presentations or a pitch. If the research was related to their thesis and if the authors thought the results from them could contribute to it, they chose to include it in the report. The external cases were more business related cases where the authors took part in sales processes where they had responsibility for the contact. These cases emerged from the authors contacting different actors on the SLM in order to schedule an interview for the interview studies. Usually, by the end of the interviews, the interviewees started asking questions related to Cling and their business. In this way, the authors could, by gaining knowledge of their business during the interview, propose offers that could lead to future business. Only the business cases that could relate and contribute to the matter of this thesis were included.

2.2 Method of Analysis

Since the design of the research was flexible, analysis of the gathered data began parallel to collection. This method is called interim analysis and begins early on from the commencement of collection and escalates as more information is gathered (Chism, Elliot & Hilson 2008). The following chapter describes each method used for this research.

2.2.1 Method for Interviews

A form of analysis during the early stages of interviews was to write five to ten points per interview in the form of key takeaways, which were consolidated in an Excel sheet. This continued for the rest of the interviews that were held, but new methods were added as the data increased. A separate file was created where patterns, repetitiveness in answers and possible findings to revisit later were annotated. This allowed the authors to get thoughts down on paper but also to determine when the interviews gave similar responses, indicating a maturity in data collection.

As data collection matured, a separate board was created to map the data from the interviews from the different sectors to facilitate analysis. Takeaways were categorized as possibilities, challenges, possible applications for scooter batteries and other takeaways. Each company, within the specific sector was then given a color and all the takeaways from the interviews were then put into the map in the form of post-it notes in the different quadrants. Within the quadrants, subcategories were also created to group similar points. By doing this, the authors achieved an overview of the challenges, possibilities, applications and other findings with data side by side which enabled analysis of patterns and findings. An example of the working environment is shown below in figure 2 and is meant to *only* showcase how the authors consolidated and structured all the valuable insights from the interviews.

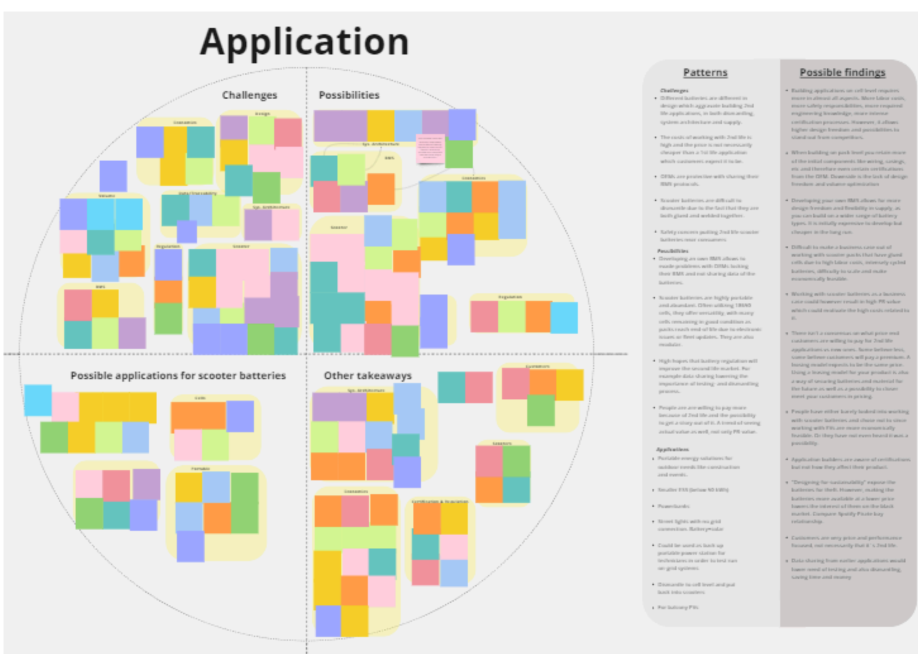

Figure 2. Example of one of the maps for collecting findings from the interviews

Each interviewed sector was assigned their own map. The notes from each map were then gathered into four different spaces, one for each quarter in the map. In these four spaces, all the takeaways from each interviewed sector within the specific theme were compiled in order to get a better overview of the findings from each sector within each theme. A visual representation of what was just described is presented in figure 3.

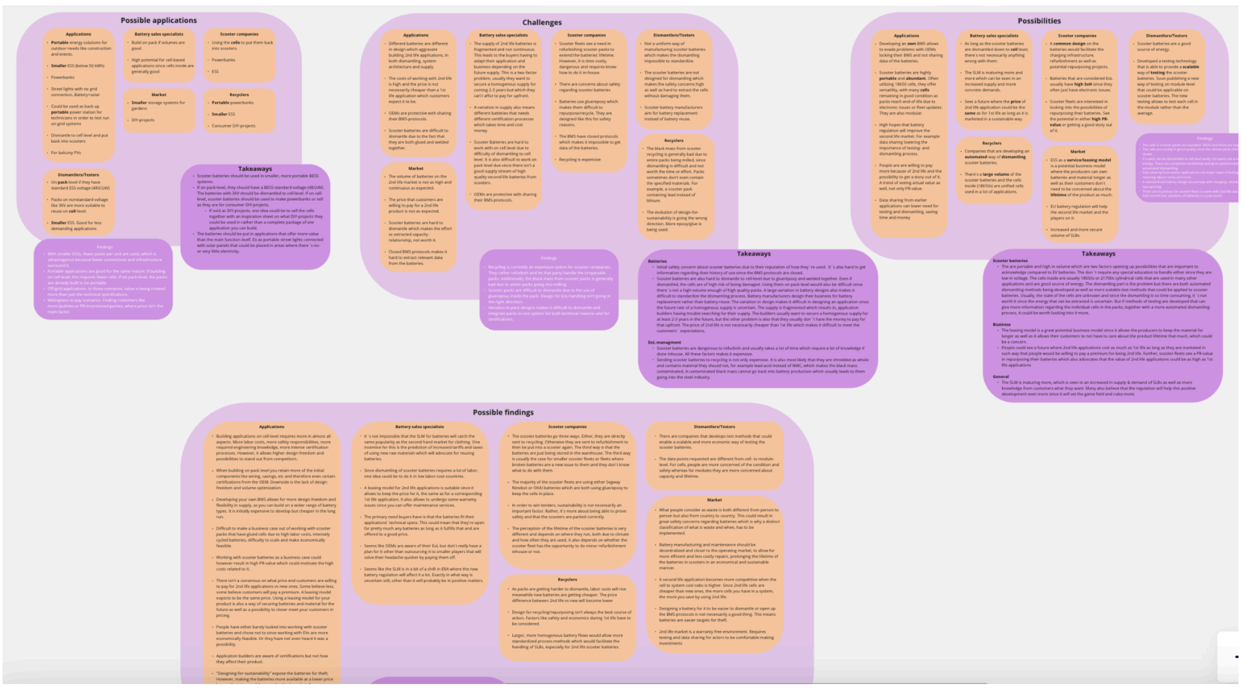

Figure 3. Visualization of the collocation of findings within each theme from each sector

The findings from the interview studies were then compiled one last step into first order, second order and aggregate dimensions according to the Gioia methodology (Gioia, Corley & Hamilton, 2012). This way of structuring allowed the authors to configure the data into a sensible visual tool. It also provided a more visual representation of how the raw data from the interviews progressed into terms and themes, while conducting the research. The choice of building a data structure like this, allowed the authors to think about the data more theoretically, not just methodologically, resulting in a more holistic view of the interview findings (Gioia, Corley & Hamilton, 2012). In order to facilitate for the reader and the analysis of the interview studies, the results from the Gioia methodology is presented in the analysis chapter “4.1 Interview studies”. The figure below presents a graphic visualization of the structure of the Gioia Methodology.

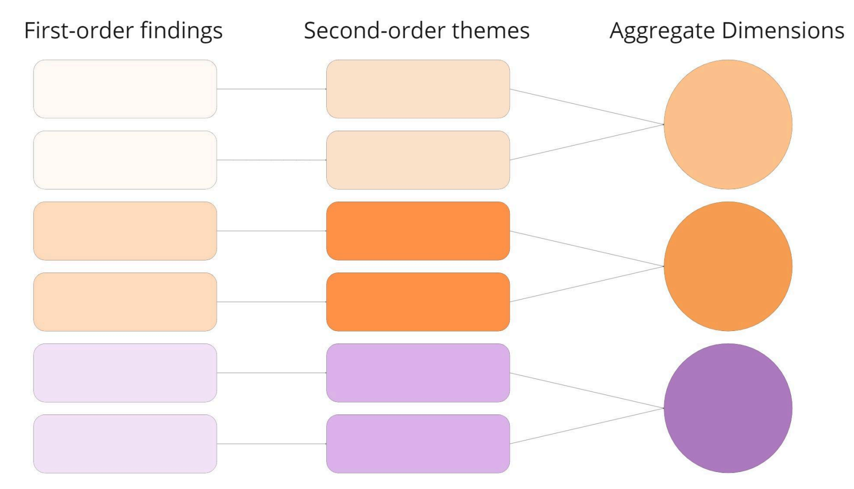

Figure 4. Visualization of the use of the Gioia methodology

2.2.2 Method for Workshops

As mentioned, the workshops were divided into three, each with a different approach and objective. However, the overall goal was to use the top-down method and cut the quantity of possible applications after each workshop, beginning from a list of 50+ applications. This list is presented in the table below.

Mobility degree	Category of Application	Application	Source
Stationary	Charging docks	On-grid buffers for EVs	(Rehme et al. 2016)
		Off-grid availability (smaller hybrid systems with solar)	(Rehme et al. 2016)
		Dock for micro-mobility	(Rehme et al. 2016)
	Special grids	Microgrid	(Rehme et al. 2016)
		Smart grids	(Rehme et al. 2016)
	Residential	ESS with Peak shaving purposes	(Casals, Garcia & Cremades, 2017)
		ESS with load following purposes	(Cready et al. 2003)
		ESS with backup purposes	(Casals, Garcia & Cremades, 2017)
	Commercial	Solar Street Light	Interview
		ESS with Peak shaving purposes	(Cready et al. 2003)
		ESS with load following purposes	(Cready et al. 2003)
		ESS with backup purposes	(Casals, Garcia & Cremades, 2017)
	Industrial	ESS with load levelling purposes	(Cready et al. 2003)
		ESS with peak shaving purposes	(Cready et al. 2003)
		ESS with transmission stabilisation purposes	(Cready et al. 2003)
		ESS with renewable firming purposes	(Cready et al. 2003)
Semi-stationary	Mobile power supplies	Power bank for phones	Interview
		Power stations for construction	(Rehme et al. 2016)
		Power stations for events	(Rehme et al. 2016)
		Power storage for hiking	Interview
		Power stations for RV, Campers	Interview
		Power stations for emergency supply	(Rehme et al. 2016)
		Automotive mobile charging stations	(Rehme et al. 2016)
Mobile	Commercial EVs	Short range EVs	(Casals, Garcia & Cremades, 2017)
		Hybrid trucks	(Casals, Garcia & Cremades, 2017)
		Retrofitting cars	Interview
		Retrofitting boats	Interview
	Industrial vehicles	Forklifts	(Rehme et al. 2016)
		Pallet trucks	(Casals, Garcia & Cremades, 2017)
		Tractors	(Rehme et al. 2016)
		Transport trolleys	(Casals, Garcia & Cremades, 2017)
		Sweepers	(Rehme et al. 2016)
		Automated guided vehicles (AGVs)	(Casals, Garcia & Cremades, 2017)
		Excavators	(Rehme et al. 2016)
	Micro-mobility	E-bikes	(Rehme et al. 2016)
		E-scooters	(Rehme et al. 2016)
		Electric wheelchairs	(Rehme et al. 2016)
	Lightweight vehicles	Golf carts	(Casals, Garcia & Cremades, 2017)
		Three-wheel vehicles	(Rehme et al. 2016)
	Autonomus robots	Robotic vacuum cleaners	(Casals, Garcia & Cremades, 2017)
		Robotic lawnmowers	(Casals, Garcia & Cremades, 2017)
	Consumer electronics	Leisure time gadgets	(Casals, Garcia & Cremades, 2017)
	Marine applications	Full propulsion	(Roschier, Pitkämäki & Jonsson, 2020)
		Hybrid propulsion	(Casals, Garcia & Cremades, 2017)
		Spinning reserve	(Roschier, Pitkämäki & Jonsson, 2020)
		Load-levelling	(Roschier, Pitkämäki & Jonsson, 2020)
		Shore-stations	(Roschier, Pitkämäki & Jonsson, 2020)
		Peak shaving/transient load management	(Roschier, Pitkämäki & Jonsson, 2020)
		Energy recapture	(Casals, Garcia & Cremades, 2017)
	Rail transport	Railway crossing power supply	(Ridden, 2021)
		Railway backup system	(Ridden, 2021)

Table 2. List of potential applications

The list was created from knowledge gained from literature studies and interviews. The method of analysis for the workshops were rather open discussions and letting the knowledge and experience from the battery engineer be the leading voice. The authors' role, besides planning the structure and execution, was to take notes and provide possible insights they had gained from interviews. Together with the battery engineer, the authors carried out the workshops with the help of variations of decision matrices until top candidates of applications were found. Following the identification of the final applications, two interviews were conducted with battery researchers to obtain further justification for the outcomes from the workshops and the earlier interviews. The information obtained through these interviews was consolidated in the same way as previous interviews. After each interview, key takeaways were written down and merged into a separate Excel sheet to easier keep track of it. Detailed description of each step, the objectives with them and the results are presented in chapter "4.3 Workshops" for convenience of the reader.

2.2.3 Method for Case Studies

The chosen method for the case studies could be compared with the "collective case study" method described earlier. The case studies conducted in this research were not pre-determined beforehand, rather they were performed naturally by both being part of the company Cling as well as engaging with external customers. This meant integrating into the company's daily operations and thereby engaging with current customers of Cling or contacts that arose from interviews, rather than having predefined target cases. This method could be compared to the PAR method described earlier in the paper. Each case study was different from the other, and gave unique experiences contributing to interesting insights and findings that the authors could use as comparison with the other analyses. The objective of the case studies was not necessarily to obtain a concrete result. Rather, the aim was to gain knowledge both of what was interesting for Cling to know in order to present valuable data points to their stakeholders. Further, it was also a way of acquiring insights on how easy/difficult it was to do business within the field of electric scooters and their batteries. By engaging in real business cases, the authors, for instance, had the chance to test their ideas on how a suitable business model could look like for the SLBs from electric scooters. The analysis was conducted by noting the main points of the business cases and reviewing the outcomes of the meetings and emails to establish findings and learnings from these real life situations.

3. Literature review

This chapter is devoted to the literature review which is organized to provide a comprehensive overview of the battery, followed by an extensive exploration of the SLM and its associated possible business models. Subsequently, the review delves more into specific technical specs crucial for comprehending the thesis and in greater depth understanding the challenges and opportunities with it.

3.1 Battery market

The battery market of Lithium-ion Batteries (LiB)s for EVs is steadily increasing each year. 2023 marked a year with continuous growth where the industry of passenger EVs topped sales of 10 million, representing 32% of the year-on-year growth according to (Volta Foundation, 2024), published by Volta Foundation. The expansion of the global battery business has unlocked a value chain with significant economic potential across multiple industries which is presented in figure 5.

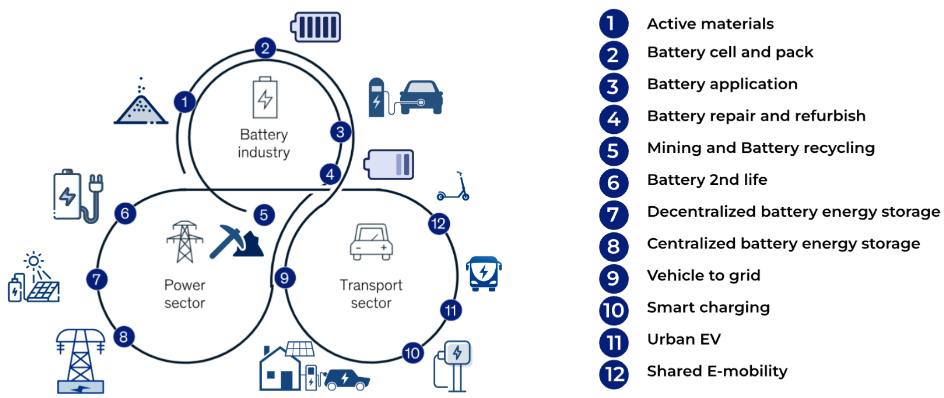

Figure 5. Illustration of the global battery value chain and the including industries (Volta Foundation, 2024, p.21)

The developing trend of vertical integration fades the conventional boundaries between upstream, midstream and downstream segments. Cell and EV manufacturers capture more parts of the value chain, both midstream and downstream. In the battery industry, upstream means extraction of raw materials and material processing. Midstream involves cell component production and cell manufacturing. Downstream includes battery assembly, end users, recycling and repurposing. Mining and recycling companies have higher gross profit margins due to lower costs of goods sold but have low net profit margins due to high operating and capex costs as well as high costs in licensing and permission expenses. To give an overview of the different industries, their biggest actors in all market segments, and to showcase the existence of economic potential in each of them, Volta highlights a compilation of some of the large- and small cap companies which is presented in figure 6 and 7.

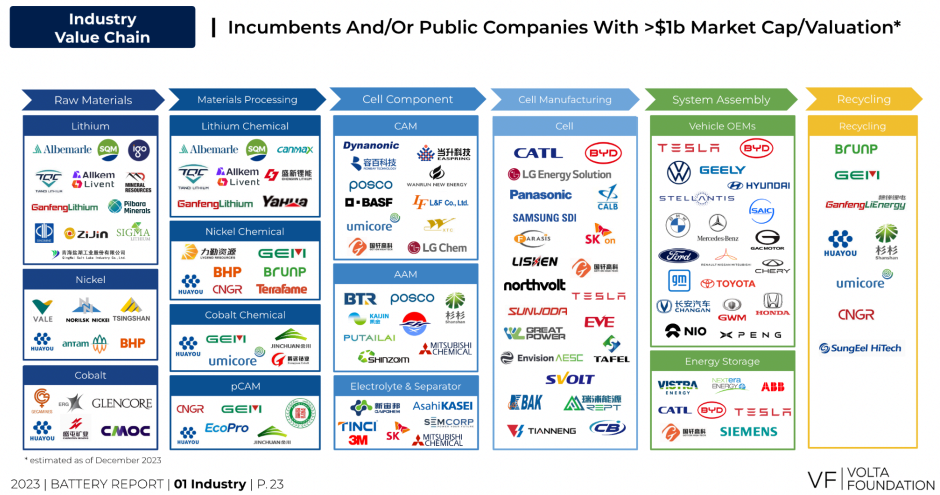

Figure 6. Large-cap actors in different industries of the battery value chain (Volta Foundation, 2024, p.23)

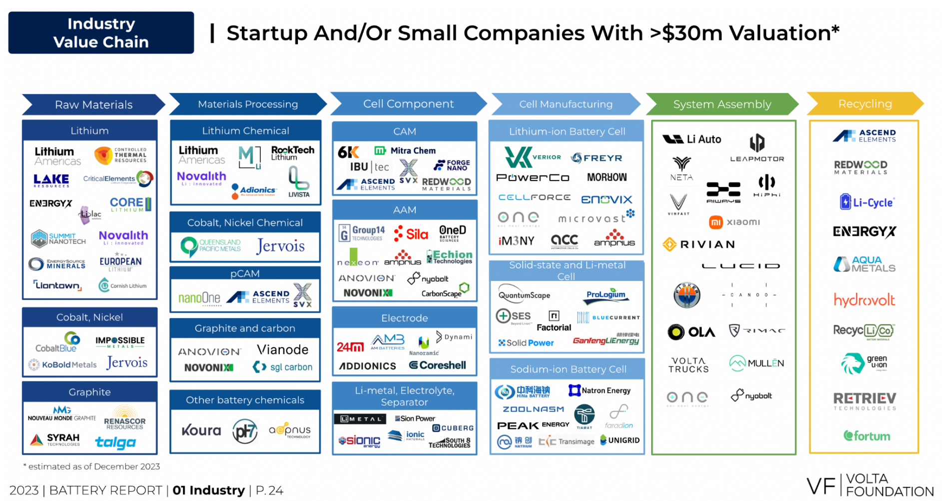

Figure 7. Small-cap actors in different industries of the battery value chain (Volta Foundation, 2024, p.24)

3.1.1 Production and market shares

According to Volta Foundation (2024), the biggest producers of capacity produced from lithium-ion batteries are North America, Europe and Greater Asia, where China is by far the biggest (~80%). Together with a rapidly growing battery application industry, Volta Foundation predicts a steady growth in lithium-ion battery capacity by 2030. The capex costs in setting up gigafactories in North America, Europe and Greater Asia are different due to labor costs, vendor proximity, vertical integration and policy. As stated by estimations in the report, the capex costs are twice as high in North America and Europe compared to Asia. The costs are €99,6 million investment per GWh/a and €105,6 million investment per GWh/a for North America and Europe respectively, while in Asia it amounts to €55,1 million investment per GWh/a. To decrease this gap, Europe and North America have responded with favorable policies for manufacturers and a support for new manufacturing technologies. The report also presents the market shares of the biggest cell- and pack manufacturers where the Chinese company CATL by far has the biggest shares. A visualization of the market shares between the biggest actors is presented in figure 8.

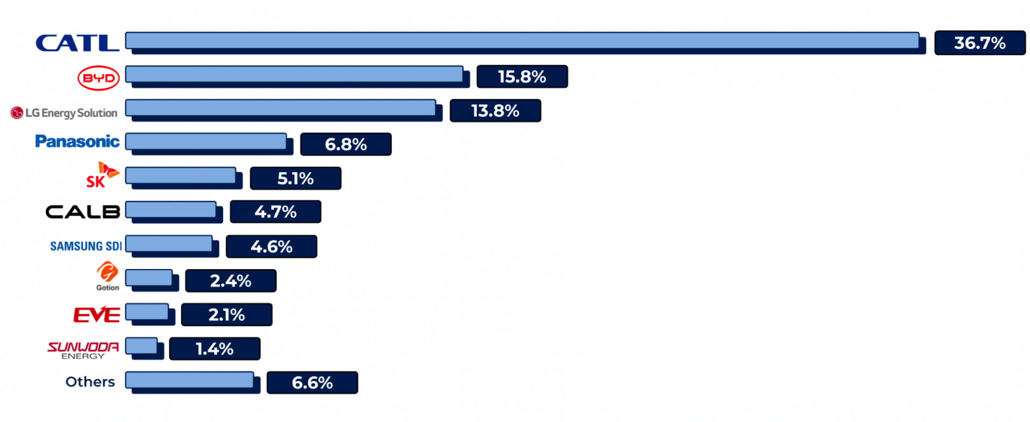

Figure 8. Global market shares of cell & pack manufacturers (Volta Foundation, 2024, p.46)

3.1.2 Applications on the battery market

Batteries are used in a lot of applications; Volta Foundation have divided them into five sectors which are the biggest ones. These are aerospace, automotive, consumer products, grid and military where the two main applications for burgeoning lithium-ion battery capacity are EVs and BESS. EVs fall under the automotive sector whereas BESS is a grid application used for balancing the energy distribution (Volta Foundation, 2024).

3.1.2.1 EVs

The report then segments EVs into Passenger Battery Electric Vehicles (PBEV)s, light transport and Heavy Duty Vehicles (HDV). By PBEVs, they mean cars, which have had the biggest increase on the market with a record number of 10 million units sold in 2023. China still has the biggest share with ~6 million units and Tesla and BYD are the biggest manufacturers. According to the research, the proportion of PBEVs sold compared to traditional passenger vehicles shifted during 2023. They could see that the price of PBEVs decreased relative to conventional vehicles, together with increasing market shares. A representation of the relative increase in PBEVs, by region, in percentage is visualized in figure 9.

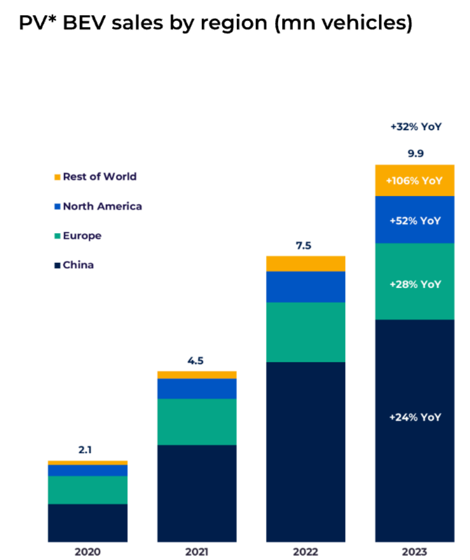

Figure 9. PBEVs sales by region in million vehicles (Volta Foundation, 2024, p.68)

The second segment that the report highlights is light transport which includes two-wheelers, (mopeds, scooters, motorcycles), that are capable of going at speeds greater than 25 kmph. While light transport vehicles only account for <5% of the global emissions, in countries like China and India, that have cities listed with some of the worst polluted ones in the world, two-wheelers are the major contributor to this pollution. The report proposes that electrifying this segment is the greatest opportunity towards the path of zero emissions since the market share accounts for around 50 million units. As with many other segments of the battery industry, China is the one country with both the largest market share in units as well as the electrification level of two-wheelers. However, the second and third largest markets are not Europe or North America, it is India followed by the Association of SouthEast Asian Nations (ASEAN). In fact, Europe and North America, *together,* have the second to last biggest market share right before Africa. Yet, Europe and North America have the second largest electrification level which can be seen in figure 10. Following the report, the countries driving the *electrification* of the two-wheeler market are India and the ASEAN-countries.

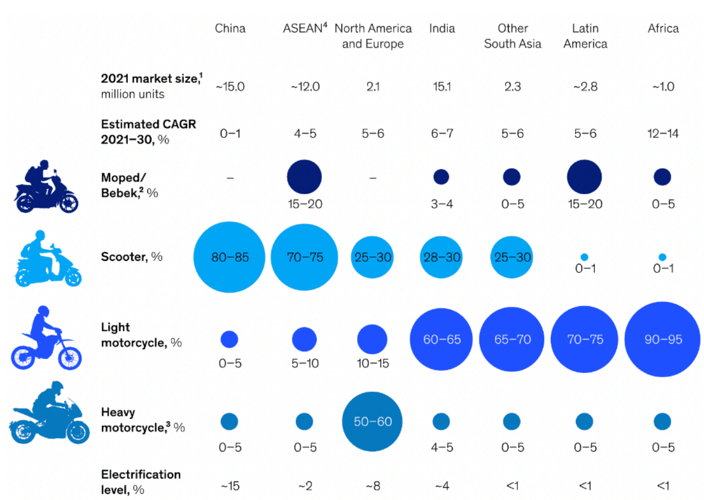

Figure 10. Two-wheeler facts and product mix by geography (Volta Foundation, 2024, p. 76)

3.1.2.2 BESS

Based on the report from Volta Foundation (2024), BESSs are one of the biggest applications for lithium-ion batteries and the investments in this market have tripled to $5 billion in 2022 compared to 2021. This market is estimated to reach $120-$150 billion by 2030 yet with a high risk and uncertainty around financers, integrators and battery chemistries. BESS are expected to contribute both to the electricity generation and distribution by for example wind- and solar energy. Moreover, it is also anticipated to play a big role in Commercial & Industrial (C&I) and residential industries, basically these systems are used throughout the entire energy landscape. The report presents research performed by McKinsey & Co in Germany of 300 people, that shows that in 2023, the residential BESS-market shifted towards LFP-batteries since the top priorities of consumers were price, safety and warranty. Additionally, the biggest challenge for the BESS value chain is the commissioning step when risks and responsibilities are transferred from contractor to client. There is a high financial risk in this step together with possible internal pressure and deadline requirements, that could result in compromises on safety and performance. The impact of delays in the commissioning step is big on the project Return of Investment (ROI) which is crucial. Further, a comparison between requirements of the batteries used in EVs versus BESS was presented by Volta Foundation that showcased interesting differences. While energy density and charge rate are the priorities for EVs, these are less important for BESS but instead the priority is cycle life. The illustration of the comparison made, is presented in table 3.

Application		Energy density	Cycle life	Cost	Charge rate	Safety
Electric vehicles	Passenger EVs	Green	Yellow	Green	Green	Green
	Commercial EVs	Green	Yellow	Green	Green	Green
	Electric buses	Grey	Green	Green	Yellow	Green
	Two- and three-wheelers	Green	Grey	Green	Yellow	Green
Stationary storage	Utility-scale	Grey	Green	Green	Grey	Green
	Commercial	Grey	Green	Green	Grey	Green
	Residential	Grey	Green	Green	Grey	Green

Source: BloombergNEF. Note: Green = most important metric, Yellow = less important metric, Grey = relatively unimportant metric

Table 3. Battery metrics and best-fit applications for lithium-ion batteries (Volta Foundation, 2024, p.93)

3.2 Second-life battery ecosystem

With a growing industry of EV vehicles, it has resulted in an increase of lithium-ion batteries on the market as well. The battery of a PBEV is usually taken out of use while still having 70-80% left of its capacity due to safety reasons. These batteries still have a lot of energy left in them that would go to waste which is why researchers have examined potential innovative ways of giving these batteries a new life. This has led to new business opportunities that must become more competitive than conventional linear business models which is why designing and applying new circular business models have become crucial (Chirumulla et al, 2023).

Batteries used for repurposing usually come from two streams, either from off-spec production scrap or from used batteries in EVs. When a battery has been used in an automotive application, most commonly an EV, and is seen as EoL it can go two different paths. From the dismantler, the battery either goes directly to recycling or it goes to repurposing of the battery which means putting it into a new application. Even though recycling could be seen as the least desirable way, it is still a vital part in the transformation towards a more sustainable transportation-future. However, the best way, both from an environmental- and financial perspective, is to reuse the batteries by finding a new purpose for them. Repurposing a used battery does not necessarily mean putting it into a similar vehicle that it has been in during its first life. Depending on the state of the battery, the proposed application for it together with other factors, it can be repurposed for completely different applications. Examples of applications where SLBs from EVs could be suitable are, applications for grid stabilisations, emergency power supplies or BESSs. After the batteries have been repurposed, they then go to recycling to close the loop of circularity of the ecosystem (Yates, 2023). An illustration of an example of the simplified ecosystem of SLBs is presented in figure 11.

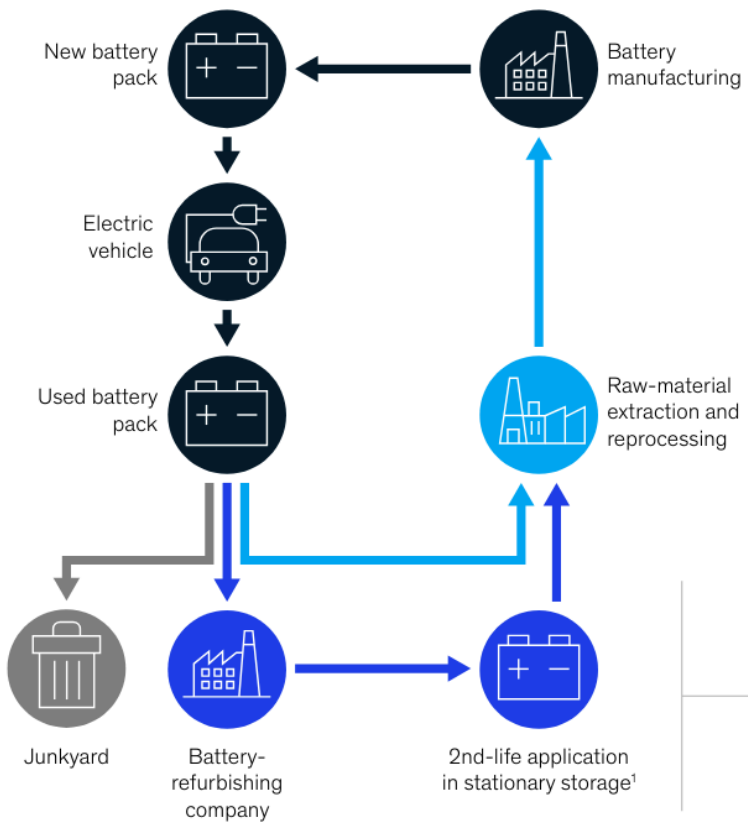

Figure 11. Simplified overview of the battery second life ecosystem. (Engel, Hertzke & Siccardo, 2019)

3.3 Second life battery market

When speaking of the Second Life Battery Market (SLBM), it refers to batteries that have reached their EoL in their first life application and have opportunities to be reused or repurposed into new applications. The biggest supply to the SLBM comes from used EVs or production scrap and on the demand side, the major segments are BESS and Retrofitters. Retrofitters are companies converting, usually vintage and classic cars, into EVs (Melin, 2022). The usual case on the SLBM today is that the majority of batteries coming from EVs derives from production scrap, which means batteries that never reached consumers and its first life application. The conclusion of this is that the location of these batteries are known.

However, since the sales of EVs are expected to grow, the prediction is that the largest source of SLBs will come from EVs reaching their EoL. This implies that the batteries in these EVs may no longer be owned by the initial owner or even remain in the same country where it was sold. These batteries will be scattered across the ecosystem with an uncertain location, which sets challenges for the SLBM.

The SLBM is a young industry and only speculations are made regarding the actual growth of it in the future. Consensus is that it is projected to grow alongside the predictions of the battery market in general growing over the current decade but to what extent is uncertain. One prediction made in 2021 was that, by 2031, the SLBM will be a $9,93 billion industry whereas another forecast made in 2022 said it will be a $20,07 billion industry by 2028 (Leimbach, 2023). Further, the market for used batteries is still open where both companies and private persons are allowed to trade packs, modules and/or cells. The prices of used batteries on the market are set mainly by car dismantlers or other companies selling used batteries from their own platform. From 2022, there has been an upward trend of the average price for used batteries from EVs, an increase of 3,1% compared to 2021. Although the SLBM is open and the prices are set by smaller actors as dismantlers or other companies. In almost all second life systems that are operating today, there has been an involvement by one of the OEMs that originally placed the EV on the market. Different segments of the SLBM also have different impacts on the price where, for example a car dismantler with limited expertise and needs lower labor costs, can sell a battery for less than a dismantler performing a more extensive disassembly to cell-level. Even though the average price of EV batteries increased, some batteries decreased which have several explanations. One could be the increased competition on the SLBM, especially from China where some of their battery packs and modules have increased in popularity. Another explanation could be the increase in retrofitters that do not have the economic possibilities to pay the price due to the tough economic situation in the world in general. The third reason could be the fact that even “third life” batteries are available on the SLBM which have a lower price than SLBs (Melin, 2022).

3.4 Electric scooters

The electric scooter market was estimated at $37,07 billion in 2023 and is expected to grow at an annual rate of 9,9% and reach $78,65 billion in 2030 (Grand View Research, 2023). The surge in fuel-efficient vehicle demand and escalating concerns over greenhouse gas emissions, notably driven by India and China, are the key factors propelling this growth. Electric scooters have high mechanical efficiency and require low maintenance compared to conventional alternatives, consequently electric scooters have become more attractive on the market. In addition, the increase of electric scooters in shared mobility and vehicle renting ecosystems is fueling the demand. Contributing to this trend are countries such as Spain, US, Germany and France with an increase in shared mobility services. The obligation for sustainable urban mobility and smart transportation infrastructure has stimulated the transition from conventional to more electric modes of transport. Where big players on the shared mobility market like Razor, Lime, Bird, Jump and Spin offer e-scooters, mainly procure from manufacturers such as Xiaomi, Gogoro and Ninebot-Segway. Furthermore, governments across the globe have developed regulations that help the adoption of electric scooters on the market. Benefits for both consumers and manufacturers in the form of financial aid. Other than this, governments are also facilitating the utilization of electric scooters by, for example, allowing them on bicycle paths and public roads which has increased the adoption of the scooters on the market. Even with the expansion of electric scooters, there are challenges on the market from alternative vehicles such as light duty electric vehicles like motorcycles and mopeds, but also an increased competitiveness due to regulations on some geographical markets (Grand View Research, 2023).

Many of the major cities in Europe today enable electric scooter sharing through trial periods where only a set number of scooters through certain companies are allowed to act for a given time period. For micromobility operators, this means a competitive landscape in winning contracts for the major cities. For example, the contract for London's e-scooter sharing was only awarded to three companies over a two-year period, with a fleet size of 6600 scooters per company (VNV Global, 2023). The tender, which lies as ground for the competition of securing the contract, is primarily based on safety and reliability in delivering the service, but also includes delivering data on how the service impacts the city's goals such as Vision Zero, shifting to walking, cycling and public transport as well as zero emission targets (Mackela, 2020). The success of these trial periods are crucial for the growth of electric scooter use and micromobility sharing schemes in cities. But also, the competitive format for these trial periods and tenders lays a solid groundwork for the technical development of scooter safety and sustainability. (Transport For London, 2023)

In 2022, Asia Pacific dominated the global industry of electric scooters and accounted for 74,85% of the overall revenue. China is the country that has not only emerged as the top consumer of electric scooters, it is also the leading producer and exporter. Most of the manufacturers come from China and other Asian countries such as Taiwan and Japan. Not only does Asia have the largest market share right now but it is expected to grow due to continuous activities in R&D. Recent Japanese companies like Honda, Yamaha, Suzuki and Kawasaki have presented their own electric scooters which will further amplify the competition on the Asian market. Furthermore, Europe is also expected to grow due to both investments in charging infrastructure as well as research support for innovative high-density batteries. Moreover, a steeper growth in entries of international manufacturers, vendors in Europe will focus on attracting the younger population which will fuel the overall growth (Grand View Research, 2023).

Depending on the end-use of the electric scooters, it can be divided into personal- and commercial use where the segment of personal use represents more than 60% of the market. Especially in the landscape of personal use, the electric scooters are seeing a positive trend compared to its alternatives mainly due to them being eco-friendly, affordable, lightweight, low maintenance and easily maneuverable. Apart from this, scooter manufacturers are focusing more on developing private charging stations or designated charging spots because of the expected increase. The commercial segment is expected to grow at an annual rate of 12,7% from 2023 to 2030. Shared mobility trends and the economic viability of applications in settings like factories, universities, warehouses, and industrial construction are key factors driving the growth in the commercial segment (Grand View Research, 2023).

Concerning the batteries inside electric scooters, the market is segmented into LiB, Lead-acid (La) and other battery types, more on this later in the report. The market segment of LiBs is the one expected to grow the most during the forecast period (2024-2030). As discussed earlier in the report, the price of LiBs is expected to decline which will result in a decrease in the overall cost of electric scooters as well (Grand View Research, 2023).

3.5 Circular business models

From the conventional, linear economic Business Models (BM), with a higher negative effect on climate change, more Circular Business Models (CBM) have increased in the industry. The concept of a CBM is to use already existing material or reuse products in order to decrease the overall environmental footprint of the businesses activities. While this is the short description of the concept, the effects and drivers of implementing a CBM on a business turns out to be more complex and intricate than the obvious business-related questions. According to Pietrulla & Frankenberger (2022), a sustainable BM allows competitive advantages through an innovative approach. A CBM faces both social and environmental challenges that create shared value, collaborative growth and more value through stakeholder synergies. The research, among other things, describes the main challenges, drivers and potential effects of implementing a CBM. According to the research, there have been identifications on various barriers for implementing CBMs such as high investment cost or mindset issues. These barriers do have catalysts in the form of drivers that they decided to summarize in three groups. First one was cognitive drivers that briefly can be summarized as the overall commitment and communication of sustainability matter from top management and making sure it is aligned with the company mission and design. The second group was dynamic capabilities such as processes and features within the business that respond to changes in the environment such as the increased risk of climate change. The writers bring up holistic innovation processes and employee tools that allow them to generate creative ideas and inventive problem-solving as features fostering a more circular business mindset. The last group, they called “other drivers” where they brought up different organizational structures such as cross-functional structures aiming for short response loops as well as organizations with high level of design flexibility. Described in the literature, the biggest challenges of a CBM goes hand in hand with the drivers. They emphasize that culture, mindset and higher cost are the main challenges. For example, a challenge could be to convince a company to increase costs to redesign their process or product that in the long term possibly could increase the revenues due to different factors. It could be using less material, gaining market shares due to a more competitive strategy or product, or improving company reputation.

Clearly, the consumer habits and the urgency to face the challenges of climate change has shifted. Habits to reduce your own footprint have become almost mainstream which forces a transition in company's strategy and business design. According to Orebäck (2022) the lack of ability to improve a process by design in a conventional linear business model has led to more companies applying a more CBM. In this new era of business models, the products are more thought through using a more holistic view of the product lifecycle and even after its lifecycle. The possibilities a CBM brings of applying design thinking using competence across industries, the author emphasizes, could bring a huge competitive advantage. In the research, a list of five key dimensions of inserting design process and thinking to achieve results is presented:

1. **R&D and Design**
   Instead of traditionally designing for a product spec or a design brief, design teams try to develop an ecosystem in a more circular model.
2. **Sustainable material sourcing**
   Instead of choosing the obvious way of working with recyclable material, designers and material experts rethink the product itself and the way it is packaged and shipped.

3. **Circular business models**
   The way a product is designed, dictates the way it is produced. As energy sources move to renewables and transport moves to electric, the emissions of the lifecycle of a vehicle moves from its use phase to production. To reduce emissions even more, designers could apply a CBM to decrease the need to produce new products with new materials.
4. **Distribution and Providing Access**
   Smarter distribution models reduce carbon footprint. Here, designers play an important role in understanding the actual customer need and the value that companies provide - and that customers are willing to pay for.
5. **Use and Reuse**
   Reuse and repair are as much customer experience as purchase and use. In order for customers to embrace these behaviors, they have to be designed easy, accessible and rewarding.

In order to develop your business in a more sustainable and circular manner, improvements in all these dimensions together with a holistic view is needed. A transition to a more CBM, as seen in the report, is not an easy step, however very important. For both environmental reasons and strategic advantages that could be gained if using a unique and innovative design of your business, a CBM plays a key role. Some even mean that, companies that are established with a more CBM have a bigger advantage. According to the Circular Economy Handbook in the article "*5 circular economy business models that offer a competitive advantage"* (The Smart City Journal, 2022)*,* the following five CBMs are superior to the conventional linear ones.

1. **Circular inputs**
   Born-circular manufacturers benefit from lower costs for their production since their input does not have to be from scarce materials. Instead it comes from recycled and excess materials. Born-circular designed products do not become EoL, instead they become End-of-Current-Usage Loop (EoCUL).
2. **Sharing economy concept**
   Born-circulars maximize their utilization of their assets by providing customers with affordable access to products and services. This results in a higher utilization rate of their expensive assets.
3. **Product as a service**
   The customer buys the service for a limited time and the seller keeps the ownership of the product while being in charge of the product´s ongoing maintenance, durability, treatment etc. A shift from focus on volume to performance during the whole lifecycle which results in retaining the control of products and their material which saves material costs. This allows continuous customer contact which is beneficial for getting insights on how their product is used.
4. **Product use extension**
   Born-circular designs their products for repairability, upgradability, reusability, ease of disassembly, reconditioning and recyclability of all components. Responsibility of products extends from only EoL/EoCUL states.
5. **Resource recovery**
   A greater focus on the end stages of the usage cycle with an emphasis on the materials, energy and resources from products that are no longer usable in their current usage state. The

born-circular focuses their design on making it a recoverable value. This BM ensures that the users return products, for example via contracts or through a self-service model.

3.5.1 Applicable business models for second life batteries specifically

With an increasing EV battery market, the need of applicable CBMs specifically designed for this purpose have intensified. One study has found three criteria that identifies different CBMs, characterizing and categorizing them into archetypes:

1. **Resource flows**
   This criterion focuses on managing resource flow in a closed-loop system to enhance efficiency, minimize waste, and reduce environmental impact in production and consumption.
2. **Collaborative ecosystem engagement**
   This criterion evaluates companies' active engagement with external stakeholders to collaboratively create value for battery circularity. It gauges the intensity and nature of collaboration (open, semi-open or closed relationships) required to optimize resource flows, share knowledge, and collectively drive circular initiatives.
3. **Ownership dynamics**
   This criterion assesses how ownership structures impact the design, adaptation, and implementation of circular product-service combinations. It categorizes businesses by ownership and highlights the link between ownership, governance, and product-service strategies.

By using these three criterions of identifying a CBM for EV batteries, the research presents three main archetypes along with eight sub-archetypes. The three main archetypes are extending, sharing and looping and have substantial outcomes for the business. The outcomes include value proposition, value co-creation, value delivery, value capture and also as for the way value is co-created, delivered and captured in collaborative agreements with relevant stakeholders.

The extending CBM archetypes´ objective is to extend the useful life of batteries and their sub-components while operating in their first life or second life. This target is achieved through maintenance, repair, upgrades and refurbishing which results in a CBM that minimizes waste together with contributing to the reduction in demand of finite resources. This kind of CBMs´s value proposition is extending battery life, ensuring access to refurbished parts while offering maintenance and repair services. Value is co-created through collaborations with third-parties, joint ventures and the allocation of services via different channels.

Second type of architecture discussed in the research is the sharing CBM with the objective of maximizing the utilization of batteries or related systems. It is done by adopting different strategies such as shared access, ownership and responsibilities as well as product-as-a-service. By using these strategies, these archetypes can reduce the demand of new products which in turn decrease the demand of finite resources. The value propositions of the sharing CBM architecture are access batteries through leasing, charging infrastructure, swapping services and reduction in environmental impact. Co-creation of value is possible through collaboration with dealers, energy utility companies, local suppliers, manufacturers of battery packs and/or cells or companies allowing shared use of EV batteries. The co-creation process occurs through building a network of battery-swapping stations and infrastructure for trading platforms.

This results in that the value of this kind of architecture is also valid through a digital infrastructure of direct and indirects distribution channels on a digital platform. Revenues can be achieved by using subscription models, battery-swapping fees, battery arbitrage, commission per sale or transaction as well as the sale of energy or energy-related services. The main costs in this architecture is usually refurbishing, infrastructure, inventory, integration and transportation.

The last architecture the research discusses is the looping CBM that aims to keep the batteries and their sub-components in a closed, extended loop in order to obtain as much value as possible from the original product, component or material. The value propositions within this architecture are the reuse of batteries in-house, total lifecycle of the batteries or the energy management in operations. Further, the reduction of resource consumption is also one of the value propositions. Co-creation of value is similar to the sharing CBM architecture in the manner that it is created through collaborations with energy utility companies and their local suppliers. Which could be digital marketplaces, battery pack and/or cell manufacturers, recyclers, repurposers, vehicle manufacturers and sharing third-party networks. Revenue could be created by subscription or leasing fees, sale of remanufactured batteries or BESS, battery arbitrage and commission of sales. The major costs for the looping CBM would be related to repurposing and upcycling, infrastructure, recycling, inventory, integration, operation costs as well as transportation costs.

Together with these three main architectures of CBMs, the research then highlights eight sub-architectures that describe possible CBMs with a more detailed objective. The authors have decided to list the sub-architectures beneath each of the main architectures. To the extending architecture, the writers have associated two sub-architectures:

- **Product life extension**
  These business models aims to extending the life of used EV batteries
- **Refurbishing**
  These business models include refurbishment of a battery in order to extend their usability and life.

Connected to the sharing architecture, there are three sub-architectures:

- **Battery leasing as a service**
  These business models offer batteries on a lease or rental basis instead of selling them where customers pay a fee to use the batteries for a specified period of time or level of usage.
- **Charging infrastructure as a service**
  In these business models, a charging infrastructure as a service is provided. It involves building and maintaining charging stations at various locations. These charging stations can be accessed through subscriptions or pay-per-use arrangements.
- **Gap-exploiter model**
  These business models include identifying and capitalizing on gaps or inefficiencies in the existing market or business. Seeking opportunities or innovations to provide a solution to these gaps are usually the reason for companies to follow this model.

Furthermore, linked to the looping architecture, the writers describe three more sub-architectures:

- **Remanufacturing**
  These business models include working with worn-out products or components to try to restore them into new condition. The process usually consists of disassembling, inspecting and repairing to then reassemble the part.
- **Total energy management solutions**
  These business models allow comprehensive strategies and systems for optimizing energy use within an organization or along multiple entities. These solutions include different ways of saving energy and being more eco-friendly in operations. They involve keeping track of, controlling, and making energy use more efficient in various operations and processes within the business.
- **Recycling**
  These business models involve the process of collecting, sorting, processing and reusing materials from dismantled batteries or waste materials.

(Chirumulla et al, 2023)

These are all examples of possible CBMs that were identified by the research today. With the new industry of SLBs, it is then up to each company itself to choose the right architecture or even a combination of them to ensure they are competitive enough for commercialization.

3.5.2 Business model of Cling systems

William Bergh, the founder of Cling, identified a market void in the exchange of SLBs, characterized by a lack of effective communication between sellers and buyers of batteries. The absence of such communication prompted his initiative to establish a digital market platform for SLBs. The primary goal of this marketplace is to facilitate the connection between supply and demand while serving as a technical support intermediary. Cling operates within the framework of the “three Ts - Trade, Trace, and Transport - which constitute the cornerstone of its business model.

In the realm of Trade, cling engages in the identification of potential buyers and sellers of SLBs, orchestrating the alignment of supply with demand, essentially facilitating the movement of batteries. The Trace component involves Cling providing support services for batteries available in the market through its platform. This encompasses furnishing essential and pertinent data about the batteries, including their history, crucial documents for logistical purposes, regulatory compliance, and tracking services. The Transport aspect embodies Cling's provision of battery transportation services, executed through a triangular agreement. The transportation of batteries involves compliance with numerous documents and safety requirements, all of which Cling manages on behalf of all stakeholders in the logistics chain, correlating with the trace aspect of the business model.

Looking ahead, Cling aspires to evolve into a digital mine of SLBs by the world´s first Circular Asset Management (CAM) system, aligning with its commitment to a circular economy business model. This system is supposed to facilitate the enterprise customer´s EoL-management while creating a price-engine for SLBs in order to unfreeze the market (Cling systems, 2024).

3.6 Lithium-ion batteries

The LiB is the most popular rechargeable battery chemistry that is used today and consists of a Lithium-based compound as one of their electrodes. A single LiB cell consists of the parts presented in figure 12.

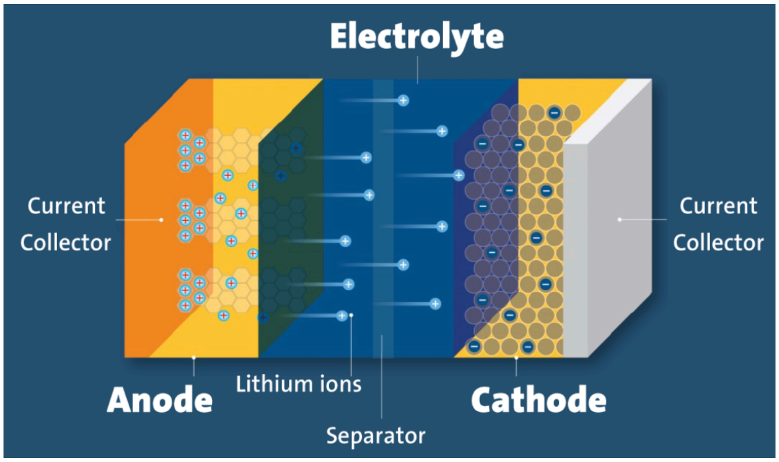

Figure 12. Visual representation of a LiB-cell (UL Research Institutes, 2021)

Attached to the current collectors on each side of the cell, there are the electrodes which are the negatively and positively charged sides of the battery. The current collectors are conductive foil that are connected to the terminals of the cell. The cell terminals transmit the electric current between the battery, the device and the energy source that the battery is connected to. Further, a cell has one negative electrode that is called Anode and one negative electrode called Cathode. Inside the battery, there is an electrolyte which is a liquid or a gel that conducts electricity. In the middle of the cell, separating the negative and positive side, there is the separator which is a thin polymeric film. While separating the electrodes, the separator still enables transportation of li-ions from side to side which leads to the theme of how the LiB actually produces energy. In a LiB, there is an *internal* transportation of li-ions (Li+) that moves between the anode and the cathode. The electrons move the opposite direction in the *external* circuit and this mitigation creates an electrical current which enables powering the device. When a LiB is used in a device, it is discharging itself which on cell-level means that the anode releases li-ions to the cathode which generates a flow of electrons. When charging a battery, the direct opposite occurs, i.e. the cathode releases li-ions to the anode (UL Research Institutes, 2021).

Until now, this section has discussed how a LiB works on cell-level, however that is not how they are used in industrial applications. A battery can be described as in three levels, first there is the cell which can come in different shapes and sizes which will be discussed later. These cells need to be structured and protected in some way which is done via either connecting them in parallel or series, usually a combination of both. How the cells are connected depends on the requirement of the system it is supposed to give power to. Connecting them in series increases the system voltage whereas connecting them in parallel increases the system's current capacity. This connection of cells in series and parallel creates what is called a battery module. As mentioned, the connection of the cells can be done in multiple ways and is up to the battery engineer and her design. A common way of describing the module design in the battery industry is by saying that the module design is *"xSyP"* which refers to that the cells are connected to *"x"* in series and *"y"* in parallel. Lastly, the highest level of the battery is the battery pack which is a shell that surrounds and protects the modules. All these three components of the battery need a device to operate, which is why a battery also includes a Battery Management System (BMS). The BMS is the central core of a battery and is sometimes referred to as "the brain of the battery". The BMS is a combination of several components, both hardware and software, and can either work on cell-level (slave) or pack-level (master). The BMS provides protection against overcharging, over discharging, high- and low temperatures, short circuiting and other failure modes. Besides protecting the battery, the BMS also manages the functionality of the battery. One of the most important tasks the BMS has is balancing the State of Charge (SoC), how much power that is left in the battery at a certain time, in each cell. As with every manufactured item, it comes with defects which is also the case with batteries. Even though a new battery should come with 100% SoH, due to leakages or self-discharge, they can arrive with for example 98% SoH. This might not seem like a big difference but it quickly adds up when working with battery packs with thousands of cells. Lastly, the BMS also provides an optimization of the battery performance by controlling and calculating the batteries´ SoC and State of Health (SoH) (Warner, 2015). Another value of the LiBs that is important to understand is the Depth of Discharge (DoD) that basically is the opposite to the SoC. If the DoD is 0% it means that the battery is full and if it is 100% it indicates that the battery is fully discharged. The value of a battery´s DoD highly affects its lifetime. If a battery is constantly cycled and drained to its maximum DoD, it will have less useful cycles and shorter lifespan (Federal Batteries, 2020).

The battery's SoH refers to the current state compared to when it was at the beginning of its life. The SoH is supposed to tell you how long, from its current energy state, it will take to reach its EoL. The energy in a battery is described in terms of Watt-hours (Wh) which is a common way of valuing a battery on the market (Warner, 2015). Important to understand is that the SoH is just an estimation of the current capacity left in the battery since the degradation is *nonlinear*. The formation of the Solid Electrolyte Interface (SEI) degrades the LiB faster during the first, initial use cycles and proceeds to reach a linear degradation, to then go back to quick and uncontrolled degradation just before EoL, as the SEI builds up. A representation of this can be seen in figure 13 below. A common threshold around 80% of SoH has therefore become industry standard for batteries to be taken out of use from its first life application (Xu et al. 2016).

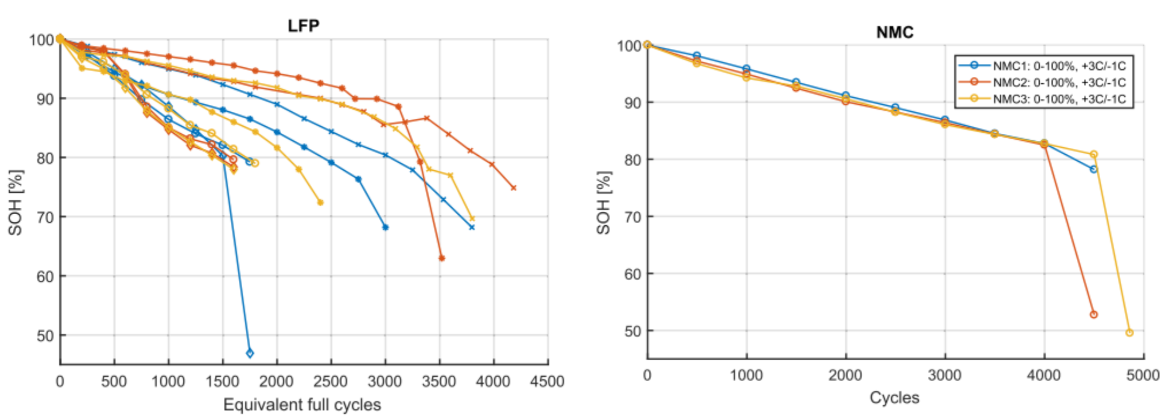

Figure 13. Cycle Aging. (Jenu et al. 2022)

The batteries can then be put into second life applications (SLAs) with lower C-rates. C-rate is an important value for batteries and it refers to the rate a battery can be charged or discharged, i.e. how fast a battery can charge and give up its power. The C-rate is described in relation to one hour which means a battery with 1C can charge and discharge in one hour. A battery with 2C can charge and discharge in 30 minutes and a battery with 0,5C can charge and discharge in 2 hours and so on. A lower C-rate is less harmful on the battery and its health which is why SLBs are put into new applications that allow for a slower charge and discharge of the battery (Warner, 2015).

3.6.1 Battery chemistries

Lithium-ion batteries is an umbrella term which includes different combinations of materials in the cathode and anode, with the common feature of containing lithium. Within this umbrella, there are five major chemistries: lithium iron phosphate (LFP), nickel manganese cobalt (NMC), lithium cobalt oxide (LCO), nickel cobalt aluminum (NCA) and lithium manganese oxide (LMO). Depending on the chemistry, different performance characteristics can be created relevant for the applications needs. In first life production in 2022, the market share by chemistry type was 60% favored to NMC, followed by LFP at 30% and lastly by NCA at about 8% (IEA, 2023). Since NMC and LFP batteries are the most commonly used chemistries for EVs and light means of transport (LMTs), they are therefore described more thoroughly below.

3.6.1.1 Cathode

Lithium Nickel Manganese Cobalt Oxide (NMC) is a very popular li-ion battery chemistry which comprises nickel manganese and cobalt in different quantities in the cathode. The notation for the different ratios is written as x-x-x, for example NMC111 which represents a third of each component. Cobalt is however an expensive raw material and manufacturers are therefore attempting to reduce its ratio in the composition. Successful combinations include NMC532, NMC622 and NMC811. The metals in the cathode serve different functions and complement each other; the different compositions will therefore alter the characteristics of the cell. Nickel is used for its high specific energy but has poor stability, which cobalt stabilizes. Manganese allows low internal resistance by forming a spinel structure, but has low specific energy. The combination of these metals enhances the inherent strengths of one another. Its nominal voltage is ca. 3.6/3.7 V with a typical operating range between 3.0-4.2 V/cell. The high specific energy makes it a common chemistry for EVs and industrial use (Battery University, 2023).

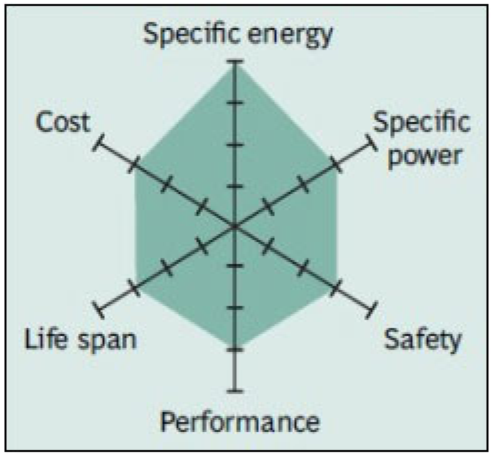

Figure 14. NMC (Battery University, 2023)

Lithium-Iron-Phosphate (LFP) is characterized by good electrochemical performance with low resistance which enables high current rating and longer cycle life. A LFP battery is less sensitive to full charge conditions and can therefore be kept at high voltage for a longer time than other lithium-ion systems. This chemistry has a high level of safety and high power density. However, it has a lower nominal voltage of around 3.2V/cell which reduces its specific energy. The typical operating voltage is between 2.5-3.65 V/cell. Other disadvantages include a higher rate of self-discharge compared to other Li-ion batteries which can cause balancing issues, especially as the battery ages (Battery University, 2023). Due to its high power density it is a suitable chemistry for medium-power traction and heavy-duty traction applications such as e-mobility, marine traction and industrial vehicles. It is also suitable for energy storage applications due to the functionality of deep cycling (PowerTech Systems, n.d).

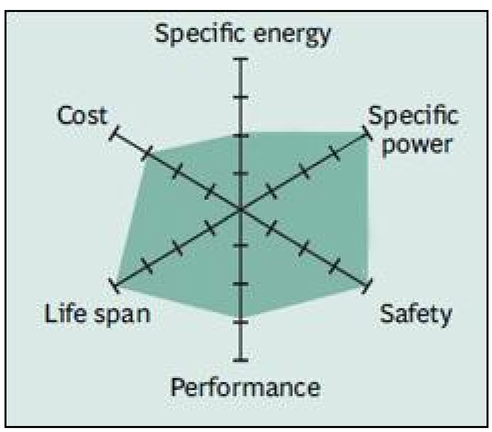

Figure 15. LFP (Battery University, 2023)

3.6.1.2 Anode

On the negative side of the electrode is the anode. The material selection for the anode also results in different performance characteristics of the cell and is therefore an important design feature. Most anodes are made of a mixture of graphite, soft or hard carbons or silicon. The anode must be able to support the chemical process of intercalation which means that ions can be inserted and withdrawn from the layered structure of the anode, as well as having good ionic and electron conductivity of course. Carbon materials are great layered materials, but the problem is the theoretical specific capacity, which is lower than alternative materials. The lithium-ions also have a tendency to form lithium metals at the anode, resulting in a SEI, which inhibits the intercalation process, resulting in an irreversible loss of capacity. Within the list of carbon materials, graphene is a good anode material, yielding higher theoretical capacity than other types of carbons. Silicon is sometimes added to an anode mixture due to its high specific capacity, making the anode lighter. According to the IEA, 30% of anodes contained silicon in 2022 (IEA, 2023).

3.6.2 Raw Material Prices

One important factor to consider for 2nd life battery business cases is the cost of the components for new batteries. The raw material prices used in the cathode and anode drive the overall price of new batteries, which in turn affect 2nd life. As many parts of the industry are growing, the report from Volta Foundation (2024) presents a serious decrease in the battery price in the future due to a decrease in price of raw materials. This includes the four main raw materials of Lithium carbonate, Lithium hydroxide, Cobalt sulfate and Nickel sulfate, where Lithium- carbonate and hydroxide have decreased the most. According to Volta, this decrease will continue over the decade which will have a huge impact on the battery market in the future. The forecast estimates the cell production costs in China to drop below \$55/kWh for LFP-batteries and \$65/kWh for NMC-batteries by 2028 compared to the production cost of ~\$70/kWh and ~\$80/kWh respectively, year 2023. A cell cost of \$65/kWh would result in a battery pack cost below \$100/kWh since cell costs usually account for 70% of the combined battery pack and cell cost. The cost projections are mainly influenced by the price of lithium supply-demand dynamics but the projections state that the prices for NMC-batteries will be more sensitive to Nickel prices in the future. When cheap Indonesian nickel production becomes more available, it will reduce the risk of higher nickel prices for those who use nickel in their products. However, there are difficulties in obtaining Indonesian nickel, and if a company obtains nickel from other countries, it will come with an extra cost. Also important to state, is that the relative influence of lithium on cell costs will decrease only if the price of lithium remains low. On the contrary, the expected increase in the cost of lithium at the end of the decade suggests that there might be a shortage in supply compared to demand. Yet, this prediction has risks and relies on the *assumption* that nickel prices stay the same and not change. A visual demonstration of the predicted raw material cost makeup evolution for NMC 811 batteries is presented in figure 16.

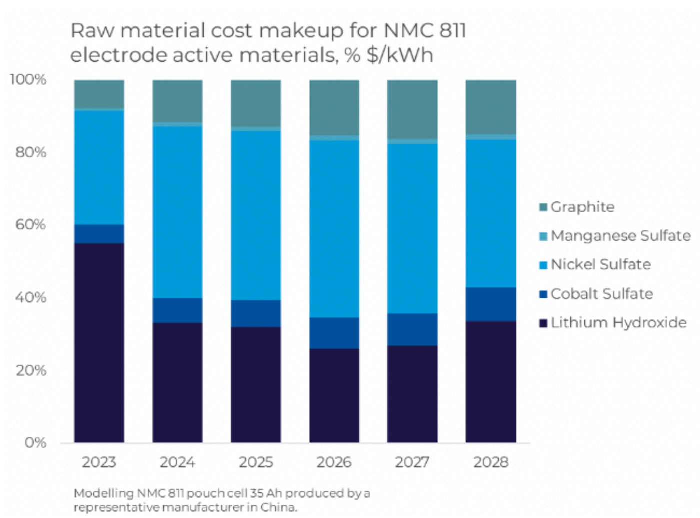

Figure 16. Prediction of raw material cost makeup for NMC 811 (Volta Foundation, 2024, p.36)

The report also attributes the decline in the aforementioned raw materials to increased mining investments, leading to a surplus in supply. The Chinese market, in particular, experienced significant inventory levels at the start of this year. Moreover, the shift towards LFP-batteries has reduced the demand for nickel and cobalt, contributing to a decline in these raw materials. A decrease in raw material prices, of course, lead to a decrease in battery pack prices as well. According to the Volta Foundation, the price of battery packs decreased 14% to a record low of $139/kWh where the cheapest packs were found in China, followed by the US and Europe. Further, during 2023, LFP-batteries were 32% cheaper than NMC-batteries (Volta Foundation, 2024).

3.6.3 Cell types and sizes

There are three notable types of lithium-ion cells: cylindrical, prismatic and pouch, as depicted in figure 17, from Cling Systems. By volume, the 18650 cylindrical cell is the most produced lithium-ion format globally (Warner, 2015, p.84). “18650” represents the dimensions of the cell, meaning 18 mm diameter by 65 mm length. In the automotive industry, this cell type is considered applicable mainly for small battery vehicles like hybrid-electric vehicles (HEV). The large exception is Tesla, which produces battery packs with many small, cylindrical cells. The benefits include that the cylindrical cells in themselves are rigid and can therefore bear some load, requiring less casing material for the pack, they tend to have higher specific power, the cells do not swell, as well as the spacing between the cylindrical cells that arises naturally, acts as a cooling method through convection. (Warner, 2015)

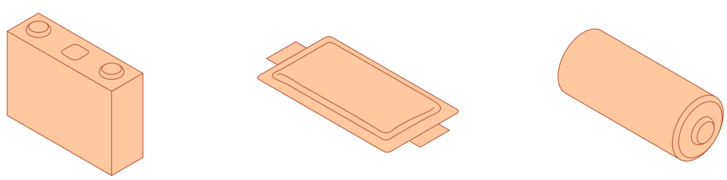

Figure 17. A prismatic, pouch and cylindrical cell.

Prismatic cells are generally rectangular and make optimal use of space due to its use of layering. Compared to the cylindrical cell however, it is less efficient in thermal management and design needs, to allow for some swelling which could cause stresses or pressure points in the pack to arise, affecting the structural integrity of the unit. (Warner, 2015)

Pouch cells are constructed with a soft laminate casing, without the use of a metal enclosure, making it a very lightweight cell type. Achieving 90 to 95 percent packaging efficiency, it makes the most efficient use of space. The cells are stackable in a side-to-side configuration and are considered very flexible in the sense that variations in size and form of the pack is easily attainable. The trade-off is that the cells need more support and space to allow swelling.

Prismatic cells, rectangular or cylindrical, and pouch type polymer cells are more commonly used in the automotive industry due to the fewer amount of cells needed for the desired capacity. With more cells in a pack or module, more connections are needed which amount to more points of failure. The original equipment manufacturer (OEM) sees this as a high potential for future warranty cost, making the case for larger cells with fewer connections.

3.6.4 Battery degradation

As mentioned earlier a battery degrades which means it decreases in performance, more in detail, loses its capacity and internal resistance. The degradation is happening due to mechanical and chemical factors such as aging of the battery, which in turn, can be divided into two types. Calendar aging is the aging of the battery occurring naturally even though the battery is not used (Edge et al. 2022). This kind of aging is occurring due to parasitic reactions between electrolyte and electrode and are classified into three different reactions. Anode reactions, where electrolyte reductions result in SEI growth. Cathode reactions which include electrolyte oxidations and transition metal dissolution. Lastly, coupled reactions where transition metals dissolved from the cathode increase the SEI growth in the anode. Capacity loss during calendar aging is dependent on various parameters where one research highlighted temperature and SoC as important ones. The tests showed that capacity loss due to calendar aging is higher at elevated temperature and at higher SoC. The authors presented that a battery with 50% SoC had less capacity loss than a battery with 70% and 90% SoC and that the capacity loss occurred exponentially (Krupp et al. 2021).

Cycle aging is, however, the aging transpiring from the *usage* of the battery. Each time a battery is cycled (charged and discharged), it degrades. From the perspective of a user, three main factors to degradation have been classified: temperature, SoC and load profile. The relative importance of each of these factors depend on chemistry, form factor and historic use of the battery. The research highlights the deviation from typical 25 °C usage temperature as one of the most significant factors along with operations on higher SoC. Two variables that are highly dependent on the historic use of the battery. Moreover, the research also discusses manufacturing defects as a secondary factor to degradation (Edge et al. 2022).

3.6.5 Electric Scooter Batteries

Batteries for electric scooters are designed for the key features: energy density, lightweightness and durability. This means having high energy storage while keeping the battery as small as possible to allow for simple battery swapping and overall performance of the scooter and also to withstand vibrations, impacts and environmental factors since they are used and placed outdoors (ZipPil, n.d.). The types of batteries used in scooters are usually LiBs due to their great energy density and longevity and range from sizes with the capacity of a couple of hundred Wh to thousands of Wh (Rider Guide, n.d). Even though LiBs are the most common batteries in electric scooters there are different kinds of batteries used in them. Another type of battery used in electric scooters is La-batteries that are less expensive than LiB but are not that commonly used since they are larger, less efficient and need higher maintenance. The third type of battery used in electric scooters is Nickel-Metal Hydride (NMH) which is a next step innovation from the La-batteries. These are around 30% lighter and last longer than most La-batteries but are still relatively heavy compared to LiBs, can discharge when not used and are likely to deteriorate quicker. Even though LiBs are generally more expensive than the other types, they are, as mentioned, the most common batteries in electric scooters. They are smaller, lighter, require less maintenance, last longer and are substantially more efficient. Among the LiBs on the market today, the price range differs from high-end batteries from producers like Samsung, LG, and Dynavolt, to more cheap batteries produced in

China. The last mentioned ones are usually used by electric scooter manufacturers if the objective is to keep costs low.

The LiBs used for electric scooters are usually made of many cylindrical cells combined into a single pack. The cells used are typically either 18650s or 21700s. Since the 21700-cell is larger, has higher capacity and can provide more power, it is better than the 18650-cell. Regardless of size, these cylindrical cells look like AA-batteries strapped together into a battery pack. This battery pack can be placed in different areas on the scooters which has different pros and cons regarding battery life, safety, weight distribution etc. These are called stem, deck and removable and the exact placements are illustrated in the figure below.

Figure 18. Placements of the battery pack on the electric scooter (Left:Stem, Middle:Deck, Right:Removable) (Frisby, 2023)

The pros with the stem-placement is that it is further away from the ground which allows for less risk of damage. It also tends to remain cooler since it is constantly air-cooled. The deck-placement allows for a better weight distribution but it is closer to the ground which increases the risk of damage. This placement also increases the heat on the housing components due to lack of ventilation. The removable-placement allows the user to remove the battery which is a theft deterrent for the scooter itself since the scooter does not run without a battery. Further, this placement is usually placed at the stem which means the same pros and cons are applied for this kind as for the stem-placement (Frisby, 2023).

The lifetime of the batteries in an electric scooter depends on multiple factors such as how often it is used, *how* it is used, during what conditions and environments, how quickly you charge/discharge, quality etc. The general perception is that the lifetime of a battery in an electric scooter is 2-3 years, but more interestingly, around 300-500 cycles. Properly charging the battery and taking care of it of course extends the lifetime as well as using high quality batteries. Using low quality batteries can reduce the lifetime to only 1 year whereas a high quality battery and properly taken care of may extend the lifetime to 5 years (Fluid Freeride, n.d). The lifetime of batteries from the scooter battery companies have however been criticized to have a short lifetime and looking for a number from them was more or less non-existent. However, the *scooters* from Voi (the model from 2021) is estimated to have a lifespan of 4,6 years while their *batteries* 3,7 years, which Voi estimates to be 5 times longer than their 2018 models, according to the company website (Voi, 2022), which gives the reader an approximate number.

3.7 Design for battery safety

When working with LiBs, one must be aware of the severe accidents that can occur if they catch fire. The liquid electrolyte inside a LiB is extremely flammable which must be considered when designing a product that involves LiBs, especially if working with B2C products. Liu et al. (2018) divide the thermal runaway in a LiB into three stages:

- **Step 1:** The onset of overheating
- **Step 2:** Heat accumulation and gas release process
- **Step 3:** Combustion and explosion

The different steps set different requirements on what design features to use in order to decrease the risk of that step to occur. Each of the steps is a sequence of events inside the battery cell which is outside the scope of this project and the expertise of the project group and will therefore not be discussed in more detail. Just acknowledging that there are different steps that take place in chronological order is enough to understand this topic.

The thermal runaways can happen due to various reasons such as short circuit within the cell, physical abuse, manufacturing defects or exposure to extreme external temperatures. LiBs do have gas exhaust nozzles that are supposed to be opened during a thermal runaway in order to lead hot gas away from potential people surrounding the battery pack. A visualization of a design of the exhaust nozzles in an EV is presented in the figure below (Arora, Shen & Kapoor, 2016).

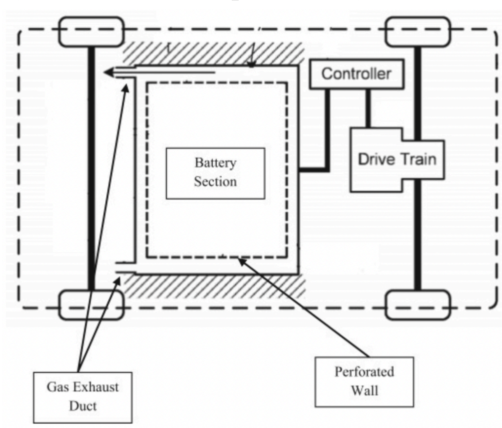

Figure 19. Design of exhaust nozzles of a battery in EV. (Arora, Shen & Kapoor, 2016)

Although the authors (Arora, Shen & Kapoor, 2016) describe this design solution as highly effective in minimizing the risks associated with thermal runaway, the exhaust nozzles depend only on the pressure released from the battery cell. This means that if only a few battery cells are under a thermal runaway state, the pressure might not be high enough for the nozzles to break the nozzle seal. This might lead to the gas propagating within the battery pack creating a thermal runaway at more battery cells.

Furthermore, the authors state another reason for thermal runaway that has to be taken into account during the design phase. A lack of proper vibration isolation in the battery pack has been cited as the primary cause of durability failures of battery packs. This is also proven to be one of the main reasons for a reduced battery life-cycle. The design of conventional battery packs does not function against undesired vibrations to the battery cell assembly. For use in automotive applications, specific mechanical design features need to be implemented to minimize the risk of vibration. Primarily it is the battery pack structure and mounting frame that are designed accordingly. For example, the most severe vibrations to the battery cells are the ones in z-directions, i.e vertically, which is why you usually design the pack structure with a compressive force on the top. (Arora, Shen & Kapoor, 2016)

The material selection of a battery pack does also play an important role in withstanding thermal shocks, mechanical vibrations or other external loads that could cause thermal runaway or decrease the life-cycle of a LiB. To summarize the authors, when choosing a material for a battery pack you must first look at the requirements of that specific pack and the environment it will be used in. Generally, lightweight metals such as aluminum with high thermal conductivity are useful for some parts of the pack. Other parts must have a material that is electric conductive and low thermal conductivity (Arora, Shen & Kapoor, 2016).

3.7.1 Safety for transportation

When transporting LiBs it is important with proper packaging since they are classified as dangerous goods. The packaging should be designed for protecting against physical damage, short circuits, along with other potential hazards. Further, it is important to design the package so that it minimizes the movement of the batteries during transportation. In order to make sure LiBs are packaged and transported in a safe manner, minimizing the risk of fire or explosions, there are regulations. The International Air Transport Association, and the International Civil Aviation Organisation have their specific regulations for airborne transportations. Likewise, the International Maritime Organisation have their regulations for transport on sea of LiBs. More in detail, these regulations specify what type of packaging has to be used together with the correct documentation, labeling and handling requirements. As mentioned, the packaging of LiBs have to be rigid enough to withstand damage during transport. Moreover, the package itself has to be labeled and marked to indicate the type of battery and the risk of safety associated with it. Concerning the documentation that has to be present in the packaging, the requirements of what type of documents needed are depending on the mode of transportation (air, ground or sea), as well as the quantity of LiBs being shipped (Epec Engineered Technologies, n.d).

3.8 Repurposing

One of the first areas to understand when dealing with SLBs, is how the EoL batteries systematically can be repurposed for second-life application. From “*The Handbook of Lithium-Ion Battery Pack Design”* by J. Warner (2015, pp 169-176), the second life process for electric vehicles begins with the first-life battery reaching approximately 80% of its initial capacity or power. At this point, the battery pack is removed from the application and shipped as a whole to a recycling/reuse company. In the initial phase of the battery repurposing process, incoming batteries undergo a comprehensive evaluation involving capacity, voltage, and performance testing. Subsequently, the batteries are disassembled, and their components are categorized into distinct recycling streams based on material composition. Modules, featuring either bolt-installed or welded cells, undergo meticulous characterization testing. Cells or modules failing to meet minimum performance criteria are routed for recycling, while those meeting the standards are organized by capacity for subsequent reinstallation. This marks the commencement of their second life within a new application, as illustrated in the flowchart below.

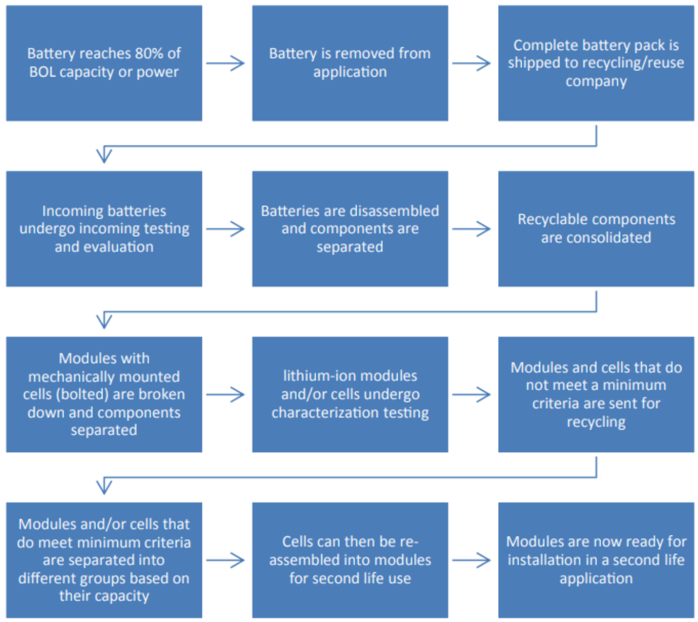

Figure 20. Flowchart of battery repurposing process. (Warner, 2015)

An important aspect in this process is the need to characterize the modules and the cells. Grouping modules and cells in terms of matching voltage, capacity and aging is essential for the success of a second-life battery. This is due to the fact that a battery packs´ overall power and capacity is limited by the weakest cell or module in the pack.

At the moment however, most EV battery recycling comes from production scraps or off-spec batteries that do not meet the quality requirements for their industry and have therefore never even reached the consumer. (Yates, 2023) In these cases the SoH is generally speaking close to 100% as the cells and modules are new but defer due to mechanical, structural or cosmetic imperfections, or even incorrect production instructions which creates a product not suitable for its intended purpose.

Making BESSs from SLBs involves the same components as a regular BESS, namely battery packs, associated power electronics systems and the BMS. The BMS for a second-life battery energy storage system (SLBESS) is required to have cell-balancing capabilities, as SLBs are likely to be imbalanced, even after testing (Hossain et al. 2019). Moreover, as SLBs inherently exhibit increased unreliability, attributed to a higher likelihood of individual battery failures compared to new batteries, the design of power converter topology has the potential to mitigate this issue, thereby enhancing the overall reliability of SLBESS. This was studied (Mukherjee & Strickland, 2014) based on factors of reliability and cost, as well as in the application of grid frequency response (Mukherjee et al. 2012).

The areas of applications for SLBESS are found in on-grid stationary, off-grid stationary and mobile applications alike. A comparison of applications for first-life and second-life batteries and a measure of their frequency was summarized in the table below. The most frequently used applications for SLBESS was found in renewable farming, area and frequency regulation as well as micro and smart grids.

Applications of ESS		1st life usage	2nd life usage
On-grid stationary	Renewable Farming	***	***
	Peak reduction	***	*
	Load levelling	***	**
	Area & frequency regulation	***	***
	Generation-side asset management	***	**
	Voltage or reactive power support	**	*
Off-grid stationary	Microgrid	***	***
	Smart grid	***	***
	Power quality & reliability	***	*
	Load following	***	**
	Spinning reserve	***	*
Mobile applications	EV charging station	***	**
	V2G for fast charging	***	*
	EV for long range trips	***	X
	EV for short range trips	***	**

*** Frequent, ** Occasional, * Rare, X Infeasible

Table 4. Comparison between applications for first-life- & second-life batteries. (Hossain et al. 2019)

In terms of creating competitive businesses from second life in the battery landscape, innovative ideas and business models need to be employed. Boston Consulting Group (BCG) states that for the three most common stakeholder groups: OEMs, repurposers and end users, the benefits of second-life need to be seen from a value standpoint. For OEMs this ties in with EPR and by repurposing a battery, the cost of recycling can be time delayed and shared with the new producer of the battery. For repurposers and end customers, second life applications can offer higher flexibility in cost and performance, tailoring the energy storage systems to the user's needs. For repurposers specifically, three strategic levers proposed by BCG include developing standardized, modular solutions to reduce the cost of the product while also making available a range of capacity to the customer. An important element of this to lower costs is to secure access to batteries with high-volume where possible, and to primarily use full packs or modules to reduce disassembly costs. Secondly, offering a more complete scope of hardware would build a cost advantage by selling entire systems of hybrid energy solutions or offering services. Lastly, innovative business models decoupling price from a battery's remaining useful life (RUL) such as battery rentals or ESaaS could create cost advantages (Niese et al, 2020).

3.9 Recycling

The majority of batteries at their EoL are disassembled from the EV and then sent to a recycling facility specializing in batteries. Recycling is one of the last stages in the lifecycle of metals which includes extraction, transformation, manufacturing, usage and eventually waste management. Recycling is a crucial factor of the circular economic framework, enabling the utilization of resources such as energy or chemicals in treatment processes, with less energy than is used in new production. Research has shown that a closed-loop recycling process for batteries can cut 51% of the environmental impact of the manufacturing process. A closed-loop recycling process allows materials to be recovered and reused in similar applications as before. Moreover, it is also possible to create an open-loop recycling process where the recycled materials are possible to be reused in different applications from the initial one. A common recycling process may comprise four main stages: shredding, disassembling, incineration or acid treatment, in order for separation of elements to recover. The recycling process of LiBs can be divided into two main steps and four sub steps. The two main steps are mechanical treatment and chemical treatment. During the mechanical treatment the battery pack is first discharged before it is dismantled to battery modules and lastly disassembled to spent LiB cells. The chemical treatment can either be done by pyrometallurgical (pyro-process), hydrometallurgical (hydro-process) or a combination of them. Moreover, a biometallurgical process can also be used which uses micro-organisms that allow insoluble substances to recover. An illustration of the recycling process of a LiB is presented in figure 21.

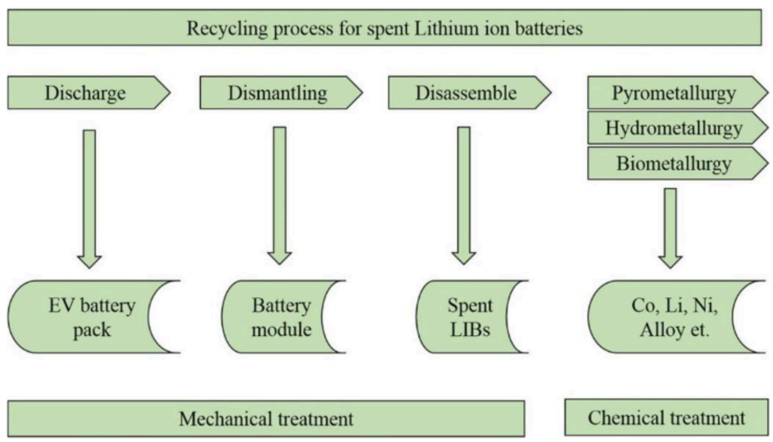

Figure 21. Illustration of the recycling process of a LiB (Danino-Perraud, 2020, p.19)

There are several different recycling processes for batteries, namely the pyro-process, hydro-process and pyro-hydro process, wherein the latter is the preferred method. Main reasons for this is that the pyro treatment avoids the disadvantages related to safety issues originating from the various chemical compositions of batteries, their constitution and SoC. To then separate the different materials in the slags, the hydro-process facilitates different materials being prone to treatments using different kinds of chemicals and acids (Danino-Perraud, 2020). This process consists of a pretreatment of the battery that processes the battery modules into fine substances which are then separated into steel, plastics and active materials in the form of *black mass*. After this, the black mass undergoes a hydro-process that separates it into valuable materials like lithium, nickel, cobalt and manganese (Grudzień, 2024).

Recently, a new recycling method has been used that, compared to pyro- and hydro-process, allows obtaining electroactive materials by regeneration of exhausted batteries. This process is called direct regeneration with the main advantages that it is consuming low energy, its non-destructive nature and the reduced generation of secondary waste. One of the methods for direct recycling is lithiation that consists of adding lithium to spent material in order to restore its stoichiometry.

With the main objective for recycling being the recovery of as much material as possible in depleted batteries, the materials in the cathode are the ones that have been the main target. These materials are nickel, lithium and cobalt and have been the main aim because of their economic value. However, not only the cathode materials hold valuable metals, the anode materials also have noteworthy attributes. The anode mainly consists of graphite, as well as copper and lithium. Moreover, an important element of the recycling of LiBs is the electrolyte, which due to its lithium salts and volatile organic compounds, requires careful handling to prevent negative effects on health and environment. Therefore, developing safe extraction methods have become crucial for responsible waste management of electrolyte materials. After the materials have been extracted from the used batteries, the final step is the reintroduction of the recycled materials for the production of new products. Concerning materials recycled from LiBs, they are generally used for resynthesis which means they are reused in their original function.

Associated with battery collection, recycling methods, metal extraction and application of recovered materials, there are of course challenges. Addressing these challenges are crucial given only 5% of spent LiBs are currently recycled. Some of these challenges are:

- Inefficient waste sorting, where a lot of batteries are disposed of as common waste.
- The pretreatment process faces multiple challenges regarding safety, such as short circuits and explosions. In order to reduce these risks, automated disassembly processes need to be developed.
- As for now, many of the recycling processes cost more than they generate value which means they are not economically feasible. The only material worth recycling from an economic standpoint today is cobalt.
- A lot of focus has been directed towards recycling of the cathode material and less towards the others. Few studies address the fact that you can recycle the plastic casings, current collectors, electrolyte and anode materials.
- A big challenge is the lack of policies and regulations regarding recycling of LiBs where federals should use their power to mandate or encourage the storage, reuse and recovery of LiBs.

The recycling of LiBs, as with any other recycling, contributes to a circular economy and contributes to the reductions of waste disposal, mining impacts and extraction of finite materials. Designing the batteries and their production might lead to even more changes that stimulate the circular economy. In the research, the authors (Leal et al. 2022) address two approaches for LiB recycling that are crucial for the future. The first one is focusing on the existing batteries and understanding the challenges with reusing and recycling them. The second approach aims at the future LiB generations, emphasizing design improvements to overcome the current obstacles. A testing infrastructure for consistency and recycling capacity is essential where the governments will have a vital role deciding the regulations and facilitate for companies to establish these infrastructures of collection networks. Another important objective is the quality control which today is a huge problem for waste management. To summarize the future of battery recycling, the priority should be to design batteries for recycling convenience throughout the entire cell design.

3.10 Disassembly

As mentioned in the previous section, disassembly is an essential step in the recycling process, but also for repurposing. Disassembly is a complex process, mostly because there exists so many different types and forms of packs. Due to this fact, automated disassembly is not very common compared to manual disassembly, which poses cost and time challenges (Wu, Kaden & Dröder, 2023). To reach the cells within the pack, disassemblers must unscrew the pack's casing and eventually saw through it, remove auxiliary electrical connections, circuit boards and then components within the pack such as wiring, sensors and BMS. The disassembly as mentioned earlier varies with each pack manufacturer, some being easier to pull apart than others. Scooter batteries are designed with the main objectives of being lightweight and durable, meaning compact designs and the ability to withstand vibrations, impacts and environmental factors. In design terms this means encapsulating the battery pack in protective casings to protect them from external shocks (ZipPil, n.d.). One concept for automated disassembly is the gripper system, which aims to remove the cells from the modules and can possibly measure the cell voltage and internal resistance simultaneously. Other automation processes focusing on the unscrewing of the pack have come into attention as a semi-automated disassembly process, due to screw fastening being a prevalent feature of battery packs. This solution lets a robotic arm unscrew and remove the casing of the pack and later be handled manually with more complex tasks as described above. A study showed that using this semi-automated approach, robot unscrewing achieved a time saving of 55% (Wu, Kaden & Dröder, 2023, p.14). If battery pack design becomes more standardized, the pathway for automated disassembly seems more and more viable.

3.11 Regulations

A new landscape of policy regarding batteries was set in the summer of 2023 when the European regulation on batteries and waste batteries was accepted by the European Parliament. The European Commission states that the regulation will ensure that batteries will have a low carbon footprint, require less raw materials from non-EU countries, use less harmful substances and that batteries are collected, recycled or reused to a greater extent in Europe. The legislation therefore considers all parts of the battery value chain including sourcing, manufacturing, use and recycling in a single law. From 2025 onwards, targets for recycling efficiency, material recovery and recycled content will be introduced step by step. Eventually, all collected waste batteries will have to be recycled, where critical raw materials will have to be recovered and used in the manufacturing of new batteries (European Commision, 2023).

A central point for recycling, in the regulation, is to develop mandatory percentages of recycled content for certain minerals in the production of new batteries for certain applications. By 2026, the Commission shall have established a methodology for calculation and verification of recycled content in affected batteries for cobalt, lead, lithium and nickel, so that by 2028, these percentages can be included in documentation for the batteries. The affected batteries are industrial batteries with a capacity above 2 kWh, EV batteries and Starting, Lighting, Ignition (SLI) batteries that contain the aforementioned active materials. The set amounts for 2031 of required recycled material content for the affected active materials are:

- 16% cobalt
- 85% lead
- 6% lithium
- 6% nickel.

By 2036, these amounts are increased to:

- 26% cobalt

- 85% lead
- 12% lithium
- 15% nickel.

LMT batteries are also affected, but with a separate time plan, where the documentation is first to be included by year 2033, and will have the same obligations as the previously mentioned batteries, concerning recycled content by 2036. An LMT battery, per the EU regulation, means a battery that weighs under 25kg, is sealed and is designed to provide electric power for the traction of wheeled vehicles that are powered by an electric motor. The category “industrial battery” encompasses several different types of batteries. The relevant types for this paper that are included in the category affected by the regulation are ones that are used for the generation and distribution of electric energy, ones that have industrial use after being subject to repurposing and ones used for energy storage in private or domestic environments. The regulation affects all categories of batteries placed on the market, whether they were produced in the Union or imported (European Union, 2023). This implies that by 2031 and onwards, producers of batteries outside the Union will have to offer companies acting on the European market batteries that comply with this law. How supply and demand will be affected is unclear but it poses opportunities for competitive costs of second-life repurposing in the future.

For the battery supply and value chain, the regulation will mandate a battery passport to enhance transparency for stakeholders by enabling exchange of information, tracking and tracing, information on carbon intensity during manufacturing, origin of materials, composition including raw materials and use of recycled materials, if the battery has been repurposed as well as other relevant information. The battery passport in the form of a QR code will apply to industrial batteries with capacity over 2 kWh, LMT batteries and EV batteries, from 18 February 2027. Information is made accessible to different parties depending on the sensitivity of this information. To the public, data including composition, carbon footprint, recycled content, expected lifetime in cycles, rated capacity, weight, manufacturer, place of manufacturing shall be made accessible. For person(s) with a ‘legitimate interest’, which is not yet defined exactly, information on dismantling, safety, detailed information on composition and part numbers shall be made available. As mentioned, it is not yet defined who this pertains to, but the regulation does elaborate that this information should be accessible to “those who have purchased the battery or parties acting on their behalf for the purpose of making the battery available to independent energy aggregators or energy market participants, evaluating its residual value or remaining lifetime for further use, and facilitating the preparation for re-use, preparation for repurposing, repurposing or remanufacturing of the battery.” Additional information such as results of test reports are only to be made available to notified bodies, market surveillance authorities and the Commission to prove compliance with the regulation. Already from August 2024, read-only information on a batteries’ SoH and expected lifetime should be attainable from the BMS of stationary BESS, LMT and EV batteries, per the EU Regulation 2023/1542 (European Union, 2023). As mentioned, this mandate will enhance transparency for stakeholders along the value chain, but perhaps most importantly for the second-life market, where a major challenge today is knowing a battery’s history and its state. Reducing risk for stakeholders at this point is important for attracting investment and activity.

The term EPR from the EU directive applies to producers of batteries and implies that these producers need to secure the management of their batteries when they are deemed to be waste. This responsibility includes organization of and financing the collecting, treating and recycling of the batteries. The financial contributions take into account both costs and eventual revenues obtained from the mentioned activities (European Union, 2023). In Sweden, automakers and importers of cars have EPR, meaning that they need to be registered with the Swedish Environmental Protection Agency (EPA). This in turn means that the producer has an obligation to dispose of EoL cars to authorized dismantlers, which also satisfies the requirements for a battery collection scheme, thus not being required to take part in a separate system for battery collection (Naturvårdsverket, n.d.). When collected batteries reach a recycling plant, this facility should report the recycling efficiency of the batteries that they receive. The legislation states that EPR should also apply to actors placing a battery on the market that results from the preparation of re-use/repurposing or repurposing and remanufacturing operations, i.e not only the original producer. This implies that the original producer and economic operator does not bear the responsibility of waste management for end of second-life and associated costs.

In Article 11 of the Battery Regulation, it is stated that LMT batteries, as well as individual cells in the pack should be readily removable and replaceable by an independent professional at any time during the lifetime of the product. An additional point is made here that the definition of "readily replaceable" is where after its removal, it can be substituted by another compatible battery without affecting function, performance or safety. This article is applicable from 18 February 2027 (European Union, 2023). The legislation still needs implementation and clarification as to what is meant by "readily replaceable cells", with its proposed form getting pushback from a large industry body, CONEBI. More answers to this question will come as guidelines to facilitate application are published by the Council (Peace, 2023).

3.12 Standards and Certifications

Experts believe that the expansion of the LiB market and the great implication of the EVs has been remarkably inhibited by the LiBs safety performance. Recently, there have been a lot of LiBs retrieved due to fire and explosion accidents which have resulted in damaging the reputation of the batteries while causing economic issues for the industry. As a consequence of this, there has been an increased attention towards the safety issues related to LiBs culminating in various certifications related to safety. The safety of a LiB is deeply determined by the chemistry, its operating environment and the abuse tolerance (Chen et al. 2021). Certification is an important factor to consider for repurposers of second life batteries, to ensure the battery meets the applicable safety standards for its new industry. In some cases, the certifications from its first life can be used, but for other applications the battery could need recertification, which incurs costs (Byczek, 2020). As the extensive list of standards and certifications is not crucial for the analysis in this thesis, the authors have included the complete list in Appendix A for interested readers. Although the analysis briefly addresses the topic, it refrains from delving into the specifics of individual standards and certifications, which is why the list was kept in the thesis.

4. Findings

In this chapter, the findings from data collection are presented. The findings are divided into three segments, representing the different qualitative collection methods, which include interviews, case studies and workshops.

4.1 Interview studies

The following chapter aims to provide a coherent narrative detailing how the authors arrived at the five aggregate dimensions, following the Gioia methodology, based on key findings derived from the interview study. It serves to offer a comprehensive understanding of the issue at hand and construct an informative narrative that leads to theoretical discovery with presentation of evidence. This section will explain each aggregate dimension and its associated second-order themes, supplemented by quotes from informants found in table 5, that correspond to the examples illustrated in figure 22 of the data structure. The objective is that the reader should be able to see the data-to-theory connections in the form of linkages among the quotes in text, first order findings in the data structure, and their connection to the emergent second order themes and dimensions. Moreover, this chapter will introduce each emergent theme and/or dimension, with a particular emphasis on "zooming in" on the key findings or themes. Findings that will be subjected to further examination later in the thesis (Gioia, Corley & Hamilton, 2012).

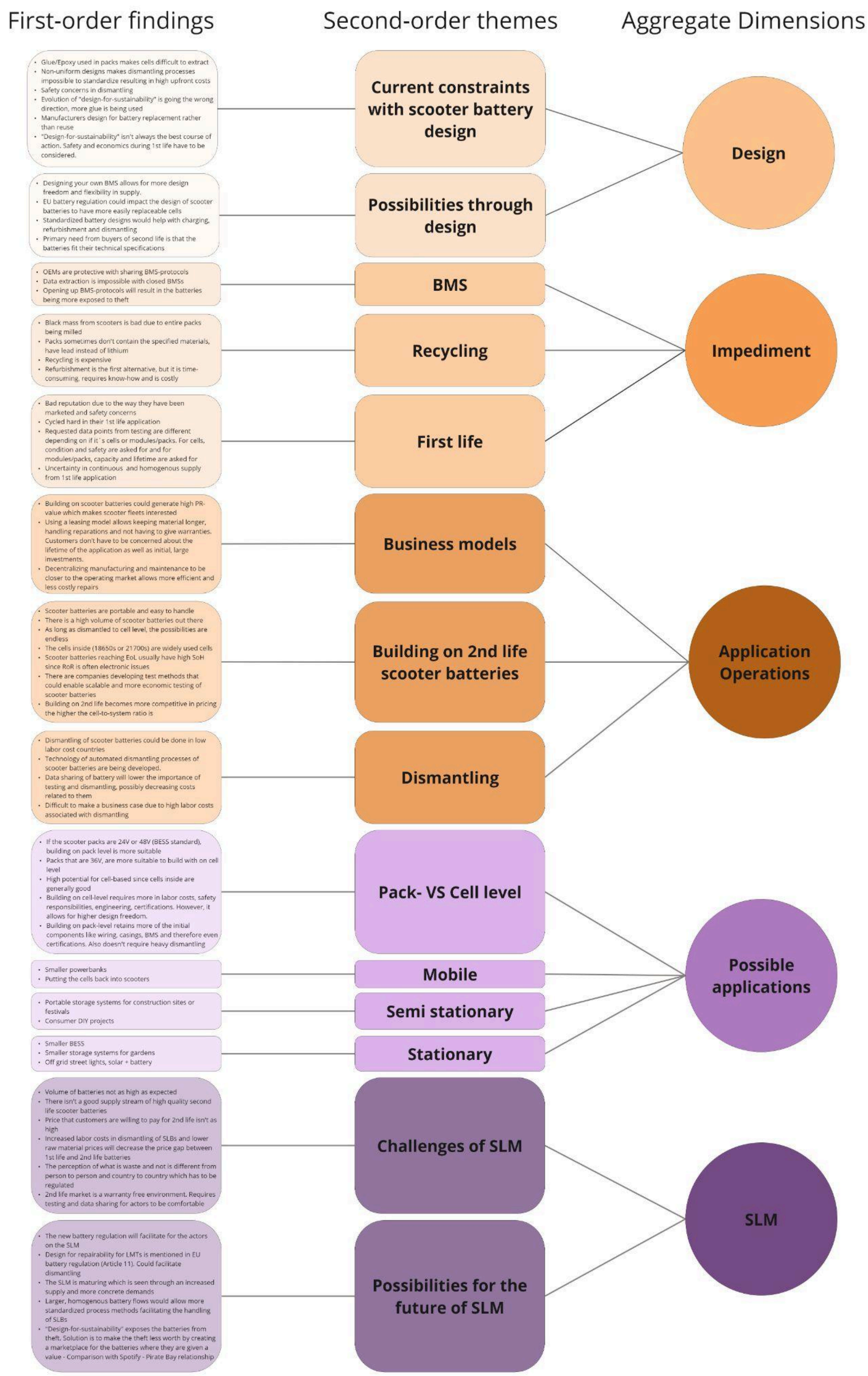

Figure 22. Data structure of the compiled findings from the interview study

One aggregate dimension identified in the study pertained to "Impediment", encompassing three second order themes: "BMS", "Recycling" and "First life". Throughout the interview process, the researchers observed numerous challenges associated with scooter battery utilization, potential applications and viable business models. The three aforementioned second order findings were characterized by the prevalence of obstacles. Moreover, challenges emerged from both inquiries related to design considerations and broader issues with the SLM affecting scooter batteries. Nevertheless, amidst these challenges, the researchers also found opportunities stemming from strategic design choices and the implementation of SLM practices as evidenced in the interviews. Consequently, the decision was made to delineate "Design" and "SLM" as aggregate dimensions, given their nuanced interplay of *both* challenges and opportunities within each domain. This dynamic relationship was not found in the second order themes: "BMS", "Recycling" and "First life" and were therefore compiled under the aggregate dimension "Impediment".

As indicated earlier, during the interviews, the researchers identified two distinct areas where discussions encompassed both challenges and opportunities. These areas were categorized as the aggregate dimensions: "Design", which pertains to the configurations of the scooter battery and its associated components, and "SLM" which denoted broader challenges and opportunities within the context of sustainable management practices affecting scooter batteries. Thus, "Design" and "SLM" emerged as intuitive aggregate dimensions, with "Current constraints with scooter battery design" and "Possibilities through battery design" representing the respective aspects under "Design," while "Challenges of SLM" and "Possibilities for future SLM" were encapsulated under "SLM" as second-order themes.

The second to last aggregate dimension identified was labeled "Application Operations", encompassing its second order themes of "Business models", "Building on 2nd life scooters" and "Dismantling". Throughout the interviews, two prominent themes emerged regarding the operational aspects of developing applications utilizing scooter batteries. Primarily, attention was drawn to the practicalities of building applications on 2nd life batteries from scooters, alongside the exploration of suitable business models for implementation of such operation. Additionally, the authors noted an intriguing finding pertaining to "Dismantling", which they categorized as a second order theme within this dimension. It became apparent during the research that the effectiveness and scalability of building SLAs with scooter batteries depended significantly on the efficiency of the dismantling process, underscoring its pivotal role in the viability of such business ventures.

The final aggregate dimension arose from a specific inquiry posed consistently during all interviews by the researchers. Participants were asked to engage in a brainstorming exercise envisioning potential applications for SLBs derived from electric scooters. This question primarily aimed to leverage diverse expertise of stakeholders involved in the SLM, utilizing their insights to inform the researchers´ brainstorming sessions and further analysis. Thus, the ultimate aggregate dimension was designated as "Potential Applications", accompanied by second order themes such as "Pack- vs Cell level," "Mobile", "Semi-stationary" and "Stationary". The first theme pertains to the structural level at which the application should be constructed, whether on pack- or cell level. While the latter three themes delineate the varying degrees of mobility associated with the envisioned applications.

Interview Quote	1st-order finding	2nd-order theme	Aggregate Dimension
“The best correct way is to break it down to cells, segregate cells and make a new pack. This will perform the best. Unfortunately, that's a dead end because it's so labor consuming, and because many packs are built with a lot of glue or you know resins” - I.14	Glue/Epoxy used in packs makes cells difficult to extract	Current constraints with scooter battery design	Design
"We need this flexibility for the module we're receiving. What we find today, we may not have access to tomorrow, so we must be able to adapt very quickly to new modules or new cells. Therefore, we simply must have our own BMS." - I.7 [Translated]	Designing your own BMS allows for more design freedom and flexibility in supply	Possibilities through design	Design
“What you get in the end is not the best black mass… that gets disturbed a little bit by silicon by plastic housings, but it's not worth the time economically to dismantle more than just to get to the plus minus poles” - I.26	Black mass from scooters is bad due to entire packs being milled	Recycling	Impediment
"I believe in building locally. Building and repairing should be done locally... For example, we're going to build battery packs in Denmark. And they will repair them. So when something breaks, you send the battery back to the one who produced it. They inspect the cells. They have their own cell storage. They take these out and inspect them." - I.3 [Translated]	Decentralizing manufacturing and maintenance to be closer to the operating market allows more efficient and less costly repairs	Business Models	Application Operations
“When you find 18650s from Panasonic or whatever you find in there, those can be, I mean everyone that has any real user application, second life application, whatever they want to do, you can build a power bank from it, on the low end and you can go all the way up to battery energy storage system, maybe even up to something more advanced than this” - I.26	The cells inside (18650s or 21700s) are widely used cells	Building on 2nd life scooter batteries	Application Operations
"You can put them inside a battery pack that you can use for. Battery storage, yeah. Place some solar panels on them and you have battery storage... Maybe for small light towers" - I.9	Off grid street lights, solar + battery	Stationary	Possible Applications
“So there's new battery regulation going on within Europe that says that everything has to be open source. So in the future, we hope that we don't have to invest too much time anymore in that reference engineering part” - I.9	The new battery regulation will facilitate for the actors on the SLM	Possibilities for the future of SLM	SLM

Table 5. Examples of data-to-theory connections

In the interviews, the final questions asked to each interviewee was what possible application scooter batteries could be used for in a second life. With the large number of answers, the data was quantified to show the most frequently occurring answers. These are presented in table 6 below.

Possible Applications	Mentions	Reference
Portable ESS	6	I.5, I.6, I.7, I.8, I.13, I.27
Powerbanks	6	I.3, I.7, I.10, I.13, I.18, I.26
General applications on cell level	5	I.3, I.7, I.17, I.18, I.22
Smaller ESS	4	I.23, I.24, I.26, I.27
DIY-projects	3	I.3, I.10, I.27
ESS for homes/gardens	3	I.3, I.11, I.12
Light Towers	3	I.4, I.6, I.9
Refurbishment	3	I.9, I.14, I.21
BESS with slots for packs	2	I.10, I.14
Dock for micromobility	2	I.6, I.13
ESS for Peak shaving/Grid stabilising	2	I.8, I.23
Low intensity products	2	I.1, I.6
Balcony PV	1	I.14
Larger ESS	1	I.1
Low safety requirements	1	I.1
Mobile backup powerbanks	1	I.23
Tourist Applications	1	I.13
Tuk Tuks	1	I.16
Total	**47**	

Table 6. Frequency of Mentioned Possible Applications from Interviews

4.2 Case studies

The case studies derived from the reach outs that were made inquiring about interviews, leading to actual business cases where the researchers went into sales and business development meetings. The real life cases gave valuable insight to the study as they included EoL-management, insights into supply and demand of the scooter batteries and discussions about action plans.

4.2.1 Scooter company and Circular Asset Management system

This case study emerged from an interview the authors held with a global scooter company in Sweden. During the interview, it appeared to the researchers that the company had not yet looked into repurposing their batteries but had an interest in what Cling could offer them. The company had a solution for refurbishment and recycling but not on giving the batteries a second life. The authors saw this as an opportunity to both apply a possible business model to see if there was any interest in using it, but also to bring in a potential future client to Cling.

The proposal that was presented to the scooter company was a CAM system. The management system would be a platform on which the scooter company could upload their batteries and together with registering their logistical companies, solve the logistics of moving their batteries at EoL. On the platform, the scooter company would register all their warehouses where their batteries were stored. They would then be able to upload all the batteries that were taken out of use to the platform at their various warehouses. When the minimum quantity of shipping was reached they could simply schedule a shipping with their chosen logistical company. From here, Cling would then solve the logistics with the batteries to a repurposer, tester or dismantler that would give the batteries a second purpose. What Cling would offer with this system, other than an easy way for the company to keep track of their batteries, was also preparing the necessary documents needed for transport and tracking of where their batteries would end up. In this way, the scooter company could, via the platform, generate reports on how many of their EoL batteries that were sent to repurposing, recycling, refurbishment, etc. These presentations could then be valuable for the scooter company to showcase sustainability practices, which could be a useful asset to win tenders in cities or for investor relations. The platform would also allow Cling to keep track of the supply of batteries in an automated way, making it easier for the company to approach possible buyers.

The price model that the authors proposed was in the form of a subscription model where the scooter company would pay a fixed cost for using the platform x amount of months. To be able to tailor the platform and learn from each other, the proposal included a free trial where the scooter company would have the chance to try if this model suited them. Further, regarding the revenues from potentially selling the batteries, they would be split between both parts according to the price model in figure 23. The revenue sharing model was based on the idea of value creation by Cling, meaning that the alternative cost of recycling and therefore money saved for the company by Cling was factored in. In the example, by selling for 20 €/pack and with saved recycling costs of 10 €/pack, the value creation for the company was 15 €/pack and the same for Cling if the revenue share was split 5 to 15 €/pack.

2nd life example

Selling price:	+ 20€/pack
Recycling cost:	- 10€/pack
Clings´ share:	+ 15€/pack
Scooter company share:	+ 5€/pack

Figure 23. Example of price model of revenues from the CAM system

Since the company already had a solution for refurbishing and recycling their batteries, they were ahead of most scooter companies in terms of managing their batteries. Further, a decision like implementing this kind of system would require investments in both time and money. Therefore, the company was hesitant to commit to the service. However, the company of matter did show genuine interest and a possibility to circle back to Cling in the near future.

What the authors found through this case was that this kind of business model, with some modifications, could work as a CBM between a company like Cling and a scooter company. Moreover, it was interesting that a company, already having a better solution than their competitors for sustainable management of their batteries, still showed interest in this kind of model. This demonstrates that global scooter companies are open to finding solutions where their batteries go to repurposing, even though it requires an initial investment.

4.2.2 Scooter company and their batteries

This case study also emerged from an interview with a scooter company where it was clear that they did not have any solution for their batteries when reaching EoL. During the interview, the authors discovered that there were a large amount of batteries with broken pins or connector issues, that were currently just stored in their warehouse. The concerned battery was a typical scooter battery, as can be seen in figure 24 below. The cells in the batteries were most likely in good condition, since the issues were related to the electronics and not the actual batteries. As this was wasting both energy and money, the authors wanted to try to help them find a solution for their batteries. Since the volumes were not as continuous as in the previous case, the researchers decided that proposing the CAM system would not be economically feasible for either parts.

Figure 24. Scooter Battery.

Instead, the authors reached out to testers, repurposers and dismantlers within Clings' network to see if there was any interest in the scooter batteries. Offers came in and they were all different from each other. One offer came from a tester that proposed an extensive testing of 10 batteries that would generate valuable data for the company, increasing the price of the total quantity of the batteries. This process however, is expensive in both logistics and testing, as the manual labor of dismantling the batteries is time consuming. The interest for the tester of conducting this work was contingent on the future supply of batteries, as otherwise the time and effort put into the work would not be worth it. From both sides of the eventual trade there were clear downsides. Another offer came from a repurposer showing an interest in buying them. The repurposer agreed to receive a test batch of 10 batteries and cover the logistical costs. In return, the scooter company would receive a report on the batteries´ state and health. The upside in this trade was larger for both parties as the scooter company would get reports free of charge and the repurposer a potential supply of batteries to build on. The last offer came from a dismantler that, at first showed no interest since the batteries contained Chinese cells and were therefore, in his opinion, not worth the time and effort of dismantling. However, the dismantler was always on the lookout for cheap batteries and therefore wanted an offer on all the batteries as they were, untested and uncertain of the actual state of them. All the offers were proposed to the scooter company in order to see what they wanted the most. The objective of this strategy was to both understand the difficulty of trading batteries from electric scooters, but also to investigate the interest in them as well as what an actual scooter company wanted to do with their retired batteries.

One of the factors that aggravated the whole process was the lack of knowledge of what the batteries were actually worth, from the scooter company's side. The authors got the intention that the scooter company had the perception that the batteries in their warehouse were a huge pile of money. From knowledge of conducting the research together with internal experience from Cling, it was safe to say that this was not the case. The batteries were worth money, just not as much as the scooter company thought. The authors therefore sensed their disappointment when they proposed several offers to them, which was reflected in their sudden silence in communication.

The case study provided insights into the will of working with scooter batteries from different perspectives. For the tester, the process of dismantling the batteries was the challenging and most costly part, since the testing itself would take only a few seconds. Testing the batteries on pack-level would therefore be a very valuable first assessment, to make sure that the time and effort of dismantling to cell level is worthwhile. From the repurposers perspective, they were willing to accept the batteries free of charge to assess the possibility of building an application on them. Choosing batteries from micromobility was due to the much lower price compared to larger EVs. However, the repurposer expressed that ideally they would build energy storage systems on batteries without glue inside, since the plan was to dismantle and build on the cells instead of the packs. Ideally, this would mean building on electric mopeds, whose packs are bigger and do not have glued cells, according to the repurposer. The dismantler expressed similar reasoning, that the packs could contain good cells but that the price would have to reflect the costs associated with the time consuming manual labor. As a dismantler, the core business plan is to receive packs cheaply, dismantle to cell level and finally resell the cells. Naturally, the cheaper the packs are acquired, the easier they are to dismantle, and the better the cells are inside the packs, the more lucrative the batteries are. Scooter batteries containing good cells have therefore been sought after on the market from the dismantlers point of view.

4.3 Workshops

Workshops were held internally together with employees at Cling Systems. The objective of the workshops was to make use of the competence within the company and be aligned with the Cling-way of working.

4.3.1 Workshop 1

The objective of workshop 1 was to have an open discussion with the battery engineer at Cling. The authors went through the sheet of potential applications they had compiled, presented in chapter "2.2.2 Method for Workshops". The sheet was sent out beforehand to the battery engineer so that he could go through it thoroughly before the workshop. The first part of the workshop was then to further discuss the sheet and whether the battery engineer wanted to add any more to the list. After discussions, nothing more was added which meant that the list of applications used as the basis for the workshop consisted of 50+ applications. They were divided into three main groups of stationary, semi-stationary and mobile. Within these groups, there were subcategories. The list of possible applications was then walked through together with the battery engineer where he, from his technical perspective, gave each application a red, yellow or green flag. A red flag was given to an application that he thought was unsuitable to build from scooter batteries, from his experience.

The objective with the first workshop was to get a list of 5-10 possible applications where it could be technically possible to use second life batteries from electric scooters. The choice was mainly grounded on the battery engineers´ thoughts together with the input from the interviews that had been held by the authors. The number of applications with a green flag was above 10 applications, which were the intended maximum applications to go further with. Therefore, some of the applications were decided to be merged since they were very much alike each other in the technical requirements. For example e-scooter and e-bike were merged to "micromobility". The outcome of stage 1 was 13 applications from the initial list presented in table 2 in chapter "2.2.2 Method for Workshops", and are presented in table 7 below.

Mobility degree	Category of Application	Application	Source
Stationary	Charging docks	On-grid buffers for EVs	(2nd life battery applications)
		Off-grid availability (smaller hybrid systems with solar)	(2nd life battery applications)
		Dock for micro-mobility	(2nd life battery applications)
	Commercial	Solar Street Light	Interview
Semi-stationary	Mobile power supplies	Power bank for phones	Innov8
		Power stations for construction	(2nd life battery applications)
		Power stations for events	(2nd life battery applications)
		Power stations for RV, Campers	
		Power stations for emergency supply	(2nd life battery applications)
		Automotive mobile charging stations	(2nd life battery applications)
Mobile	Micro-mobility	E-scooter and E-bikes	(2nd life battery applications)
	Lightweight vehicles	Golf carts	(EV battery reuse)
	Autonomus robots	Robotic lawnmowers	(EV battery reuse)

Table 7. List of applications decided to go further with after Workshop 1

The reason for doing the first cut in a more speculative way, was because of time limitations of putting each application in the decision matrix, presented later. Further, since the workshops were not meant to constitute one final application, rather a result to use as a tool and compare with other analyses, the time it would take to metrically go through 50+ applications in the list would simply be too time consuming.

Further, using the experience from both the battery engineer and the insights from the authors, would make accurate enough speculative decisions at this step of the product development stage of electric scooter batteries in general.

4.3.2 Workshop 2

The point of stage 2 was to screen the initial 13 applications that came through from stage 1, with two metrics: Acceptance of risk of failure and safety. These parameters were chosen because they were considered the most important for second life deployment, reliability and safety. Stage 2 was initially not a stage that the researchers planned to take but since they noticed that the battery engineer used both the parameter of safety and acceptance of risk of failure in his reasoning during stage 1 the researchers decided to include this step. It was also a way to shorten the list in order to reach the goal of 5-10 applications to include in the decision matrix. The methodology of this step was inspired by the commonly used Failure Mode and Effective Analysis (FMEA) that is used as a proactive risk assessment tool that aims to identify potential failures in a process, product or system, and prioritize them based on their impact and probability (Visure Solutions, n.d.). In this case, the parameters "safety" and "Acceptance of Risk of Failure" were used as the parameters "probability" and "impact", respectively, that are actually used in a FMEA.

The 13 applications were scored on a scale of 1-5 for both parameters. The safety scoring was decided by the reasoning that an outdoor application received 3+ rating. From there, everyday contact with consumers was rewarded a 3, occasional contact gave 4 and no contact with consumer received 5. If the application was indoors, no contact gave a score of 3, occasional 2 and everyday 1. For acceptance of risk of failure, the scoring was determined through the question: what are the consequences of not delivering power? A 1 was given if people can be harmed, 2 if business interests were inhibited, 3 if outcome is not ideal but alternatives exist, 4 if good enough alternatives exist or that the end application is not very important and finally 5 if the end application is not important at all. I.e. a score of 1 was worst and 5, best.

The two parameter ratings were then multiplied together and a threshold score was chosen so that less than 10 alternatives were left. This resulted in 9 applications ranging from a score of 8 to 20. The list of the applications chosen to go further with (marked green) are presented in table 8.

	Application	Indoor/outdoor	Acceptance of Risk of Failure	Safety	Score
Stationary	On-grid buffers for EVs	Outdoor	3	4	12
	Off-grid availability (smaller hybrid systems with solar)	Outdoor	3	4	12
	Dock for micro-mobility	Outdoor	3	3	9
	Solar Street Light	Outdoor	4	5	20
Semi-stationary	Power bank for phones	Indoor/outdoor	4	2	8
	Power stations for construction	Outdoor	2	3	6
	Power stations for events	Outdoor	2	3	6
	Power stations for RV, Campers	Indoor/outdoor	4	2	8
	Power stations for emergency supply	Indoor/outdoor	1	2	2
	Automotive mobile charging stations	Outdoor	2	3	6
Mobile	Micromobility	Outdoor	4	3	12
	Golf carts	Outdoor	4	3	12
	Robotic lawnmowers	Outdoor	5	4	20

Table 8. List of the applications compared in Workshop 2 and the ones chosen to go further with, marked green

The objective of this step was partly to reduce the number of applications that were going to be assessed in the decision matrix. But also to, in an early stage, get rid of the applications that had the highest safety concerns and least acceptance of risk of failure. These two criteria were found to be very important for a SLA, especially made from scooter batteries.

4.3.3 Workshop 3

The third step in the workshop was to create a decision matrix that was inspired by the concept screening matrix presented by Ulrich and Eppinger (2014) in their book *"Product Design and Development"*. The matrix is mainly used as a tool for doing an objective screening of concepts from chosen criterias important for the function of a product in a product development process. In order to create the decision matrix, important criteria have to be set up. For this project, criteria to consider when building a SLA and considering the batteries coming from scooters, were set up and are described below.

The parameters that were chosen for stage 3 were decided on by the authors together with the battery engineer from Cling. The selected ones with explanations are listed below:

- Capacity Range (kWh)
  This parameter will determine suitability of using scooter packs/cells in the application due to the amount of packs/cells needed. If the capacity of the application judged was large, the score was negative.
- Voltage Range (V)
  A scooter battery is generally around 36 V. The suitability of using scooter packs for very high voltage applications is not ideal due to the amount of packs needed in series, leading to safety concerns.
- Max Discharge/Charge current (C-rate)
  For applications demanding high c-rates, scooter packs would not technically be able to meet those requirements, due to the c-rate of the packs. High c-rate requirements of the application were judged negatively.
- SoH Requirement (%)
  Generally if the application judged has a lower requirement on State of Health to operate, more batteries from second life can be used. Lower SoH requirement of the application was positive.
- Safety Requirement
  This parameter is judged similarly to stage 2
- Cycle Frequency (N/Year)
  Applications with high cycle frequency are less optimal than low cycle frequency for second life batteries, especially scooter batteries which have a lower cycle lifetime compared to other batteries. The scoring of this parameter was based on reasoning with the battery engineer, rather than precise data.
- Acceptance of Risk of Failure
  This parameter is judged similarly to stage 2
- Packaging Density

This parameter is judged on the importance of having high packaging density in the application. Some applications are more volume sensitive than others and building on pack level will lower the packaging density. Having lower requirements for packaging density is positive.

- Branding of 2nd life
  This parameter is used to determine the suitability in scaling and marketing or branding the use of second life scooter batteries in the application. If the consumer is impacted negatively by the product being second-life, the scoring was negative. Scoring was positive if the feature of the product being second life, added more value.
- Serviceability
  The serviceability of a product means how easily reparations and replacements are performed, for example can it be done by the user, does it require a professional and in that case how easy is it to service? High serviceability is positive.
- Battery Control
  This implies how much the manufacturer needs to know about the battery, such as the historic data. Having high control is positive, but requiring high control in the application is negative as the second life scooter battery may not meet this requirement.

Some proposed parameters that were removed included ‘Legal Knockout’, which did not have an impact on any of the included applications, but could serve as a discussion point instead. ‘Operating temperature range’ was removed as this factor was not as important as the rest of the parameters and also had strong correlations to charge/discharge. ‘Cost sensitivity’ was removed as the cost ratio battery to system was more precise and comparable. ‘Willingness to pay’ was initially used as second life products are difficult to scale and usually more expensive than expected. It was however removed since it, somehow, negated the ‘Cost - Battery to system’ - parameter which was seen as more important. Further, the vital values of it were covered by the parameter ‘Branding of 2nd life’. The last criteria that was chosen to be removed before finalizing the scoring in the matrix was ‘Cost - Battery to System’. The reason behind this was mainly due to the lack of knowledge with breakdown of the cost of each application, by the battery engineer and the authors. The amount of research needed to investigate each, and what *really* was inside them, cables, material, software, etc., in order to reach the accuracy for it to be reasonable to include as a criterion, was seen as excessively at this point. Also due to the actual uncertainty concerning the pricing of second life versus first life that is a big question itself.

After the criterias had been set, the first discussion between the three participants was whether the screening should be done on cell- and pack-level separately. With recommendations from the battery engineer together with the authors´ experience from interviews, the decision of making one screening for cell- and pack-level independently was made. Further, some criteria suggested by the battery engineer were even implemented in order to easier make the comparison between the same application but built on cell- versus pack-level, which supported this decision. At this stage, the criterion ‘Battery control’ was also removed for the applications on cell-level. The battery engineer motivated this by saying *“When building on cell-level, the manufacturer can basically decide herself how much control over the battery they want”*. Therefore, each application on cell level was given a “0” on this criteria.

In order to do the screening, reference applications had to be chosen for each screening (yellow in table 9). The reasoning here was to choose the application that the authors had in mind for the longest time out of the ones remaining. This resulted in "Dock for micro-mobility" being the reference application on pack-level and "power bank for phone" being the reference application on cell-level. Each reference application was then handed out "0" on each criteria and the other applications were then scored either "+" or "-" depending on if they were better or worse than the reference for each criteria. After the screening was done, each "+", "-" and "0" was added up and resulted in a net score. The application with the best score, one for cell-level and one for pack-level, was then considered the winner and used for further comparisons with results from the other analyses. The scoring was done on a reasoning technical level, with expertise from the battery engineer, rather than a quantified technical level. Each parameter was discussed by the three participants to reach an agreeable scoring from their experience and knowledge within the field. The two applications that scored the best are presented in the table below and the full decision matrix with every scoring is presented in Appendix B.

	Application	**Example**	**Cell Pack**	**Score**
Stationary	On-grid buffers for EVs	Link	Cell	-5
	Off-grid availability (smaller hybrid systems with solar)	Link	Cell	-2
	Dock for micro-mobility	Link	Cell	-1
	Solar Street Light	Link	Cell	1
Semi-stationary	Power bank for phones	Link	Cell	0
	Power stations for RV, Campers	Link	Cell	-2
Mobile	Micromobility	Link	Cell	-2
	Golf carts	Link	Cell	-2
	Robotic lawnmowers	Link	Cell	0
Stationary	On-grid buffers for EVs	Link	Pack	-8
	Off-grid availability (smaller hybrid systems with solar)	Link	Pack	1
	Dock for micro-mobility	Link	Pack	0
	Solar Street Light	Link	Pack	7
Semi-stationary	Power bank for phones	Link	Pack	-2
	Power stations for RV, Campers	Link	Pack	0
Mobile	Micromobility	Link	Pack	1
	Golf carts	Link	Pack	-2
	Robotic lawnmowers	Link	Pack	1

Table 9. Results from the Workshop studies

As presented, the two winning applications from the Workshop studies were solar street light both on cell- and pack-level. Before going into the analysis of these results, note that the results from the battery engineer through these workshops are subject to the authors involvement. The outcome could have been different if the original list and parameters were only chosen by the battery engineer himself or another battery expert. Further, worth mentioning again is that this is *one* perspective of possible applications through a more reasoning technical approach. Another engineer or researchers might have said differently or found other results that could be worth comparing to these results.

4.3.3.1 Explanatory comments on the scoring

The following chapter brings up a couple of short explanatory comments from the scoring done on the last workshop in the decision matrix found in Appendix B. The comments brought up here were the ones the authors felt most important and maybe not as self explanatory. Bringing up each decision on the scoring would simply not be relevant for the matter of this thesis. Especially since the results from the Workshops were just used as a tool to compare the results from the other analyses.

The battery engineer suggested that the criterias ‘Capacity range’ and ‘Voltage range’ should all be scored “0” on cell-level. The reason behind this is that when building an application on cell-level, the manufacturer has the opportunity to choose the capacity- and voltage range themselves. The authors agreed, but decided to challenge the battery engineer concerning one of the applications which was “On-grid buffers for EVs”. These applications are usually of bigger size and from the interviews, the authors had noticed that bigger systems are usually built on module- or pack-level. If they are built on cell-level, the cells that are used are usually more energy dense cells like pouch- or prismatic cells, not cylindrical ones. Since the cells from scooter batteries are cylindrical cells, usually 18650s, the authors thought that this application would score lower than the others. Therefore, “On-grid buffers for EVs”, built with cells, were scored “(-)” on ‘Capacity range’ and ‘Voltage range’.

When reasoning for the criterion “packaging density” on cell-level, a comment arose about the golf cart battery having lower requirements for packaging density than the other applications within the mobile section. This is due to the golf cart being a larger vehicle with more space to contain a battery as well as the fact that presently, golf carts use lead-acid batteries which are much less energy-dense than lithium-ion batteries, indicating that this application does not require high packaging density (Golf Cart Garage, 2022). Another suggestion from the battery engineer was that all the applications on pack-level should be scored “(0)” or worse on the ‘High packaging density’ criteria, since the reference application is dock for micromobility, which does not require building in a confined volume.

4.3.4 Workshop Interviews

As a concluding phase of the analysis concerning the outcomes of the workshop study, the authors opted to conduct interviews with battery researchers. The aim was to gather their insights and perspectives on the broader topic of repurposing second-life batteries from electric scooters, as well as delve into their views specifically regarding the applications delineated in Workshop 3 and the previously held interviews. Two interviews were held with battery researchers from two separate Swedish institutions and are referred to in the table below.

Battery Researchers			
Professor in smart electricity grids - power systems components	16/4-2024	0:41:06	W.I.1
Associate Professor, Materials and Manufacture	23/4-2024	0:36:43	W.I.2

Table 10. Reference list of Workshop interviews

In order to structure the feedback and findings from these two interviews, the same methodology as with previous interviews was used. The authors transcribed both interviews, took notes and consolidated key takeaways from each. The findings were then summarized using the Gioia method, described earlier, and are presented in figure 25 below.

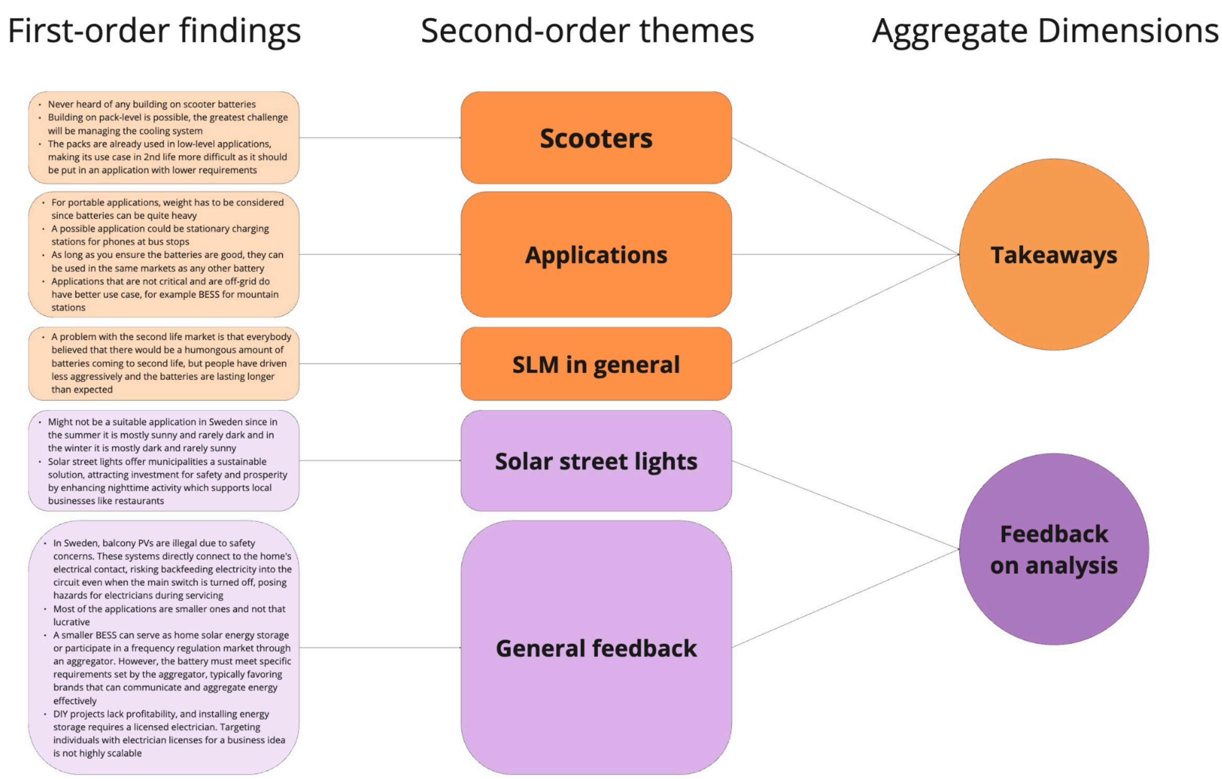

Figure 25. Data structure of the compiled findings from the workshop interviews

5. Analysis

In this chapter, the findings from the different qualitative research segments are collectively analyzed, to gain a holistic view in answering the research questions. Moreover, this section oversees the connections from the qualitative research and the literature review.

5.1 Scooter Battery Design

A big factor that determines the success of using scooter batteries in a SLA is how the scooter battery pack is designed for its initial use. However, from the interviews, it was gathered that the current battery design of scooter packs from the biggest producers, such as Ninebot Segway and Okai, use glue and epoxy between the cells in the pack, as can be seen in figure 26. The reasons for this are manifold; firstly, to provide structural integrity in the packs since the scooters are exposed to vibrations. If the cells are loose and vibrate within the packs, connections between them can release and cause severe safety problems like fires due to thermal runaways caused by various reasons, vibrations being one (Arora, Shen & Kapoor, 2016). Secondly, the potting of the packs seals them from exposure to moisture as well as aiding in electrical insulation. Since electric scooters operate outdoors and in fleet sharing operations are also stored outdoors when not in use, resistance to moisture and environmental conditions is crucial in the design. Thirdly, the addition of glue makes the packs very difficult to disassemble, which acts as a theft deterrent. Theft was expressed as a problem for some scooter fleets when experimenting with packs that did not have the same potted design.

> *"If one has problems with theft, then I set glue."* [Translated] - I.3

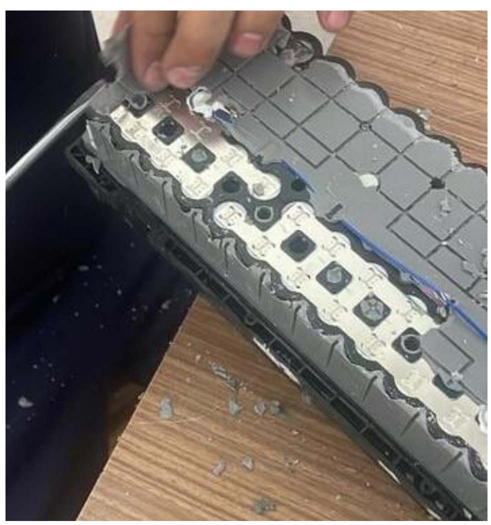

Figure 26. Electric Scooter Battery

The problem with this design is in the disassembly stage of the battery pack, as the measure to counter theft also leads to issues in extracting individual cells from the pack. This inhibits circularity efforts, both for eventual second life purposes, but also for recycling and refurbishment. One counter argument to using this kind of design in order to make the batteries more difficult to steal would be to make them more available instead.

> *Making the cells more available would "kill" the reason for stealing. Compare it with Spotify and The Pirate bay, making the cells more available at a cheap price would not make it worth stealing them.* - I.14

When the packs are potted like this, the time and effort it takes to dismantle to cell level is not worthwhile, especially if the cells inside are not high quality, brand name, like Panasonic or Samsung. A second life builder with experience from building with scooter batteries said that it is impossible to make a business case of using extracted cells from glued packs since the labor costs are too high for the capacity extracted. For example, a pack like the one above contains 90 cells with a total nominal capacity of 1 kWh (new) and takes a few hours to dismantle completely. Additionally, the disassembly process for this design poses a high risk of cell damage and poses challenges in extracting them for reusability, says a dismantler. As for recycling, this design also comes with challenges. From an interview with a battery recycler, the recycling process for scooter batteries was described, wherein the packs are only dismantled to reach the plus-minus poles to discharge the battery. After the battery is short-circuited, the entire pack with housing goes into the mill, which leads to a poor black mass. The recyclers interviewed also stated that the design of batteries is going in the wrong direction in terms of recycling purposes, since more glue and epoxy is being used.

> "*What you get in the end is not the best black mass because our target is to have a good black mass where you find anode and cathode materials inside, but not the foils, just the coatings. So that gets disturbed a little bit by silicon by plastic housings, but it's not worth the time economically to dismantle more than just to get to the plus minus pole"* - I.26

> *"Rather the opposite, it's going in the wrong direction. Concepts like sealed for life, cell to pack, cell to chassis, where very large amounts of epoxy paste glue are used."* [Translated] - I.27

Further, one of the recyclers also mentioned that the recycling of the scooter batteries is challenging in other matters as well. For example, since it has occurred that the batteries do not contain what is stated, which results in a contaminated black mass too impure for battery production and therefore goes to the steel industry.

> *Due to contaminations of other materials inside scooter batteries, there´s no chance of an industrialized way of recycling them back to scooter batteries. Most of it goes to steel industry.* - I.27

For refurbishment efforts, which bigger scooter fleets want to handle in-house due to economical reasons, this design is dangerous for the mechanics to handle and requires know-how, which minimizes the amount of batteries that can be refurbished.

> *"We do some basic stuff in house and we will be looking at expanding it. Yeah, a lot of the rework that needs to be done, it's kind of dangerous for in-house teams to do"* - I.21

For the future however, the EU Battery Regulation has included a point which could largely impact the design of scooter batteries, which will be applicable from 18 February 2027. It clearly states that LMT batteries (which includes electric scooters), should be designed for readily removable cells, which the current, standard design does not meet. How the Regulation is interpreted and supplemented with information will be crucial for the future design. In Article 11 paragraph 5, the Regulation (European Union, 2023) states:

> *"Any natural or legal person that places on the market products incorporating LMT batteries shall ensure that those batteries, as well as individual battery cells included in the battery pack, are readily removable and replaceable by an independent professional at any time during the lifetime of the product."*

Interestingly, there are companies already producing LMT batteries with no welding between the cells or glue/epoxy in the packs. Innovative companies like Gouach, who produce LMT batteries, and Vruzen, selling DIY battery kits without the need for spot welding or soldering also suitable for LMTs, could act as demonstration projects to support the Regulation in its decision making of how to implement these laws. Gouach have even announced that they will begin licensing their battery technology to industry players, which could exponentially grow the adoption of circular battery design (Gouach, 2023).

> *"The EU has created such a regulation that will come in 2027. So our project is that we want to collaborate with the EU. We want to try this in advance and show everyone that it works. If it works, then it could be that* [Scooter Fleet] *and others should use the new design."* [Translated] - I.3

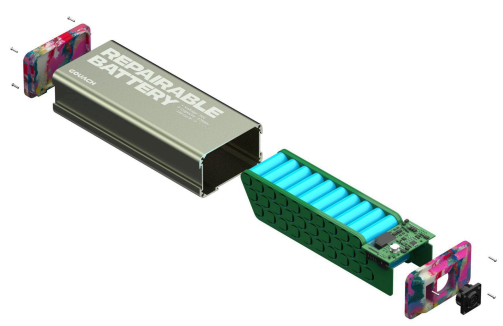

Figure 27. Gouach LMT battery (Left) (Gouach, n.d), *Vruzen DIY battery (Right)* (Vruzend, n.d)

The discussion around design for sustainability is interesting, as one end of the argument is the need for sustainability and circularity in a production line such as batteries, which is growing exponentially. On the other hand, design for sustainability can have negative implications on the usage of a battery in its first life, overlooking important factors like safety, economics and if the design increases the amount of repairs needed. Designing a product for repairability can lead to the product being in need of more repairs, thus mitigating the sustainability efforts that it was proposed to achieve. As stated in the chapter "Design for battery safety" in the literature review, the primary cause of durability failures for automotive batteries is the lack of vibration isolation (Arora, Shen & Kapoor, 2016). Removing the glue that is currently used in the battery packs will therefore have to solve the issue of vibration isolation for the batteries to be safe. The interplay of sustainability, economics, safety and regulation will be a leading discussion in scooter battery pack design in the coming years, the outcomes of which will set the conditions for repurposing and recycling.

> *"Just because some recyclers have a problem with it, I don't think that designed [sic] for recycling always is better than safety and always is better than, you know, economy and recycling."* - I.26

An additional challenge in the current design of scooter batteries for the shared micromobility market is the diverse electrical infrastructure and proprietary protocols used by various manufacturers. This divergence not only results in the need for different charging infrastructure, but also prevents interoperability between scooters deployed by different fleets, even if they are of the same make and model. Naturally, this discrepancy serves as a significant incentive for scooter manufacturers, as it complicates the transition to a competitor's products for the fleet operators, since they have invested in a specific charging infrastructure. Therefore, standardized charging infrastructure will more likely be the outcome of regulation rather than market incentives, similarly to the USB-C charger. For the locked protocols, this again serves as an anti-theft measure, as providing open access to the BMS makes the batteries a target. Scooter companies and other market players even mention that a standardized battery for micromobility would be ideal, to allow for battery swapping during its first life use but also for dismantling purposes at end of life. From the literature review on disassembly, one of the reasons disassembly is such a complex process is due to the many different types and forms of packs (Wu, Kaden & Dröder, 2023). With standardized designs, automated dismantling processes would be easier to develop.

> *"If you want to change the provider of the vehicles of your OEM provider, you have to switch all the electrical infrastructure. You have all the chargers, everything"* - I.13

> "[We] *get some same model of scrap battery. But this battery can't work at* [Other Scooter Company] *scooters. They are locked with the firm. This is very bad.*" - I.23

In conclusion, the design of scooter batteries plays a pivotal role in the dismantling process and by extension, the possibilities for repurposing and recycling efficiency. The use of glue and epoxy is a beneficial design element for vibration isolation, thermal control, moisture resistance and anti-theft. However, it makes the reuse of cells in packs almost impossible and lowers the quality of the black mass from recycling. A standardized battery design would facilitate collaborations in battery charging, refurbishing and dismantling but make the manufacturers less competitive. The future design of scooter batteries is uncertain, as currently more glue and epoxy is being used, but regulation could impact this greatly. In essence, the evolution of scooter battery design stands at the nexus of sustainability, safety, economics, and regulatory frameworks, requiring a holistic approach to meet the demands of both first life usage and end of life management.

5.2 Application Battery Design

Following the detailing of scooter battery design with the restrictions and possibilities that current and future designs pose on end of life treatment, building a SLA on scooter batteries can take two paths: using individual cells or entire packs. The case for using individual cells is largely dependent on if the pack uses glue or not. As mentioned earlier, a BESS builder with experience working with scooter batteries stated the challenges on extracting cells from glued packs and went on to say that if it is not needed to disassemble to cell level, one should build on packs.

> *"They are glued like inside the cell holders as well. And then that 's almost impossible. I mean it's possible but then you destroy all the, sometimes you destroy the cells or you destroy the isolation of the cells."* - I.11

> *"So then, we would find, maybe, a way to use the whole pack. I mean, why do we need to dismantle it when we can use it as a whole?"* - I.11

The main reason however for breaking down the pack to its component cells, is the design freedom you can achieve for the SLA. With building blocks on cell level, one is free to choose configuration which in turn means voltage and capacity. Secondly, the design can be made more compact, as unnecessary casings and such can be removed. Thirdly, the cells can be sorted and thus grouped together by performance so that the new pack is not limited by one cell. As mentioned in the literature review, the overall capacity of the battery pack is limited by its weakest cell. For second life products, it is not uncommon that cells have varying SoH and therefore limit the entire pack. Fourthly, design for repairability can be made at cell level, meaning that if failures to certain cells occur, individual cells can be replaced instead of modules or packs, leading to cheaper and more sustainable repairs. Fifthly, as portrayed in the literature, the cells used are cylindrical which have the advantage of not needing extensive protection in terms of casing and that they do not swell (Warner, 2015). Further the void between the cells when packed act as natural cooling channels (Warner, 2015). The advantages of building a SLA on cell level are numerous, but the current design does not make it feasible. If the design improvements for circularity discussed earlier are implemented in the future, the business case for using cells is much more reasonable, as the cells inside the packs can be of good quality and from reputable manufacturers. An incentive for the battery manufacturers to improve their design for sustainability is that it would use the "product use extension" CBM, seen as an important factor for creating a successful business, according to literature (The Smart City Journal, 2022).

> *"So the scooter packs, there is an advantage to them, which is the fact that they do need to be super energy dense because people have to carry their scooters around. So the packs usually have really good quality cells in them. "* - I.10

The high quality of the cells presents opportunities for constructing nearly any SLA around them, aligning with the prevailing consensus. The widespread use of the common 18650 cell, recognized as the most produced lithium-ion cell globally (Warner, 2015), highlights the high potential for repurposing scooter battery cells. However, this premise hinges on the precondition that the cells are indeed disassembled to the individual cell level. This, in turn, circles us back to the fundamental challenge of disassembly, namely the adhesive and welding used in the construction of the scooter packs.

> *The 18650 cells that are inside the scooter batteries can, in theory, be used to build anything as long as they are on cell level*. - I.10

> *As long as the scooter batteries are dismantled, you can do pretty much anything with the cells.* - I.17

Until design improvements for circularity, as previously deliberated is a fact, building on pack level is more suitable. However, SLAs on pack level have to compete with the alternative stream of refurbishing. If a pack is to be suitable for second life, it generally has to have functioning cells inside, where the reason for retirement is associated with faulty connectors or other electrical issues. From both an economical and sustainable aspect, the battery should in that case be sent to refurbishing streams over repurposing. Refurbishing extends the lifetime of the product in its original use case, saving scooter fleets money and requiring less material and workaround than repurposing. The scooter fleets however, do not currently have optimal solutions for refurbishing in-house, as it can be dangerous, requires know-how and is expensive. This is something that fleets are looking to expand on in their operations, which could imply that healthy scooter batteries that exist on the SLM today will stay within the fleets' own streams. Although this does not speak good fortune for the development of available volumes of scooter battery packs for second life builders, it is a convenient solution to minimize battery waste within the heavily criticized micromobility industry.

For healthy, retired batteries that do not end up in refurbishing streams due to reasons above such as lack of know-how or sufficient investment in in-house operations, repurposing is the natural best step, over recycling. Despite all the advantages of cell-level applications listed earlier, there are some perks of building on pack level. Building an application on pack level retains more of the original material, saving money on material costs and contributing to less waste. Keeping the packs as a whole can also be less dangerous to handle, as there is no contact with individual cell connections where short circuits are more likely to happen. Another benefit is that certain certifications from the batteries first life can be kept if the battery itself is kept intact. The scooter packs are also smaller compared to EV batteries which makes them easier to handle both inhouse and logistically, portrayed in the literature as a quite extensive and time-consuming operation (Epec Engineered Technologies, n.d) and should be considered a possibility with the packs.

> *Scooter batteries weigh less and are more easy to handle.* - I.7

A limitation for pack-level applications is the sensitivity to volumes of good packs and also with the correct voltages, as packs from different suppliers can differ in voltage which complicates the system architecture. Luckily, for scooter packs, most of the big manufacturers have the same operating voltage of 36V, but there are packs operating on 24 or 48V as well, especially in other micromobility applications. This voltage distinction influences the adaptability of the pack to various applications, such as solar storage. For instance, solar setups commonly operate at either 24 or 48 volts. Aligning the pack voltage with that of the solar system simplifies the system architecture. In the case of a 36 V battery, integration with a solar system would necessitate a DC-DC boost converter to match the voltage required.

> *"They do not have the common voltage for solar applications because solar applications used to have like 12 for this, 24 or 48 volts. And here we had 36 volts. So it was a little bit hard to find all the electronics or we also put inverters for example"* - I.11

> *"Scooter batteries are ok in pack level if they have standard ESS voltage (48v/24v) but 36v batteries are harder to use as is. Those are better for cell level repurposing"* - I.25

Another challenge with building an application on pack-level is managing the cooling which refers back to the importance of building an application that requires the same voltage.

> *Problem with building on pack level is managing cooling, especially if the power output is larger in the second life application. If the heat isn't handled the batteries will age much quicker and also be a fire risk of course.* - W.I.1

Being flexible to adapt to different supplies on the SLM is one of the biggest factors for success for a second life builder, as the market is so unsure and can fluctuate rapidly and unpredictably, also proven in the difficulty of securing future supply and actually financing it. All that has been discussed above needs to be considered for each new kind of battery you work with. A new type of battery might result in a new kind of BMS that has to be reverse engineered differently, a new type of cell that has to be configured in another way, or a different design which makes the pack difficult to fit in your current application.

> *Securing supply of batteries. Working with more suppliers means different batteries which becomes a challenge since their BMS all communicate differently* [Translated]. - I.6

> *Future volumes are an important factor to consider. Upfront costs when using different types.* - I.15

> *The discontinuous supply is a 2 factor problem, first one is actually being able to secure a similar supply for 2-3 years ahead and the second one is actually being able to pay for it upfront which is usually not the case.* - I.18

This finding was further confirmed by the battery researcher interviewed during the last part of the workshop.

> *A problem with the second life market is that everybody believed that there would be a humongous amount of batteries coming to second life, but people have driven less aggressively and the batteries are lasting longer than expected.* - W.I.1

One way to meet this challenge is to engineer a BMS that can communicate with different packs or cells. Many interviewees stated that one of the biggest challenges with the SLM is the closed BMS protocols, which makes it difficult to work with the batteries on pack level.

"They [BMS] are closed and you need special protocols to work with them directly." - I.11

When designing a SLA, the authors have identified three approaches to implementing a BMS in the system. The first is to use the BMS from the OEM that comes with the pack. In this case, time and money is required to reverse engineer the BMS to be able to control the battery pack. The advantage of this method lies in the control obtained by using the original BMS designed specifically for the pack. However, a significant drawback is the allocation of time and effort toward reverse engineering a single battery, limiting flexibility to adapt to changes in the supply chain. The second approach is to purchase an off-the-shelf BMS, which can be relatively inexpensive compared to hiring an engineer. However, this option does not offer the same level of freedom and control, as the BMS is not tailored for the specific battery. Additionally, currently there are not a huge variety of off-the-shelf BMSs to choose from and most of them are not CE marked, meaning they are mostly for hobby DIY-projects rather than commercial ones. The final approach is to develop a custom BMS from scratch. This is certainly the most time-consuming and possibly costly approach in the short term since it requires a lot of research and development to perfect. Nevertheless, the payoff is the control achieved, whether for a specific battery or for integrating different battery types into the system, thereby enhancing flexibility in response to changes in the supply chain. Additionally, the costs are high initially due to engineering development costs, but in the long run could show to be a cheaper option.

"We need to be able to match it price-wise, so we are eager to keep the cost of our project down, and as I mentioned, it's quite cheap to do things here [Portugal], and we need to have this flexibility [Designing their own BMS] for the module we receive." [Translated] - I.7

"Off-the-shelf [BMS] options aren't abundant, exactly. Those available are often not CE-marked, more like these hobbyist projects." [Translated] - I.7

5.3 Possible Applications

As presented in the literature review, the commercial segment of the global electric scooter market is expected to grow at an annual rate of 12.7% from the period 2023 to 2030 (Grand View Research, 2023). Shared mobility is an increasing trend in urban areas and governments across the globe are developing regulations that help the adoption of electric scooters. This development will see more electric scooters on the roads and potentially more retired batteries that can find an application in its second life. The analysis focuses on the commercial segment of scooter mobility due to the more organized collection and higher volumes of batteries compared to private use scooters. However, private scooters constitute over 60% of the global market (Grand View Research, 2023), suggesting that implementing organized collection schemes could enhance business cases in SLAs.

To prelude the analysis of the possible applications for SLBs from electric scooters, it is worth mentioning that a big part of the ones interviewed had never even heard nor thought of the possibilities of building a SLA on scooter batteries.

Had not seen or heard of scooter packs being a possible resource of batteries until he spoke with us [interviewers]. - I.7

Have not looked too much into working with scooter batteries since they [the company] have other priorities. - I.12

Despite this, a lot of interesting applications were addressed as possible SLAs. As mentioned earlier, a few interviewees had worked with SLAs from scooter batteries before, but faced challenges such as finding scalability or economics in them. These interviewees had only worked with packs that were not glued and therefore advantageous to work with. Interviewees I.10 and I.11 both extracted cells from electric scooters to integrate them into smaller power banks. Interestingly, this application was among the most frequently cited possibilities discussed in the interview studies, as outlined in table 6 of Chapter 4.1, "Interview Studies". According to both literature and interview findings, LMTs require high energy density but have low cycle life (Fluid Freeride, n.d), as represented in table 3 in 3.1.2.2 "BESS" (Volta Foundation, 2024, p.93). For a portable power bank for phones, high energy density is a benefit for the user, as it should be light and volume optimized to take up as little space as possible. As for the cycle life, power banks are generally not used everyday, as identified in this online survey (Simons, 2024). This implies that second-life scooter cells could potentially find extended longevity in the new application.

The other most frequently mentioned SLA from the interviews was a portable BESS, incorporating usage areas such as power supply for events and construction sites. While a high cycle life is not imperative given the potentially sporadic use of this product, it holds greater significance compared to a power bank. This is primarily due to the higher investment costs involved in its construction and its use case as a business product. A shorter lifespan would negatively impact the ROI due to the high depreciation, making cycle life a significant consideration for investors. The market is seeing a shift towards LFP batteries due to longer cycle life and that they do not contain critical raw materials like nickel and cobalt, making them cheaper to produce, as presented in the report by Volta Foundation (2024). Currently, most scooter batteries contain NMC cells due to the higher energy density and that cycle life is nott valued as much, thus posing obstacles for these applications. An intriguing point to note is that the only portable BESS making it to the final step in the workshop was the one for recreational vehicles (RV)s and campers. Surprisingly, it was not because of safety considerations; rather, it was the other way around. The decision stemmed from the realization that the willingness to accept the risk of failure was higher for portable BESSs intended for RVs and campers compared to those for construction sites and events. This was reasoned by the greater pressure typically placed on BESSs for construction sites and events to consistently deliver energy.

Figure 28. Example of Portable BESS (EcarAccu, n.d)

During the interviews, the second most frequently discussed application revolved around general cell-level applications. This interest likely stemmed from the widespread perception that the 18650 cells within the scooter batteries serve as a reliable energy source, as previously highlighted in the analysis. Yet, it is challenging to obtain further insights from this, except that the authors and the battery engineer deliberated on it during the workshops. This circumstance contributed to the decision to segment the scoring into applications at the cell- versus the pack-level. The analysis earlier delves into the fundamental question of whether building at the cell level is even feasible.

Shortly behind portable BESS, the most commonly mentioned application was smaller BESS or BESS for the home/garden. This kind of application has similar characteristics in terms of cycle life and production costs, with the exception that the usage is for private energy production and consumption, and therefore usually offers lower capacity, around 10-15 kWh (Dorfman & Drolet, 2024). One of the big differences with this kind of application, is that it usually can be placed in areas further away from people, such as in cellars, garages or outside, compared to the previously addressed applications. The safety concerns in this case differ from those associated with items such as a power bank or a battery-powered generator at a festival. This application could be compared to "smaller off-grid hybrid systems with solar" used in the workshop. A benefit with certain scooter batteries, as mentioned before, is that the voltage can be matched with the solar storage system, facilitating the design and potentially lowering the production costs. A BESS for home use, as mentioned by an interviewee, needs to be price competitive with new products from for example China, as this customer category is quite price sensitive. Lowering costs in every area possible is therefore key.

> *"It's inexpensive to buy from China. We need to be able to match that price-wise, so we're keen to keep the cost down on our project."* [Translated] - I.7

The cost advantage of purchasing products from China could stem from literature showing that setting up a gigafactory in the EU and North America incurs double the capital expenditure compared to China (Volta Foundation, 2024). However, initiatives of decreasing this gap have been made by offering favorable policies and support for battery manufacturers which could lead to lowering the production cost of applications like BESS, even more.

The applications mentioned all represent the different product categories of SLAs that were constructed in order to structure the possible application analysis. As portrayed earlier in the report, these categories were stationary, semi-stationary and mobile applications. Throughout the interviews and workshops, applications within all three categories were addressed. Occasionally, the interviewees genuinely supported, for instance, a BESS as the optimal choice. However, at other times, the authors perceived that the interviewees proposed a BESS as the best alternative simply because it is the dominant option in the SLM landscape, reflected in the increasing investments in that kind of application, portrayed in the literature (Volta Foundation, 2024). Sometimes, it was also the only application they were familiar with. The general perception was that, even though some answers were more repeated than others, there was no consensus on what application category was most suitable. As mentioned earlier in the analysis, regarding the quality of the cells, some reasoning was that you could build anything as long as the batteries were dismantled to cell level. Others rationalized that scooter batteries were like any other battery and could be used where you would need batteries. In several cases, the safety concern about scooter batteries was also brought forward, where the interviewees warned about applications close to consumers. This was evidently reflected in the workshops as well, since the second screening focused on the safety and acceptance of risk of failure.

> *As long as they are not on pack-level*. - I.3

> *Anything that needs batteries*. - I.21

> *Applications that don't have that high safety requirements.* - I.1

More interestingly was the interviewee that did not mention a specific application, rather a specific area of value that the application could contribute to.

> *Applications where the value around the function of the product is worth more than the actual function itself. Ex small lanterns that contribute to "Zero-vision"* [Translated]. - I.6

This statement sparked a discussion between the authors and the interviewees of possible applications being the ones that offer *more* value than only the functional value. For instance, it was during this interview, the street light connected with a solar panel was mentioned for the first time. This application would then also prove to be the most suitable application, both on cell- and pack level, during the workshops with the battery engineer. An example of the two cases can be seen in figure 29 below. A solar street light equipped with an external battery is optimal for a pack-level configuration due to its lower packaging density requirement. Unlike a cell-level design, this setup allows for achieving a higher storage capacity, providing notable benefits, particularly in areas with limited sunlight. The increased energy storage capacity facilitates more frequent usage, enhancing the system's performance. A cell-level integrated battery is highly optimized in terms of volume and does not occupy any extra ground space, which enhances safety by minimizing contact with people. When the application was discussed with the battery researchers in the workshop interviews, it was suggested that it may not be a suitable application in northern countries like Sweden. This is because in the summer it is mostly sunny and rarely dark, mitigating the need for a street light. Conversely, during winter, it is rarely sunny and mostly dark, posing challenges to power them with the solar panels. Furthemore, as a second life product, solar street lights provide municipalities a sustainable solution while simultaneously enhancing safety for pedestrians and street traffic. The long term benefits of this investment can lead to increased nighttime activity which itself holds societal benefits. The value created around the product is therefore larger than just the product in itself, ultimately yielding a sustainability premium to a customer group (municipalities) which is not solely price-oriented.

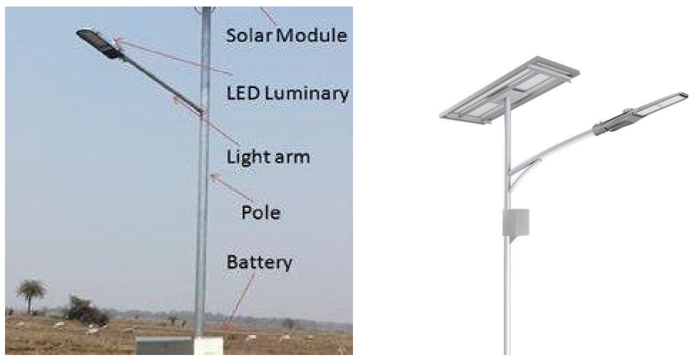

Figure 29. Solar Street Light, with External Battery (Left) (Mohapatra, 2017)*, with Integrated Battery (Right)* (MK LIghts, n.d)

Other applications that were mentioned which brought value around the product were off-grid storage systems for mountain stations or stationary charging stations for bus stations. In these cases, the battery researchers noted that one advantage was the non-critical nature of these applications for an individual or a business. Instead, the branding of using second-life batteries could be used to its advantage rather than impeding its business case.

Building an application on SLBs from scooters utilizing the possible PR-value it could generate, was something the authors had in mind early in the process. A possible application of this caliber could be repurposing the scooter batteries into charging docks for the electric scooters. This was mentioned a couple of times during the interviews as well as scored quite high in the workshops. Implementing charging docks for scooter fleets offers several advantages. Firstly, it enhances parking organization (Bolt, 2022), a crucial factor in tender applications. Secondly, charging docks reduce battery transportation, eliminating the need to shuttle them between warehouses (Bolt, 2022). These docks also serve as a buffer, enabling scooters to charge directly from stored batteries while they're docked, with the batteries replenished during periods of inexpensive, green electricity. The marketing potential of such an application should not be overlooked. One concern with them however, was the building permits required and the possible issue with which scooter companies would be able to charge their scooters in the docks.

> *Regarding the charging docks connected to parking, there are problems with building permits as well as political issues concerning whether these should be open for all scooter fleets or just the one placing it.* - I.19

While the PR-value has the potential to generate substantial revenues, or marketing value for such an application, it is evident that it would necessitate collaboration among various sectors of the industry and municipalities for it to be feasible. One could argue that such cooperation may be premature in the nascent market of SLBs from electric scooters.

Besides the projects of building power banks, the authors came across other endeavors of people building applications of SLBs from electric scooters. One was a retrofitter that had converted an old vintage motorboat into a fully electric boat. For that specific boat, he had used 1200 scooter batteries on cell level, remanufactured into new, larger battery packs. Without knowing the exact model and design of these batteries, it was elucidated that the batteries used for this specific project had cells that were easy to extract.

> "*Were inhouse batteries, so cells were easy to extract"* - I.21

Despite demonstrating its technical feasibility, skepticism remained predominant regarding the potential to expand this type of production.

> *[The project was] Due to PR, difficult to scale up. It´s a company boat. EV batteries would make it easier to scale up since you could work with modules and not having to dismantle to cell.* - I.14

He then went further bringing up two further challenges, apart from the ones explicitly portrayed earlier in the analysis.

> *Building applications on a scalable level means competing with the bigger players.* - I.14

> *People´s perception of everything that is second life is also a challenge for the SLM.* - I.14

Given the prevailing economic challenges of repurposing SLBs from scooters, competing against bigger players, generally having larger capital, is obviously not a smart business model for a smaller player. With that said, initiatives like the ones building power banks and boats showcase that it is possible, which could lead to others venturing into similar projects. If not for making money, projects building on SLBs on electric scooters could generate other values in the form of PR as also stated by the interviewee, which can be seen as an investment in marketing rather than a cost.

5.4 CBM for scooter batteries and Cling

As stated by Pietrulla & Frankenberger (2022), a CBM is a business model that has emerged from the older, more conventional linear ones. With any change, comes new challenges that have to be faced, especially in the beginning of such change. Pietrulla & Frankenberger (2022) states that a CBM faces both social and environmental challenges which the authors encountered during both case studies. The concept of a CBM is to use already existing material or reuse products in order to decrease the environmental footprint of the business activities. Moreover, the literature emphasizes the importance of shared value, collaborative growth and overall more value creation through synergies. However, in order for these synergies to take place, all involved parties have to feel that the value they get is more than the value they are putting in. In a market situation as for the scooter batteries, that is still immature, there is not always unanimity. This fact played out its role during one of the case studies “Scooter company and their batteries”. During one of the conversations with the company, the authors sensed that the perception of what their batteries were worth was higher than what the market was willing to pay for them. As stated in the findings from that case study, the authors believe that was the biggest reason for the scooter company not answering when various offers were sent to them. The justification for this could come from the market still being immature which can strongly be related to one of the findings from an interview with a BESS builder.

> *“The market is so young, the ones owning their batteries want to be “smart” with them, they want to keep them.”* [Translated] - I.6

The interviewee refers to batteries coming from EVs. However the relationship between scooter batteries and EV batteries in terms of the behavior of the owner, in such a case as described, is not far fetched according to the authors. To refer back to the literature, in order for a CBM to be successful, collaborative growth and value creation through synergies, have to be present. In this case, one of the parties experienced that the value they contributed, was more than what they would have received. An example of that the implementation of a CBM faces both social and environmental challenges, especially for a young market as with second life scooter batteries. A young market in the sense of for example the pricing of batteries being set by individual actors which is addressed in the literature.

Acknowledging the challenges stated and proved above, there are still opportunities for implementing a successful CBM, especially since the SLM is still young. With an increasing LiB market, as presented throughout the literature, the demand of suitable CBMs specifically designed for each case of battery has intensified. Chirmulla et al. (2023) brings forth three criterias that identifies, characterizes and categorizes different CBMs for second life batteries in specific:

> **Resource flows**
> This criterion aims to optimize resource flow in a closed-loop system, boosting efficiency, cutting waste, and lessening environmental impact in production and consumption.
> **Collaborative ecosystem engagement**
> This criterion assesses companies' involvement with external stakeholders to jointly create value for battery circularity. It measures the level and type of collaboration (open, semi-open, or closed relationships) needed to optimize resource flows, exchange knowledge, and collectively promote circular initiatives.
> **Ownership dynamics**
> This criterion evaluates the influence of ownership structures on circular product-service combinations. It classifies businesses based on ownership and emphasizes the connection between ownership, governance, and product-service strategies.

The study then uses these criterions to ascertain three main archetypes of CBMs that are extending, sharing and looping that have substantial outcomes for the business. The outcomes encompass value proposition, co-creation, delivery, and value capture, along with the collaborative agreements with stakeholders shaping how value is generated, delivered, and retained. Chirmulla et al. (2023) goes on emphasizing the importance of the responsibility of each company to then choose the right architecture, or even designing their own by combining them, in order to reach competitiveness. Together with tuition from Cling, the authors went through and attempted implementing a possible business model for the company in a real business case with a scooter company. The case is referred to as "CAM system and scooter company" and is thoroughly described in chapter 4.2 Case studies. Creating this business model could be seen as a combination of all three architectures described in the literature. One of the focuses of the CAM system was to facilitate for the scooter company to manage their batteries by listing them on the management platform, which would align with Cling´s current business model (Cling systems, 2024). While still allowing the company to run their existing refurbishment operations with their partners, Cling would add the value of sourcing repurposers for the batteries as well, giving them a possible second life. Further, for the batteries neither going to refurbishment nor repurposing, they would be sent to recycling. Currently, recycling stands as the primary method for scooter battery disposal despite its high cost. Many recycling processes yield less value than they consume, with cobalt being the only material of significant worth, as highlighted in the literature. This raises questions about the efficacy of recycling, especially considering the contaminated nature of the resulting black mass and the increasing production of LFP batteries, which do not contain cobalt. Furthermore, inadequate recycling regulations and significant safety concerns, as depicted in the literature, suggest a need to reconsider the hierarchy of scooter battery disposal. While refurbishment emerges as the initial preference, there is growing support for repurposing before recycling, as indicated earlier. By allowing existing operations within the company to continue, the CAM system would follow the *extending* and *looping* CBM architecture described in the literature. Moreover, since the batteries would be uploaded on the management platform, this allowed Cling to access the scooter company's current battery fleet. The third architecture of *sharing* would therefore also be incorporated through this business model. In this way, the scooter company could focus on their main business while Cling could contribute with their core competence. Leveraging Cling's expertise in SLM and the intricate logistics of batteries, as demonstrated by Epec Engineered Technologies (n.d), along with their established customer base, would enable them to co-create value effectively. Additionally, with the capability to produce critical documents and reports using the CAM-system, such as determining the ratio of batteries destined for repurposing versus refurbishment, the system could significantly strengthen the scooter fleet's competitiveness in securing tenders in new cities, as portrayed in the literature. Unlike the literature, the authors however found that sustainability, currently, was not the priority in winning tenders. Instead, the ability to show safe operation and proper parking of the electric scooters were more important.

> *Proving sustainability is not an important factor to operate in a city. More important to prove safety and that they are parked properly.* - I.22

The authors created a pitch deck that was sent to the contact person at the scooter company and that was supposed to be forwarded internally. What was captivating with this case was that the company in matter, actually already did have a solution for their batteries today that worked quite well for them, but still showed interest. Something that could indicate potential interest in this type of business model within the industry.They had not looked into *repurposing* the batteries yet, mainly due to lack of knowledge of the possibilities, and therefore needed time before circling back. The scooter company, however, did not get back within the time the authors did their internship at Cling and the business case could therefore not be pursued.

As the reader notices, unfortunately none of the case studies that the authors initiated were completed. There could be many reasons for this but the literature brings up and classifies barriers towards implementing CBMs and that they are strongly connected with the drivers. Apart from the obvious barriers like high investment costs and mindset issues, the drivers that the research describes are cognitive, dynamic capabilities and "other" drivers. Cognitive drivers being summarized as the overall commitment and communication of sustainability matter from top management making sure it is aligned with the company mission. Dynamic capabilities being processes and features within the business that respond to changes in the environment such as the increased risk of climate change. Lastly, "other" drivers being categorized as different organizational structures aiming for short response loops as well as high flexibility. The authors could see all these drivers being a possible barrier for both of the case studies described above. The most rational reason would be a combination of all. Since implementing repurposing would mean a change in their operations, a decision like that would affect many parts of the company. The more people involved, the higher the risk of encountering any of the barriers described in the literature.

Except for the sharing architecture addressed in the literature acting as a business model where the different parties allow access to vital information in order to create synergies and increase value, it also characterizes that the sharing architecture could use "product-as-service"-models in order to decrease the demand of new products as well as the demand of finite resources. The literature describes that the value proposition of this kind of CBM could be accessing batteries through a leasing model and the co-creation of value would be allowed through for example trading platforms. Interviewing different actors on the SLM, the authors were informed that using a leasing model for a second life application would be the most suitable. Not only due to the fact that it allows you to keep material in the organization for a longer period of time, which could be more valuable in the future. Also, it allows you as a company to not have to worry about pricing towards first life applications as much. As second life applications are new to the battery market, real benefits of scalability are yet to be seen and therefore pricing compared to new batteries is not as competitive as could be expected. Further, by keeping the ownership of the product, you do not have to worry about warranties.

> *A suitable business model for second life storage systems is a leasing model since the price can be kept at the same level as a corresponding 1st life storage since it delivers the same value for the customer. By keeping ownership as well, the company doesn't need to provide warranty to the customer, and can service the application (exchanging bad modules/packs with other second life ones) continuously.* [Translated] - I.16
>
> *Customers buying the application are very price focused.* [Translated] - I.6

Not having to worry about warranties was found to be a possible advantage as well. Since one of the challenges of the SLM was found to be the fact that the SLM is a warranty free environment.

> *Warranty is a challenge, we cannot give full warranty atm, ex determine the SoH more exact than now.* - I.9

Sincet the SLM is a warranty free market, substitutes for providing some kind of security to buyers have been implemented. The most usual is providing test results that prove certain data of the batteries. Testing has therefore become the norm but it is however not a standard yet due to it still being so expensive.

> *Using testing results has been kind of a workaround method instead of using warranties. However, this is very expensive and not a standard yet.* - I.4

However, just because the batteries are being tested, does not necessarily mean that they are more valuable since there are no standards in testing.

> *How to grade the batteries that come in, which is related to challenges with testing.* - I.8

Testing of the batteries can be done on different levels, either on pack-, module- or cell-level and depending on what level you test on, different data is more important than others. It is also a case of differences in what type of data you can extract from tests done on different levels as well as the complexity in performing the testing.

> *Primary data points requested are different from cell- to module level. Cell level is more condition and safety concerning and module level is more capacity and lifetime concerned. The latter data points are more complicated since they are more a phenomenon of aging rather than "real data".* - I.24

Depending on what level you want to perform tests on, you will need to disassemble the pack into modules or even modules into cells. This adds even more complexity to the operation since disassembly is an expensive and complex process itself, as described in the literature. Earlier in the analysis the authors also portrayed the challenges with disassembling the scooter batteries due to challenges in design, aggravating creating a prosperous CBM. In the literature, the authors present research that brings up key elements for a successful CBM. One of the key elements is designing a smart distribution model where the designers have an important role in understanding actual customer needs and the value that the company provides - and what customers are willing to pay for. With customers being very price focused and with a general perception that second life applications should be cheaper than first life applications, it is necessary to cut costs to successfully work with scooter batteries.

> *Customers are willing to pay less for a 2nd life product than a 1st life.* - I.9

> *The products we´ve sold were usually more expensive than what the customers were willing to pay.* - I.11

The easiest areas to cut costs could be the areas where the expenses are highest. As described above, testing and disassembly are two operations that cost a lot and that are very much connected with each other. With this said, the authors have detected a possible "Gap-exploiter"- model, that is a sub-architecture explained as part of the main architecture of sharing, in the literature. By incorporating operations, such as testing and disassembly, either inhouse or at least locally, a company building on second life could cut costs or at least control and devine them better.

Dismantle in-house in order to get a business case out of using smaller batteries. - I.8

Battery manufacturing being more decentralized and local, opening up greater possibilities for airing and 2nd life activities in general, being more economically feasible. - I.3

Not only would the company be able to control the operations better, they would also be able to source batteries cheaper since untested batteries cost less which became obvious during one of the case studies. Integrating testing and disassembling operations in your business operation would require more know-how as portrayed in the literature which in terms would lead to higher initial costs. However, with signs of the SLM developing in terms of new technology, these costs and know-how could decrease in the future.

With our groundbreaking way of testing batteries, they are able to provide a scalable testing solution for them. - I.24

They are working with [company name] that have developed a technology that is supposed to automate the dismantling process of scooter batteries. - I.26

With possible automated disassembly- and testing technologies, the operation could decrease time by a lot, as the literature portrays it did with the gripper system (Wu, Kaden & Dröder, 2023, p.14). However, for the disassembling process to be more automated, it requires that the batteries are somewhat standardized or at least are constructed in a similar way. This is usually not the case in general on the SLM. As stated earlier, one of the greatest challenges, affecting multiple parts, with running a business on building an application on SLBs is the lack- and uncertainty of continuous and homogeneous supply. The kind of issue in inhomogeneous supply is one of the problems that people hope and think require regulations in order for it to be controlled. Others also strongly believe that this problem is a matter of immaturity of the SLM and that as the market matures, more parameters will be set.

SLM is maturing more and buyers know more where to look and what kind of supply they want. - I.17

An interesting finding related to the supply of scooter batteries that could be a possible solution to the issue with inhomogeneous supply is that people believe the volume of them is large.

The scooter batteries are high in quantity. - I.10

There´s a great volume of scooter batteries out there. - I.18

There´s a great volume of the scooter batteries which makes a case for 2nd life use. - I.27

This finding could be further strengthened by literature that predicts a larger electric scooter market by 2030 which would result in an even larger volume of batteries (Grand View Research, 2023).

The battery regulation that, step by step, will be implemented in the coming years will surely affect many things on the SLM but exactly how, is still uncertain but the expectations are that it is for the better.

> *We do know of regulations and certifications but not sure exactly which of them is going to affect our product*. - I.7

> *Battery regulation will be the first step towards a more regulated and standardized SLM.* - I.7

As presented by the European Union (2023), the implementation of the battery regulation will take time and the effects from it will probably take even longer. The EV batteries are a priority which is proven by the regulation for LMT- (including scooter) batteries having a separate plan for recycled materials and will first be included by year 2033, 8 years after EV batteries. This will slow down the whole process of regulating the SLM for scooter batteries making it even more important to design a CBM taking the future effect of the battery regulation into consideration.

> *Since the effects of the battery regulation will take a couple of years, it's important to build a business model that stands over time.* - I.12

One vital part of the battery regulation that will have a high impact on the SLM is the battery passport. According to (European Union, 2023), the passport should enhance the transparency between stakeholders by enabling exchange of information, tracking and tracing information on carbon intensity during manufacturing. It should disclose origin of materials, composition including raw materials and use of recycled material, if the battery has been repurposed as well as other relevant information. The passport will be in the form of a QR code on the batteries and will be applied to both EV- and LMT batteries by February 2027. The battery passport will also include data on expected life time in terms of number of cycles, rated capacity, manufacturer and place of manufacturing, weight etc. As touched on earlier in the analysis, exactly how this passport will affect the SLM is uncertain but the fact that it is going to be in a positive manner and increase the overall circularity, is a common perception that the authors have gotten during the interview study.

> *Positive trends for the 2nd life market will come due to battery passport.* - I.1

As for now, it is stated that the information in the battery passport should be made accessible to people with "legitimate interest", which is not fully defined yet. The literature, European Union (2023), explains that people seen as having legitimate interest are people who have bought the battery or parties acting on their behalf for the purpose of making the battery available to independent energy aggregators or energy market participants, evaluating its residual value or remaining lifetime or remanufacturing of the battery. Furthermore, the literature portrays that already from 2024, information from batteries such as SoH and expected lifetime should be attainable from the BMS of stationary BESS, LMT and EV batteries. Essentially what the battery passport and the battery regulation will do is to allow a more open SLM of batteries where more data is shared. This will facilitate creating an economically feasible CBM since a lot of the more difficult and expensive operations, such as testing and dismantling discussed above, will not be as vital.

Data sharing would help lower importance of testing and dismantling. - I.15

It is safe to say that one of the biggest concerns when it comes to building a CBM on scooter batteries are the costs compared to the expected revenues and extracted capacity with them compared to EV batteries.

Began work with scooter batteries but went more towards EV batteries since it's more economically feasible. - I.10

Then, if the battery passport decreases the importance of testing and more technologies on automated dismantling increase, that could advocate for building on scooter batteries in the future, being a potentially successful business. Another interesting subject to point out, as addressed in earlier analysis, is the potential PR value generated by working with scooter batteries. This could be seen both as an obstacle and potential for creating a CBM around scooter batteries. Scooter batteries are usually cycled hard and are not treated in the best way by the users which gives the batteries a bad reputation.

Scooter batteries have a bad reputation due to the way they are abused in their first application. - I.18

Scooter batteries have got bad PR since a lot of them have caught on fire. However, does not mean that all scooter batteries are bad. - I.5

As the last interviewee mentioned, just because some of the batteries are bad and have lived a rough life, not all of them have. It is safe to say that to treat all scooter batteries the same way is not fair. Especially since building on "the problem child" of the market could generate more value to the application in the form of PR-value, especially for the scooter fleets.

The potential PR-value of building on scooter packs could make the business case interesting. - I.9

Viewing a possible business model for scooter batteries in this way could also contribute to the cognitive driver as mentioned in the literature as one of the important catalysts for a successful CBM. Emphasizing the fact that working with scooter batteries could bring more value than just functional ones, could facilitate the communication of sustainable matter for a company both internally and externally. Further, by then bringing up another driver for a successful CBM addressed in the literature, dynamic capabilities. Creating a business model that encounters the SLM for scooter batteries in a holistic way and responds fast to possible future changes, could speak for scooter batteries being a strategic successful area to invest in.

6. Results

In this chapter, short summaries in the form of results from the analysis chapter will be presented and consolidated.

6.1 Possible applications for SLBs from electric scooters

Below, in table 11, the results of the most mentioned applications during the interviews and their compared results from the workshops, are presented. In Appendix C, benchmarking for different products within the result categories can be seen.

Type of application	From Interviews	From Workshops
Powerbank	Tied most mentioned	2nd best on cell-level
Portable BESS	Tied most mentioned	For RV and Camping, tied 3rd best on pack-level
Smaller BESS (10-15kWh)	Third most mentioned	Tied 2nd best on pack-level
Street light/Light tower	Tied fourth most mentioned	1st on both cell- & pack-level
Charging docks for micro mobility	Tied fifth most mentioned	Third best on both cell- & pack-level

Table 11. Results of possible applications from the analysis

6.2 Challenges & possibilities with the scooter battery

From literature, the majority of the batteries used in the electric scooter from the micromobility companies are from battery manufacturers coming from China or other countries in Asia (Grand View Research, 2023). From findings, it has been shown that these batteries are using glue and welding to bond the cells in the packs. This aggravates the dismantling and requires a lot of time and manual work for little capacity extracted from the batteries compared to for example EV batteries. This also makes the dismantling process more dangerous and the cells extracted are usually non good-looking which obstruct the selling process of the cells.

The design of scooter batteries not only amplifies the level of complexity but also presents a challenge due to the diverse array of designs offered by various manufacturers. Furthermore, this diversity in supply leads to fluctuations, which in turn impede standardized and predictive battery handling, ultimately hindering scalability.

There are several advantages associated with these batteries. Firstly, they typically fall within the same voltage range, which simplifies system architecture. The high volume of scooter batteries could ensure a steady supply, while their small size makes them easier to handle logistically compared to larger batteries. Lastly, EoL issues usually arise from connector problems or electronic faults, resulting in a relatively high SoH.

6.3 CBM for electric scooter batteries

The CAM system is a CBM that has high potential when working with scooter batteries from the micro mobility fleets. Not only does the business model gain strength from all three architectures presented in the literature. It also allows a company like Cling to be flexible and adapt to the upcoming battery regulation in terms of the documents the described CBM could help provide.

When it comes to constructing an application using SLBs from electric scooter batteries, it was found that employing "Product-as-a-Service" models proved to be the most effective approach. Not only did it allow it to keep the material in the organization, it also allowed it to undergo the competitive pricing challenge towards first life applications. Further, by using a leasing model for the product, warranties are not as much of an issue. Since warranties are tough to get, this strengthens this type of business model even more.

The lack of warranties have instead sparked the importance to present test documents. Testing is usually strongly connected with dismantling which are two operations that should be kept as close to core business as possible. This allows the company to cut costs and control sourcing and pricing of batteries better.

The SLM is immature and a lot will facilitate operations along with the implementation of the battery regulation. More value flows will be standardized and the market will be more predictable. Unfortunately, the SLBs from electric scooters are not as prioritized as the ones from EVs, in terms of when certain regulations around them enter into force.

Scooter batteries have had bad PR due to failures that have resulted in bad exposure. All batteries are however not bad and the fact that they are seen as “the problem child” on the SLM could also be an opportunity to expand upon. The potential positive PR-value that building on SLBs from electric scooters could generate should be acknowledged and not disregarded.

7. Discussion

The following chapter deals with the final discussions and conclusions from the authors that they felt were worth bringing up and contributing with for the further research of the SLM of scooter batteries. Moreover, the reader will also follow some thoughts of the research in its whole, what challenges the researchers met and so on.

7.1 Clings´ contribution to the future of SLM of electric scooter batteries

One prominent issue discussed in the analysis pertained to the design challenges associated with scooter batteries, particularly concerning the gluing and welding of cells. Given that addressing this challenge is perceived as paramount when repurposing second-life batteries from electric scooters, it is prudent to initiate a discussion on pivoting towards a more sustainable design direction. The rationale behind constructing the batteries in the current manner revolves around two primary arguments. Firstly, it is intended to enhance their durability and resilience against the vibrations encountered during electric scooter operation. Secondly, this approach is motivated by safety considerations and the aim to enhance theft deterrence of the batteries.

Both arguments are important and related to this discussion, however more focus will be put on the second one for this specific parable. The authors have identified a potential counterargument that could exert pressure on battery manufacturers. This argument also promotes the idea of a second-life market where all stakeholders collaborate to enhance its effectiveness. Further, it very much relates to Cling and their role and what they can do to play their part towards a better SLM. As cited in the analysis of the challenges with the design of the scooter batteries, and them being less glued and welded would make them easier to steal. One interviewee brought up the possibility of killing the reason for stealing by making the batteries more available and establishing a price on them. He then went further on comparing this situation with what happened in the music industry when Spotify became big by making streaming of music more available.

Before Spotify, piracy of downloading music was a huge thing and the website “The Pirate Bay” dominated the piracy industry, almost destroying it. Spotify however, created a product that was so good that consumers began paying for music again. Reports indicate that global music piracy declined 65% from 2017 to 2021. Considering the fact that piracy only has become easier over the last year, that is quite extraordinary numbers. Much thanks to technological improvements and Spotify reaching a product-market fit, the consumers of music began willingly paying for the product they were previously getting for free. This is a clear example of a business with product-led growth and pricing power (Mensa, 2023).

The role Spotify has with counteracting theft of music could in many ways relate to the role of Cling and their product offsetting the theft of scooter batteries. The marketplace Cling has created for SLBs allows the market to put a price on the batteries as well as a more sophisticated way of tracing them. This could play out its role in the same way as Spotify's product did on the theft of music. This parable should be considered as an incentive for the battery manufacturers to begin working with companies like Cling and use the power of their product to reconsider the design choices of their batteries in their scooters. Using less glue and welding in the construction of the batteries will for sure facilitate the repurposing of SLBs from scooters, making them more valuable at end of life. With companies like Gouach in France, it is proven that the technology and innovation urge of creating a more sustainable design is there which should be brought to the prominence more. The skepticism that the authors faced with Gouachs´ innovation, should instead be met by optimism and willing-to-help-by-trying attitude. Thanks to companies like Cling and Gouach, the same evolution as with the music industry is a possibility worth keeping in mind.

7.2 The attitude of scooter fleets and repurposing as a concept

According to the analysis, none of the interviewed scooter fleet companies had a functional repurposing operation in place. While a few had undertaken isolated projects, there was no consistent or large-scale effort. The reasons for this deficiency varied among the companies, but during the interviews, it became evident that the hierarchy of refurbishment, repurposing, and recycling was flawed. Which could therefore contribute to the other challenges with repurposing. The analysis emphasizes that if batteries can be refurbished for reuse in scooters, it represents the most economically and environmentally viable option. However, when refurbishment is not feasible, priority should be given to repurposing over recycling. This prioritization is crucial not only for extending battery lifespans and promoting resource circularity but also due to the considerable costs associated with recycling. Presently, scooter fleets incur substantial expenses for battery recycling. Yet, as illustrated in one of the case studies, redirecting batteries to repurposing could generate revenue instead. Additionally, the recycling process often fails to reintegrate materials back into the battery industry. This disconnect was highlighted by a conversation with a prominent recycler in Sweden, who explained that scooter batteries typically undergo direct milling, resulting in low-quality output, contaminated with undesirable materials. Consequently, much of it is diverted to the steel industry instead. Introducing repurposing instead of recycling would naturally necessitate a period of adjustment. However, we are confident in the interest from scooter fleets in this transition. This was evidenced in one of the case studies, where a company already operating a fully functional refurbishment-recycling operation expressed willingness to explore repurposing possibilities.

A significant reason for repurposing not being a dominant choice among scooter fleets is largely attributed to the immaturity of the SLM in general, and specifically, of SLBs from electric scooters. This is evidenced by the clearly contrasting perceptions regarding the value of these batteries. Some view their used batteries, with the majority of SoH remaining, as mere common waste destined for recycling. On the other hand, others hold an inflated belief in their value, anticipating a price increase over time. Consequently, they store these potentially hazardous goods in warehouses, allowing them to degrade into even less valuable batteries. However, it is crucial for them to recognize that the likelihood of their batteries increasing in value over time is slim. Factors such as the diminishing raw materials inside LiBs, Volta Foundation (2024), and the increasing supply from China are expected to decrease the overall value of second-life LiBs. Educating scooter fleets on the true value of their batteries could significantly enhance the likelihood of finding suitable matches with second-life actors. Aligning the expected prices from both parties would facilitate smoother negotiations and increase the likelihood of striking a deal.

A more educated supply side, coupled with a continually maturing demand side, could boost the overall repurposing of SLBs from scooters. Consequently, this would enhance awareness of the challenges associated with repurposing these batteries, potentially prompting stakeholders to urge battery manufacturers to develop designs that are more sustainable. A more sustainable design would mean less glue in order for an easier dismantling process which would benefit the overall repurposing of scooter batteries.

7.3 Possible applications and CBM on second life scooter batteries

With the results of the proposed applications, the authors believe that it is indeed difficult to make a business case of repurposing scooter batteries due to the high degree of manual work needed to extract cells from the small packs. Therefore, the recommendation is to target applications that generate value beyond the primary function of a battery. For instance, providing energy to areas with limited access to batteries or leveraging their high marketing value in campaigns. Not only do scooter batteries come with issues related to design, but also the uncertainty in user history in the case of scooter sharing companies. An interesting factor for the future will be the extent of openness in the BMS protocols and the potential collaboration among scooter/battery producers, sharing fleets and repurposers. If the BMS allows for some degree of accessibility by repurposers, it could create more opportunities for them, thereby enhancing the value of batteries at the end of their initial lifecycle.

The proposed applications are not new products to the market in general, and some have even utilized scooter batteries already, such as the powerbank and smaller BESS. The common issue with companies repurposing scooter batteries was the economic infeasibility, which gave way to the use of EV batteries instead for the latter. Appendix C showcases and benchmarks examples of the possible applications within different product categories, except for 'dock for micromobility' and 'solar street lights', as these products are less available on the market. As for home BESSs, portable BESSs and powerbanks, the products are sold in a price-oriented environment, which poses a challenge as well as an opportunity for second life batteries to be competitive. The potential lies in utilizing more affordable cells, but it faces the challenge of achieving economies of scale.

For Cling, a growing company within the SLM of trading, tracing and transporting batteries, scooter batteries currently lack the necessary volumes or value to make a significant impact on their trading business. However, the CAM-system discussed holds real potential, as it focuses more on organizing and controlling the fleet's scooters and batteries through a subscription pricing model, rather than trading.

For scooter batteries to be a viable option for second life applications, the dismantling process needs to be facilitated, either by automated methods or by enhancing the design for end of life management. Maintaining the volumes of good batteries going into repurposing streams is also essential to achieve scalability, a task facilitated by the CAM-system which provides an overview of the process.

7.4 The SLM in general

It is fair to assert that the SLM, encompassing not only SLBs from electric scooters but in general, is still evolving. Future developments will inevitably impact it, driving further maturation and growth. One of the primary hurdles facing the SLM revolves around the supply aspect, encompassing both the quantity available and the difficulty in sourcing a consistent, uniform volume of batteries. Expectations regarding volume have not been fully realized, partly due to EV drivers effectively prolonging battery lifespan beyond initial forecasts. Moreover, there is evidence that batteries are still utilized even when they reach lower SoH levels. These factors contribute to a smaller, fluctuating volume of batteries circulating within the SLM than originally projected. However, this challenge is expected to diminish over time as the SLM matures. Additionally, the upsurge in battery production is likely to yield a higher quantity of production scrap batteries, further enhancing SLM volumes. A challenge for the future of the SLM and its profitability is the decreasing prices of new batteries, which can drop below $100/kWh according to the literature (Volta Foundation, 2024). Will this price pressure shift the second life market geographically to support locations where batteries are not readily available yet, or will the aspect of sustainability yield a premium for these products? While these are speculative forecasts for the SLM, if accurate, they could yield significant positive outcomes.

An essential factor to consider when contemplating the future of the SLM is battery regulation and its potential impact. As evidenced by the interview study, there is considerable uncertainty about how regulations will influence the SLM, but the prevailing sentiment is that it will likely have a positive effect. Our observations from discussions with repurposers indicate that many operate with limited clarity and endeavor to proactively anticipate forthcoming regulations. It is anticipated that battery regulation will greatly assist in standardizing processes that currently feel uncertain, at least that is the overarching goal.

Although these speculations pertain to the SLM in general, they hold significant relevance for the electric scooter market. Despite our ability to present intriguing findings regarding SLBs from electric scooters and potential CBMs that could be applied, it is important to acknowledge that many of these findings are speculative. They may be further substantiated in the coming years as the SLM continues to evolve. With this in mind, one might view this research as a preliminary study that warrants further investigation at a later stage.

8. Conclusion on the work

The purpose of the thesis was to explore alternative applications for SLBs from electric scooters and develop a business strategy addressing both technical and business constraints. The application that was found to be the most relevant from these two perspectives was the solar street light. The product itself is not placed close to consumers or houses, addressing safety concerns with the batteries. Furthermore, the customer is not solely price-oriented since the value created around the product is more than just a battery and could contribute to highlighting initiatives for example regarding safety in traffic. Finally, the product is marketable as second-life with good PR potential for the parties involved, strengthening its business case.

The future for scooter battery design is largely dependent on how the regulation is implemented and if less glue is used in the packs. For a company like Cling, positioned in the middle of the SLM, it is possible to monitor this evolution and adjust to the outcome. If scooter batteries become easier to handle, the value of the cells will likely increase. Scooter fleets may see greater value for their EoL-batteries, necessitating effective solutions for EoL management. The CAM-system presented in the paper is therefore a beneficial solution for Cling to offer to a wider array of fleets. Not only does it provide an effective means of managing EoL batteries, but it also serves as a useful tool for Cling to be able to gauge the market attractiveness of these batteries, streamlining the process of securing deals.

This research has analyzed the possibilities of reusing electric scooter batteries that are seen as EoL in their current application but that can be used in others. Presently, there is a noticeable surge in the utilization of SLBs from EVs as presented in the studies by Global Sustainable Electricity Partnership (2021), Hossain et al. (2019) and Sandberg (2023), to name a few. There is however little knowledge to be found on smaller batteries. This report aimed to improve on this and has uncovered comparable applications and potentially more efficient solutions for smaller SLBs which could be seen as a compliment to the existing research on larger batteries. The authors have mapped the evolving market of SLBs from electric scooters and highlighted the challenges and possibilities with both its design as well as perception and general knowledge of them in an extensive way not done before. The results should be seen as a preliminary investigation that aims to provide a foundation where stakeholders can gather valuable insights to enhance their work towards a more circular battery industry in general and electric scooter batteries more specifically. As portrayed in the report, the SLM of batteries is young and evolving and needs more research like this in order to get a better understanding of all its components. Batteries are becoming more present in further applications around us and they all need to be considered since SLBs have proven to be a great source of energy.

The results from the study is based on the collection of data from market players, but is also inevitably permeated by the author's own ongoing education of this segment of the battery industry. The analysis as well as the workshop with the battery engineer and the case studies are viewed from the eyes of the authors. However, the authors believe that the study requires this dimension to be able to extract the attitudes of market participators on both sides of the supply and demand line. The authors noted that conducting interviews with scooter battery producers could have strengthened the analysis, particularly given that the fundamental challenge with repurposing scooter batteries lies in their design and production for their primary use. Despite multiple attempts, the authors were unsuccessful in securing these interviews, as they did not receive any response.

To further improve this study, technical and economic analyses of the suggested applications could be performed to provide more enhanced arguments for each case. This could involve estimating costs for building each application and possible revenues during its product lifetime. Moreover, sending out a survey with the proposed applications in a subsequent stage of data collection could have refined the quantification of the results. Further research that would bring clarity to this field could be studies on automated disassembly for smaller battery packs, compared to studies already done on EVs by for example Hellmuth, DiFilippo & Jouaneh (2021). Additionally, ongoing research into LMT battery design will be crucial to ensure compliance with regulations while maintaining safety and economic feasibility in both production and usage as well as refurbishment, repurposing and recycling (Gouach, 2023).

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Appendix

Appendix A

Appendix A.1 CB - Electrical- and electrotechnical equipment

The Certificate Body (CB) is a certification scheme that was developed by the International Electrotechnical Commission for Electrical Equipment (IECEE) to facilitate manufacturers to streamline their process of obtaining national safety certifications for their products in different markets. This scheme is for mutual acceptance of test reports and certificates covering the safety of electrical and electronic equipment, devices and components. The CB certification is considered to be the equivalent of the CE mark which is used in the EU and indicates that your product is certified for multiple international markets. Further, it eliminates the need for duplicate certifications in the process of applying for them. The certification is not legally mandatory unless legislated by the government or mandated by industry or trade associations. In contrast to the CE marking, the CB scheme does not have its own separate CB mark, however it provides the opportunity to obtain conformity markings valid in participating countries worldwide (Certification Experts, n.d).

Appendix A.2 UN DOT 38.3 & IEC 62281 - Transportation

This certification is one of the most important ones since the LiB most certainly will undergo some type of transportation during its lifetime. To be able to ship LiB cells or pack within the US, the battery must pass the eight tests in the UN DOT 38.3 regulation. In order to ship the batteries internationally, the battery, however, must pass the nine tests in the IEC 62281 which are similar to the ones in UN DOT 38.3 but with an additional drop test. These two certifications consist of the most fundamental tests a battery should pass in order to be classified as safe. For this reason, many other regulatory bodies refer to these tests as a part of their pass criteria. Table 12 presents a description and comparison of the tests performed in the two certifications (Li-ion Tamer, n.d).

	UN DOT 38.3	IEC 62281
External short circuit	x	x
Abnormal charging	x	x
Forced discharge	x	x
Impact	x	x
Shock	x	x
Vibration	x	x
Thermal cycling	x	x
Altitude simulation	x	x
Drop		x

Table 12. Comparison between UN DOT 38.3 & IEC 62281 (Li-ion Tamer, n.d)

Appendix A.3 UL 1642 & UL/IEC 62133 - Secondary use of cells in portable applications

The cells of a LiB are referred to as the building blocks of the battery which of course need to be held to certain standards which is where UL 1642 comes in. This standard ensures that the cells of the LiBs are designed in a safe way for every application they are used in. The tests performed in the UL 1642 standard demonstrates that the cells can handle relative extreme conditions. Many of these tests are directly correlated to the ones performed in UN DOT 38.3 or IEC 62281 but are directed specifically towards the cells being used in technician- or user-replaceable applications. This standard is often referred to in pack-level certifications as well such as UL 2054, UL 2271 and UL 2580. The IEC 62133 standard is similar to the UL 1642 standard, a certification on cell level. The difference between them is that IEC 62133 is internationally accepted whereas UL 1642 is only accepted in the US. Further, the IEC 62133 has a few more tests included such as drop, continuous low-rate charging and internal short circuit test. The UL has also adopted UL 62133, the IEC 62133 standard, which is the same (Li-ion Tamer, n.d). The comparison between the UL 1642 and UL/IEC 62133 standard is summarized in table 13.

	UL 1642	UL/IEC 62133
Short-circuit	x	x
Abnormal charging	x	x
Forced discharge	x	x
Crush	x	x
Impact	x	
Shock	x	x
Vibration	x	x
Heating	x	x
Temperature cycling	x	x
Altitude simulation	x	x
Fire Exposure	x	
Drop		x
Continuous low-rate charging		x
Internal Short Circuit		x

Table 13. Comparison between UL 1642 & UL/IEC 62133 (Li-ion Tamer, n.d)

Appendix A.4 UL 2054, UL 2271 & 2580 - LiBs used in commercial applications

LiBs are used in many different commercial settings and applications such as consumer electronics, electric scooters and EVs. Every application is different from each other regarding the environmental-electrical and mechanical requirements which means different tests that a pack must survive in order to be approved. The UL 2054, Ul 2271 and UL 2580 are the most common which is why they are important to be aware of. The UL has a lot of different standards for LiB packs and they are usually dictated depending on the capacity level of the pack intended to be used in the application. For applications with batteries with a capacity lower than 10 Ah, the UL 2054 is applied which is a standard for household and commercial applications. Applications such as electric scooters and robotics that require a battery with the capacity of 10-20 Ah are regulated through the UL 2271 standard. This standard is more important than the others for this research since it is applied for electric scooters in specific. For LMTs and EVs that require batteries with a capacity above 20 Ah, the UL 2580 standard is applied (Li-ion Tamer, n.d). Following tables illustrate the different standards related to each other in the different test areas.

	UL 2054	UL 2271	UL 2580
Heating	x		
Temperature cycling	x	x	x
Altitude simulation			
Immersion		x	x
Water exposure (IP Code Rating)		x	
Label Permanence		x	
Salt Spray			x
External Fire Exposure	x		x
Internal Fire Exposure			x

Table 14. Environmental tests required for the different UL certifications (Li-ion Tamer, n.d)

	UL 2054	UL 2271	UL 2580
Short-circuit	x	x	x
Abnormal charging	x		
Forced-discharging	x		
Abusive overcharging	x	x	x
Limited power source	x		
Battery component temperature	x		
Battery pack surface temperature	x		
Overdischarge		x	x
Imbalance charging		x	x
Dielectric voltage withstand		x	x
Isolation resistance		x	x
General temperature			x
Continuity			x
Internal Short Circuit			x
Failure of cooling/thermal stability system			x

Table 15. Electrical tests required for the different UL certifications (Li-ion Tamer, n.d)

	UL 2054	UL 2271	UL 2580
Crush	x	x	x
Impact	x		
Shock	x		
Vibration	x	x	x
General enclosure	x		
250 N steady force enclosure	x		
Mold stress relief	x		
Drop impact		x	x
Roll over		x	x
Strain relief (cords)		x	x
Handle loading		x	x
Rotation			x

Table 16. Mechanical tests required for the different UL certifications (Li-ion Tamer, n.d)

Appendix A.5 IEC 61508 - BMS

The BMS is a critical part of the LiB which is why certifications regarding this are worth mentioning. The safety of the systems controlling the batteries are crucial to many industrial applications because there is little room for error in their operation. Batteries that are diverging from their voltage range become unstable and can cause problems quickly. The BMS makes sure that the batteries are not operating outside their ideal state and the IEC 61508 is the standard which every BMS follows (Li-ion Tamer, n.d).

Appendix A.6 UL 9540, UL 9540A & IEC 62933 - Energy storage systems

The UL 9540 standard is the new standard for ESS and its equipment which also includes electrical, electrochemical, mechanical and other types of energy storage technologies for systems intended to supply electrical energy. It covers charging and discharging, protection, control, communication between devices, fluids´ movements and other aspects. It provides a basis for safety of ESS and it refers to other crucial safety standards and codes such as UL 1973 (batteries for use in ESS) and UL 1741 (Inverters, converters, controllers and interconnection system equipment for use with distributed energy). It also covers additional criteria regarding materials, enclosures, piping, interaction with the grid and hazardous moving parts. The certification for ESS is achieved through a product testing which is typically used for off-the-shelf ESS products, or through an on-site, nondestructive field evaluation for unique systems (UL Solutions, n.d).

Another certification related to the UL 9540 is the UL 9540A which is not really a certification, rather a method to evaluate the thermal propagation of the ESS. This will not give you the certificate, it will only present to the manufacturers if their product meets the requirements to obtain the UL 9540 certificate. This method is very effective for developers and engineers to use in order to control their products´ effectiveness against key issues such as fire. This test method is divided into several steps:

1. **Cell-level test**
   UL looks at whether a cell can exhibit thermal runaway. It also checks its characteristics and flammability.
2. **Module-level test**

The main objective is to determine if thermal runaway propagates with the module. UL will also find out the heat release and gas composition.

3. **Unit-level test**
   UL will look at the whole unit and see the following. Firstly, they find out how quickly fire spreads. Then they will look for its heat and gas release rates and other hazards.
4. **Installation-level test**
   Lastly, UL does an installation test. This is optional, but it aims to determine how effective the product's fire protection is.

(EverExceed, 2021)

The IEC 62933 is a series of certifications where IEC 62933-5-2:2020 has similar requirements as UL9540, globally. The IEC certification mentions the need for large-scale fire testing for evaluating thermal runaway of Li-based battery systems and referencing UL 9540A as a possible test method.(Song, 2023)

Appendix A.7 UL 1973 - For batteries in energy storage systems

The UL 1973 certification specifies the requirements that manufacturers of BESS must meet in order to qualify. This certification ensures that the BESS is safe and reliable for real-life conditions. The UL 1973 contains a series of construction parameters such as requirements for nonmetallic materials, metallic parts resisting corrosion etc. Further, it also contains some safety tests including electrical tests such as charging/over-charging tests and mechanical tests such as vibration, shock, impact, drop and crack tests. What is crucial with the UL 1973 certification is however the fire exposure tests, one external and one internal. The purpose of the external test is that the BESS will not explode while being exposed to a hydrocarbon pool/brush fire. The internal test is meant to test how the BESS is handling eventual single cell failure within the battery system (EverExceed, 2021).

Appendix A.8 UL 1974 - EV repurposing facilities

UL 1974 is the standard for evaluation for repurposing batteries which includes sorting and grading the cells, packs and modules. The standard also assesses the process to identify the viability and rating mechanisms for continued use of the batteries. Once UL has validated that these processes are correctly performed, only then a facility can be certified as a second-life facility (UL Solutions, n.d).

Appendix A.9 IEC 62619 - Secondary use in industrial applications

The IEC 62619:2022 standard sets safety requirements for secondary, meaning rechargeable, lithium-cells and batteries for use in industrial applications, including stationary applications. Some examples are uninterruptible power supplies, electrical BESS, emergency power, industrial motive applications such as forklifts, railway vehicles and marine vehicles, with the exception of road vehicles (International Electrotechnical Commission, 2022).

Appendix A.10 IEC 62620 - Secondary Lithium cells & batteries for use in industrial applications

This certification specifies marking, tests and requirements for lithium secondary cells and batteries including stationary applications. When an already existing IEC standard, specifying test conditions and requirements for cells used in special applications and which is in conflict with this standard, the former takes effect, e.g. IEC 62660 series on road vehicles. Examples of applications that utilize cells and batteries under the scope of this standard is,

- **Stationary applications:** Telecom, uninterruptible power supplies, BESS, utility switching, emergency power and similar applications.
- **Motive applications:** Fork-lift truck, golf cart, AGV, railway and marine excluding road vehicles.

If the battery is divided into smaller units the smaller unit can be tested as the representative of the battery. The manufacturer clearly declares the tested unit and may add functions, which are present in the final battery, to the tested unit (International Electrical Commission, 2014).

Appendix A.11 IEC 62485-5 - Safety requirements for secondary batteries and battery installations

This certification applies to the installation of one or more stationary secondary batteries having a maximum aggregate DC voltage of 1500V to any DC part of the power network. It also describes the principal measures for protections during normal operation or under expected fault conditions against hazards generated from,

- Electricity
- Short-circuits
- Electrolyte
- Gas emission
- Fire
- Explosion

It provides requirements on safety aspects associated with the installation, use, inspection and maintenance as well as disposal of LiBs used in stationary applications (International Electrical Commission, 2020).

Appendix A.12 ISO/IEC 17025 - General requirements for testing & calibration laboratories

The ISO/IEC 17025 standard involves general requirements for testing and calibration laboratories that want to demonstrate that their results are reliable. The standard was developed by a couple of laboratory experts globally, along many organizations, such as the International Laboratory Accreditation Cooperation (ILAC) and helps laboratories to demonstrate valid results which facilitates national and global collaborations between testing facilities (ISO Organisation, 2017).

Appendix B

	Application	Example	Cell Pack	Capacity range [kWh]	Voltage range [V]	Max Discharge/Charge [C-rate]	SoH Requirement [%]	Safety Requirement [-]	Cycle Frequency [N/year]	Acceptance of Risk of Failure	High Packaging Density	Branding of 2nd life	Serviceability	Battery Control	Score
Stationary	On-grid buffers for EVs	Link	Cell	(-)	(-)	(-)	0	(+)	(-)	(-)	(+)	(-)	(-)	0	-5
	Off-grid availability (smaller hybrid systems with solar)	Link	Cell	0	0	0	0	(+)	(-)	(-)	(+)	(-)	(-)	0	-2
	Dock for micro-mobility	Link	Cell	0	0	0	0	(+)	(-)	(-)	(+)	0	(-)	0	-1
	Solar Street Light	Link	Cell	0	0	0	0	(+)	(-)	0	(+)	0	0	0	1
Semi-stationary	Power bank for phones	Link	Cell	0	0	0	0	0	0	0	0	0	0	0	0
	Power stations for RV, Campers	Link	Cell	0	0	0	0	0	0	0	0	(-)	(-)	0	-2
Mobile	Micromobility	Link	Cell	0	0	0	(-)	(+)	(-)	0	0	0	(-)	0	-2
	Golf carts	Link	Cell	0	0	0	(-)	(+)	(-)	0	(+)	(-)	(-)	0	-2
	Robotic lawnmowers	Link	Cell	0	0	0	0	(+)	0	(+)	0	(-)	(-)	0	0
Stationary	On-grid buffers for EVs	Link	Pack	(-)	(-)	(-)	0	0	0	(-)	0	(-)	(-)	(-)	-9
	Off-grid availability (smaller hybrid systems with solar)	Link	Pack	0	0	(+)	0	0	(+)	0	0	(-)	0	(-)	0
	Dock for micro-mobility	Link	Pack	0	0	0	0	0	0	0	0	0	0	0	0
	Solar Street Light	Link	Pack	(+)	0	(+)	(+)	(+)	(+)	(+)	0	0	0	(+)	7
Semi-stationary	Power bank for phones	Link	Pack	(-)	(-)	(+)	0	(-)	(+)	0	(-)	0	(-)	(-)	-4
	Power stations for RV, Campers	Link	Pack	(+)	0	(+)	0	(-)	(+)	(+)	(-)	0	(-)	(-)	0
Mobile	Micromobility	Link	Pack	(+)	(+)	(+)	(-)	0	(-)	(+)	(-)	0	(+)	(-)	1
	Golf carts	Link	Pack	(+)	(+)	(-)	(-)	0	0	(+)	(-)	(-)	0	(-)	-2
	Robotic lawnmowers	Link	Pack	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(+)	(+)	1

Table 17. Full scoring from decision matrix in workshop 3

Appendix C

BESS

Make and Model	1st/ 2nd life	Chem	Price (€)	Capacity (kWh)	Price/k Wh	Volt	Charge/ Discharge Max (A)	Lifetime (cycles)	Warranty (years)	Standards	Certification
Revov R200	2nd	LFP	2431	10.2	238.33	51.2	160	7000	10 years (6000 cycles @80%)	IP20	
Solplanet LV batteri	1st	LFP	3994	10.24	390.04	51.2	100		10	IP65	TUV / IEC 62619 / IEC 62040 / IEC 61000/UN38.3
Pylontech Force H1	1st	LFP	6949	17.76	391.27	240	40	6000		IP55	
Huawei LUNA2000-10 -S0	1st	LFP	4641	10	464.10	450	11			IP66	CE, RCM, CEC, VDE2510-50, IEC62619, IEC 60730, UN38.3
Growatt ARK HV	1st	LFP	8713	17.92	486.22	358.4	25		10	IP65	IEC62619(Cell &Pack), CE, CEC, RCM, UN38.3
BYD Battery Box Premium HVS	1st	LFP	5737	10.2	562.45	409.6	25		10	IP55	VDE2510-50 / IEC62619 / CEC / CE / UN38.3

Table 18. BESS Benchmark.

Portable BESS

Make and Model	1st/ 2nd life	Chem	Price (€)	Capacity (kWh)	Price/ kWh	Volt	Cont. Output (kW)	Lifetime (cycles) 80%	Warranty (years)	Weight (kg)	Standards	Certification
FossiBoT F3600	1st	LFP	1 899	3.84	494.5	48	3.6	6500	2	42		
ALLPOWERS R2500	1st	LFP	999	2.016	495.5	48	2.5	3500	5	29		
Bluetti EB70	1st	LFP	499	0.716	696.9		1	2500	2	9.7		
Goal Zero	1st	NMC	2 379.7	3	784.9	10.8	2		2	31.65		

Yeti 3000x												
Jackery Explorer240	1st	LFP	202	0.24	841.7	14.2	0.2			4.2		
EcoFlow Delta2	1st	LFP	993	1.024	969.7		1.8	3000	5	11.6		UL CE FCC RoHS PSE
Anker 757	1st	LFP	1 364	1.229	1 109.8	3.2	1.5		5	19.9		
Jackery Explorer1000	1st	LFP	1 319	1.002	1 316.4	43.2	1	4000		13.8		
Jupio Powerbox 500	1st	LFP	395	0.288	1 371.5		0.5	3500	3	5.1	IP65	
PESS Energy Wattman	2nd		15 208.9	10	1 520.9		6	2000		90	IP22	DIRECTIVE BT (2014/35/UE) ET CEM (2014/30/UE)
PESS Energy Bobine	2nd		8 773	5	1 754.6		4	2000		55	IP22	DIRECTIVE BT (2014/35/UE) ET CEM (2014/30/UE)
Instagrid ONE	1st		4 312	2.1	2 053.3		3.6			20	IP54	IEC 61140
Nunam NESS	2nd	LFP		5		48	2	2000	5	75		
EcarAccu Pagina	2nd	LFP	Leasing	15			8			160		

Table 19. Portable BESS/Powerbank Benchmark.

Mobile

Make and Model	Application	1st/ 2nd life	Chem	Price (€)	Capacity (kWh)	Price/kWh	Nom. Volt	Lifetime (cycles) 80%	Warranty (years)	Weight (kg)	Standards
Ninebot NEE1009-w	Micromobility	1st	NMC		1.004	.	36			7.3	IPX7
LG for XIaomi M365 Pro	Micromobility	1st		229	0.388	590.2	36				
Ninebot	Micromobility	2nd	NMC	328	0.551	595.3	36			6	

Make and Model	Application	1st/ 2nd life	Chem	Price (€)	Capacity (kWh)	Price/k Wh	Nom. Volt	Lifetime (cycles) 80%	Warranty (years)	Weight (kg)	Standards
NEE1006-M											
LG for XIaomi for M365, Mi	Micromobility	1st		176	0.28	628.6	36				
Ninebot NEE1006-M	Micromobility	1st	NMC	353	0.551	640.7	36			6	
Reypu RPH0011	Micromobility	2nd		183	0.28	653.6	36				
Lawnbott S1	Lawnmower	1st		166	0.2268	731.9	25.2		1		
Cameron Sino CS-HAT315vx	Lawnmower	1st		52.94	0.0629	841.7	18.5			0.28	
BatteriExperten till Husqvarna	Lawnmower	1st	NMC	70	0.054	1 296.3	18				
OKAI ES-600	Micromobility	1st			0.6768		47				IP67
RJ-LFP	Golf Cart	1st	LFP		2.4			6000	10	23	

Table 20. Mobile Application Benchmark.