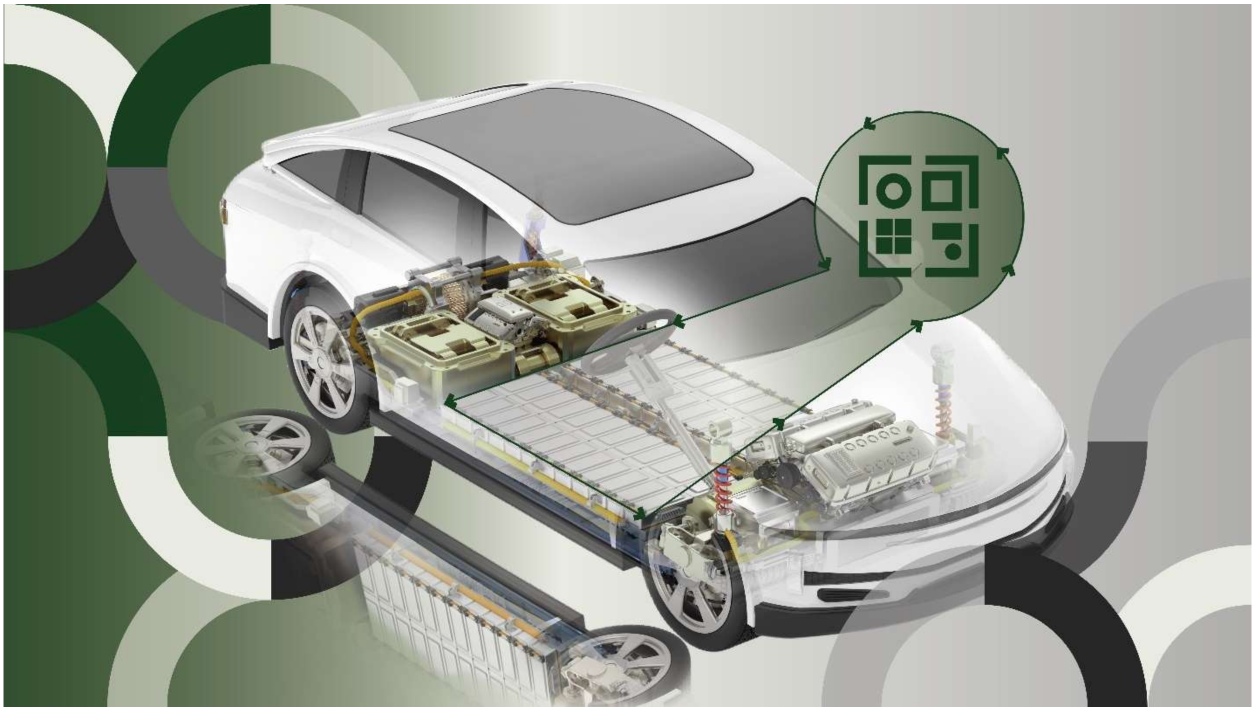

End-of-Life Management for Digital Battery Passports in Electric Vehicles

Master's thesis in Industrial Ecology

ELEONORA COTA AND MOLLY INGMAN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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Eleonora Cota
Molly Ingman

CHALMERS
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Division of Production Systems
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Eleonora Cota
Molly Ingman

Supervisor: Hanna Persson, Chalmers Industriteknik
Examiner: Mélanie Despeisse, Department of Industrial and Materials Science

Master's Thesis 2024
Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Clarifications and explanations

BESS - Battery energy storage systems

CIT - Chalmers Industriteknik

DBP - Digital battery passport

DPP - Digital product passport

DPPSP - Digital product passport service provider

EoL - End-of-life

EPR - Extended producer responsibility

ESPR - Ecodesign for sustainable products regulation

EV - Electrical vehicle

EVB - Electrical vehicle batteries

MID - Module identification

OEM - Original equipment manufacturer

PRO - Producer responsibility organization

REO - Responsible economic operator

RUL - Rest of useful life

SoH - State of health

Abstract

The use of batteries increases every year, and it is more important now than ever to transition into a sustainable way of handling them in the right way. This requires traceability along the whole battery value chain, including information from mining raw materials until the battery is recycled. The EU has implemented the battery regulation, stating that a digital battery passport (DBP) will be required from February 2027. The DBP enables traceability of the battery and facilitates the recycling process. However, the DBP system is not yet finalized, and research shows that there is a gap in guidelines for how it should be managed during its end-of-life (EoL). Therefore, this project aims to determine how to manage DBP for Li-ion electric vehicle batteries (EVB) in the EoL phase to enhance traceability, enable a circular economy and enforce a sustainable transition.

This project investigates the complete battery value chain to understand the EoL. Through a literature review and interviews, this thesis dives deeper into the management of batteries, appropriate solutions of ending its corresponding DBP and loopholes that may occur.

The results show that the responsible economic operator (REO) creating the DBP is the owner and the responsible actor during its whole existence and is the only one that has the right to end it. This means further that independent operators never will have REO responsibilities, on the other hand, they are obliged to update DBP when needed for the battery. A DBP can only end after its product has been recycled and when this occurs, the recycling station will automatically inform the REO to end the DBP. A two-step verification process controls each individual product and informs its status to the corresponding REO and reduces the risk that information for some products would not be documented. For the recyclers who receive information about all products, this thesis presents a solution for module identification (MID), enabling modules to carry information, since the DBP only follows the complete battery pack. With the two-step verification process, the proposal with MID and keeping the responsibility by the REO, the loopholes regarding lack of information on products within the system can be significantly reduced.

In conclusion, this thesis provides guidance on how to manage the DBP in the EoL phase based on currently available information and decisions on the topic.

Keywords: Digital battery passport, End-of-life management, Battery regulation

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1. Introduction

Electrifying transportation plays a crucial role in the efforts to reduce carbon emissions, putting lithium-ion batteries (Li-ion batteries) in focus for these strategies. The entire life cycle of Li-ion batteries, from their design and production to their use and eventual disposal, has gained significant attention due to their environmental, economic and social implications. This focus is driven by the rapid increase in metal extraction required for batteries, the climate impact associated with battery manufacturing and ongoing concerns about the safety, recyclability and environmental effects of batteries at the end of their life cycle. The number of Li-ion batteries on the global market has almost increased 10-fold over the past 10 years (Melin et al., 2021). As a result, these issues are becoming priorities on political agendas worldwide (Curtis et al., 2021). To ensure sustainability for batteries on the European market, the European Union (EU) has proposed a new battery regulation (European Union, 2023). Aligned with its vision for a future and careful use of the earth's resources, the EU has started an innovative developing process for a digital battery passport (DBP) (Battery Pass Consortium, 2024b).

The process of how to end the DBP for batteries is largely unexplored today, with limited guidance and resources available to support stakeholders in managing the end stages of a DBP. This research gap poses a challenge to achieving full life cycle traceability. This report is pioneering and forecasting, trying to offer innovative solutions and a framework that will enable the industry to meet compliance and prepare for the future of DBP with new needs and regulations.

1.1 Background

The Ecodesign for Sustainable Products Regulation (ESPR) is a regulation and framework providing sustainability requirements, regarding performance and information, for selected physical products that are being used or placed on the EU market, including batteries (European Union, 2024). The regulation aims to reduce products' environmental impact along their whole life cycle and to make sustainable products the standard on the market, aligning with the EU initiatives like the Green Deal and the Circular Economy Action Plan (European Union, 2023; European Union, 2024). The battery regulation (EU) 2023/1542 is an extension of the ESPR and focuses specifically on batteries, aiming to reduce harmful substances, lower carbon footprints, and recover critical materials like cobalt, copper, lithium, lead and nickel, leading to less raw metals being imported from outside of EU. This regulation mandates DBP for all batteries, with a capacity greater than 2 kilowatt hours (kWh), placed on the market or put into service within the EU market from February 2027 (Weng et al., 2023; European Union, 2023). DBP is applied on battery packs, meaning complete and functioning batteries and not on module and cell level, which follows the hierarchy of subcomponents of batteries, represented by pack, module and cell (Li et al., 2022).

To begin with, the DBP will be integrated into existing regulatory procedures and systems, such as Green Public Procurement, to support the EU's sustainability goals. It can also maximize advantages when designing for upcoming policies by fostering a circular economy and improving business to business interactions throughout the battery life cycle (Walden et al., 2021; Battery Pass Consortium, 2024a). The DBP will play a crucial role in promoting sustainability by encouraging the use of batteries across multiple cycles, including repair, refurbishment, and repurposing stages. This requires manufacturers to adapt their designs to enable modularity and enhance recyclability, fostering a transition from a quantity-driven to a quality-driven economy while reducing negative environmental impacts (Göteborgs Tekniska College, 2024; Popowicz et al., 2024).

Under the new regulation, the DBP is expected to track information on sustainability, carbon footprint and material content, organized into different content clusters covering attributes such as design for recyclability, due diligence processes collection and recycling, and extended producer responsibility (EPR) (Battery Pass Consortium, 2024a; European Union, 2023; Berger et al., 2022). The attributes will be divided into static data including e.g. production details and material content as well as dynamic data e.g., state of health (SoH) throughout the battery life cycle (Battery Pass Consortium, 2023c). DBP will also enhance transparency and consumer awareness, not only in environmental sustainability but also in social sustainability. For instance, it will address concerns related to child labor, safe mining practices, and human rights in the supply chain, particularly in the extraction of materials like cobalt, copper and nickel (Göteborgs Tekniska College, 2024).

The DBP will feature a unique identifier for each battery, which can be accessed through a label on the product, its packaging or accompanying documentation (European Union, 2024). To ensure security and prevent fraud, the EU Commission will establish a registry of unique identifiers by July 2026, with public data available via a web portal. This system will facilitate end-to-end communication, enabling stakeholders to compare information while ensuring data confidentiality. Furthermore, the actor that puts a battery on the market shall not only update data in the registry but also keep a decentralized database with DBPs where assigned actors can access and update information in the DBP (European Union, 2023).

While the DBP introduces significant benefits for sustainability and aligns with the EU's vision for a circular economy, it also presents challenges for European manufacturers, particularly in the electric vehicle (EV) sector. Stricter regulations and limited battery sourcing options may place European manufacturers at a disadvantage compared to competitors in less regulated markets, like the United States and more mature industries, such as China (Melin et al., 2021). However, by supporting the recycling of materials, the DBP has the potential to reduce the EU's reliance on imported raw materials, potentially covering 5–20% of the material needs for European passenger cars by 2045. This positions the DBP as both a transformative sustainability tool and a key component of the EU's broader regulatory framework to be able to keep better track of the critical materials and keep them within the EU borders (Melin et al., 2021; Battery Pass Consortium, 2024a).

1.2 Aim and research question

To decrease the extraction of raw materials and to keep scarce battery materials within the EU borders it is important to make sure that the battery is used to its full capacity through circular usage followed by proper recycling to reduce its environmental impact. DBP can help ensure responsible actors have fulfilled their obligations and can resign the responsibility when complete. This will raise awareness and enable prevention for risks and loopholes.

Therefore, the aim of the project is to determine how to manage DBP for Li-ion batteries in the end-of-life (EoL) phase to enhance traceability, enable a circular economy and enforce a sustainable transition.

One main research question will fulfil the aim of the project:

> How to manage and transfer DBP among actors up until EoL for DBP?

The research question is divided into three objectives:

1. Determine suitable actors to end DBP.
2. Define handling procedures for EoL information.
3. Identify possible loopholes and preventive actions.

1.3 Scope and limitations

This project will define EoL triggers and management strategies for a DBP, assigned to electrical vehicle batteries (EVB). The EU legislation for DBP aims to ensure that both the batteries and the valuable metals they contain remain within the EU borders. Therefore, the geographic boundaries for this project will be how DBP is supposed to be managed in the EoL phase within Europe. On the other hand, one has to keep in mind that many products where batteries are put into application are both exported and imported in and out of the EU borders. Therefore, global supply chains will have to be explored for those cases. However, the interview targets of this thesis project only include stakeholders of the value chain who are located and operating within Swedish borders.

The repurposer connected to the SmartPass project is creating battery energy storage systems (BESS) out of used EVBs. For the repurposer, this project will focus on how to handle DBP when batteries are repurposed and later recycled. Since the repurposer partner is using modules from different battery packs, this thesis project will not take cell-to-pack batteries into account.

DBPs for batteries that for some reason have left the value chain are out of control and will therefore not be taken into consideration. DBP will be mandatory from February 2027, therefore, the recommendations and results from this project will be applicable from that date.

According to the EU battery regulation, it is stated that products placed on the market or put into service shall have a DBP. It is therefore assumed that an oversupply of batteries, which have not been placed on the market, do not necessarily have a DBP and can therefore not be taken into consideration. As a conclusion, only batteries that have been put on the market or into service will be included in the study.

2. Methodology

This qualitative research process includes several key components, starting with a formulation of the aim, research questions and scope of the project, followed by data collection through literature review and interviews. The literature review was aiming to understand ongoing research regarding DBP. The interviews aimed to let important stakeholders, relevant to the project, express their thoughts and experiences, giving new perspectives from their area of expertise.

2.1 Literature review

This structured literature review focused solely on mapping all research published in the area of EoL management for DBP (Uppsala University Library, 2024; Tulane University Libraries, 2024). To map relevant, credible and up-to-date data, authoritative databases were used, Scopus, Web of Science and IEEE. Following the recommendations from Karolinska Institute University Library (2024), to ensure the relevance of the papers for EoL management for DBP, a limitation of the publication date 12 July 2023 of the new EU battery regulation was set for this thesis (European Union, 2023). Although when scoping the value chain in this thesis earlier papers and studies were investigated. The short timeframe helped to ensure that the papers stay aligned with the latest regulatory updates since this is a research area under development and constant change.

Keywords used in literature databases included "Digital battery passport" combined with alternative statements:

- End-of-life management
- Deactivation of battery passport
- End of battery passport
- Digital product passport end-of-life

The result of the mapping of literature was carefully documented, see Appendix A, to identify research gaps. The table in Appendix A, clearly proves the importance of further research in the area of EoL management for DBP since no other papers or research could be found on that exact topic. The results of the literature review were presented through a Prisma flow diagram (University of North Carolina Libraries, n.d.).

2.2 Interviews

Interviews were used as the primary question-based method for collecting qualitative data about handling DBP in the EoL phase. Interviews provided the opportunity to take part in qualitative information on a deeper level, such as opinions, experiences and behaviors (Given, 2019). The interviews followed a semi-structured approach, often used to gather clinical data for qualitative research purposes.

To make a suitable selection of interview targets for the study, an overview of the actors involved was required. By mapping the value chain for batteries with DBP it was possible to pinpoint what different stakeholders could contribute with and where valuable and needed information for the project was to be found. Along the value chain mapping, key stakeholders connected to the SmartPass project at CIT, included personnel from one battery manufacturer, one repurposer, as well as one original equipment manufacturer (OEM), one recycler and other experts within the field of batteries and DBP.

After initial startup meetings with representatives from the battery manufacturer and the repurposer, it was obvious that different actors in the value chain hold different types of information and have different needs when dealing with DBP. Therefore, the interview protocols were modified and customized to fit each category of stakeholder listed in Table 2.1. The first interviews held with CIT experts were executed as scoping interviews, with the purpose of both getting a basic knowledge of the research area of DBP and testing the interview structure. Table 2.1 further shows more detailed information about all interview targets and the aim of each interview. The interview protocol and summaries of each interview can be found in Appendix C1-K2.

Table 2.1: *Interview targets.*

Organisation [Actor category]	**Role**	**Duration [Minutes]**	**Purpose**
CIT expert, [Outside value chain. Expert in DBP]	Previous work with DBP in other product areas	48	Scoping-oriented interview to provide knowledge in the research area of DBP
CIT expert, [Outside value chain. Expert in DBP]	Involved in several DBP projects connected to batteries	53	Scoping-oriented interview to provide knowledge in the research area of DBP
Car manufacturing employee, [REO]	End of Life Battery (Circularity) Manager	42	Solution-oriented interview. Car manufacturers' perspective on ongoing and future work for implementing DBP and managing EoL
The Swedish Transport Agency employee, [Public authority]	Working with regulations for cars and previously been involved in electric cars due to the EU battery regulation	57	Scoping & solution-oriented interview regarding the workflow of the Swedish vehicle registry and the potential of integration of DBP into existing systems.
Global standardization organization employee, [Outside value chain. Expert in DBP]	Head of global affairs and involved in the CirPass 1+2 project among others	67	Solution-oriented interview regarding predictive research regarding how DBP EoL will be managed in the future
Repurposer and creator of battery energy storage systems, [REO]	CTO and founder of the company	79	Solution-oriented interview regarding a repurposer’s perspective on DBP EoL and adaptation to the legislation.
Recycling center employee, [Independent operator]	Business and prior technical specialist	3-hour study visit + 49 minutes of interview	Solution oriented interview regarding recycler’s workflow, perspective on DBP EoL and adaptation to the legislation.
Battery manufacturing employees, [Supplier / REO / DPPSP]	Production manager, manager of application, two employees in the Sustainability department and a quality engineer	240 minutes of interviews followed by a manufacturing round tour	Solution-oriented interview regarding manufacturing workflow, perspective on DBP activation and the industry’s adaptation to the legislation.
Swedish Environmental Protection Agency employee, [Public authority]	The battery regulation adaptive work	67	Solution-oriented interview to discuss extended user responsibility and the Swedish Environmental Protection Agency’s interpretation of the battery regulation
Swedish Environmental Protection Agency employee, [Public authority]	ESPR expert	54	Solution-oriented interview to discuss the Swedish Environmental Protection Agency’s interpretation of the ESPR
Swedish PRO employee, [Independent operator]	Market and communications manager	55	Solution-oriented interview regarding PRO workflow and the industry’s adaptation to the legislation.

A guide was used for how to conduct semi-structured interviews, requiring the following steps (Rabionet, 2011):

1. Establishing guidelines
2. Crafting the interview protocol
3. Conducting and recording the interview
4. Transcribing and analysing the interview.

The first step, establishing guidelines, ensured that the interviews would target our aim and research questions of the project. A goal and objectives were stated for the interviews to gain information on actor-specific approaches to the DBP for batteries and during EoL. Except for the actor-specific information, a set of general objectives for all stakeholders were listed to create clarity in how different parts of the value chain are affected in different ways by the introduction of DBP. This aims to find impacts in operations, including work methods and regulatory challenges. It also assesses the company's approach to battery life cycle management, post-sale tracking and sustainability goals; environmental, social and economic. Additionally, they address concerns about data integrity and business confidentiality.

Secondly, the interview protocol was created to match the objectives stated in step 1. As mentioned earlier, the interview protocol included specific areas of interest for each stakeholder to address the research questions structurally and in-depth. Starting with a general section of questions designed to extract specific insights into the operational challenges and requirements associated with DBP implementation, see Appendix B. These questions were asked to all stakeholders in all interviews to enable understanding between stakeholders, highlight differences and provide the opportunity to compare the answers. The questions that followed were actor-specific to match the individual objectives and aim for each interview with the different stakeholders.

In the third step, the interview was conducted and recorded. Some interviews were held physically while others were held digitally over Microsoft Teams meetings. Each interview was audio recorded with the consent of the interview target. The procedure was always the same with a presentation of the thesis students and the aim of the interview. Both students in this project were asking questions during each interview to be able to focus on the discussion, to ask follow-up questions for deeper understanding and be able to follow the interview target on unexpected subjects. The duration of the interviews varied from around 40 minutes up to 60 minutes. Lastly, the interviews were transcribed through a transcription program built into Microsoft Teams and through klang.ai. Klang.ai is a digitized tool that converts audio files into transcribed documents. The analysis of the interviews was conducted through a KJ-analysis which is described further in Chapter 2.3. In connection with two of the interviews that were held at a recycling site for batteries and a battery factory, the opportunity was given to tour the facility. The tours were held to broaden the understanding of the system in which DBP will operate.

2.3 Data analysis methods

After the data collection phase, the findings from the literature review, background research and empirical studies were examined and interpreted. This section demonstrates how insights from all parts of the data collection were systematically converted into a coherent process and understanding of the subject.

The analysis phase involved several key steps which aimed at organizing and evaluating the data collected from the literature review and interviews. The analysis involved several iterative cycles, analyzing how the various actors affect the value chain and what could be part of their responsibility linked to each step of the value chain of DBP and batteries. This mapping was based on the information found in the background and literature review and further supported by the interviews which worked as a tool in the analysis process when identifying uncertainties, risks and the possible effects on case outcomes.

A KJ-analysis was specifically applied to analyze the interview. KJ-analysis aims to compile and structure large volumes of qualitative data. The process involved selecting relevant quotes from the interviews and grouping them into clusters based on similar content. These clusters were then analyzed to identify common themes, points of contacts and issues related to the research question and objectives. This method helped to organize and prioritize subjective data, making it easier to define the needs and requirements for the project results (Spool, 2004). It also made it possible to identify connections and key findings from various data sources when comparing the KJ-analysis with the literature review. It enabled a comprehensive view and facilitated analysis by organizing and linking individual notes and provided a structured way to explore relationships within the data as seen in Figure 2.1.

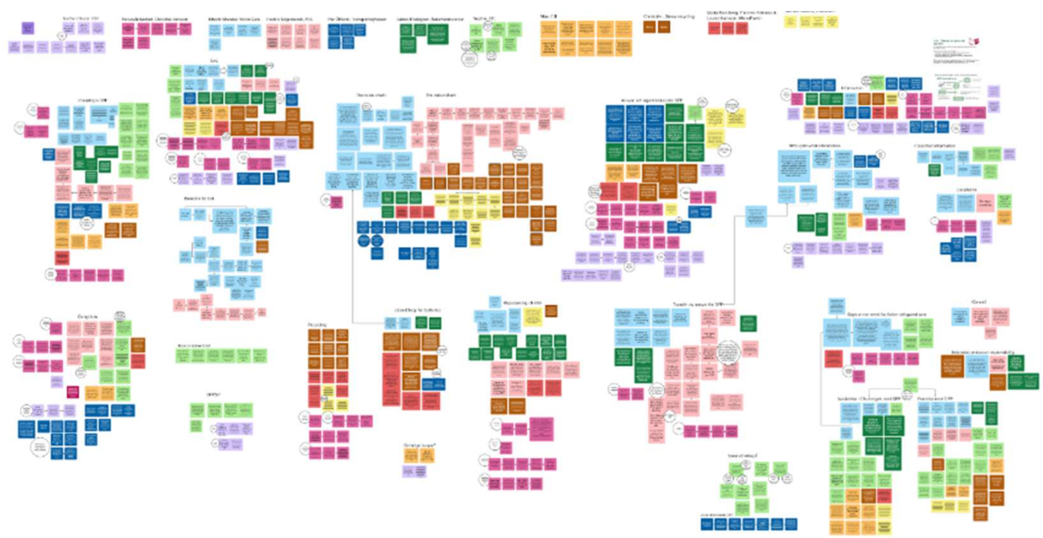

Figure 2.1: *Showing clusters of information where each color represents one interview stake holder.*

The methodology is intended to ensure that the project's outcome is valid and reliable by giving a full understanding of the factors influencing EoL management for DBP. This was achieved through a combination of qualitative and quantitative methods. By following the systematic approach listed above the project aims to minimize potential biases and further increase the reliability of the findings. This resulted in a broad understanding of the needs for how DBP can be managed in the EoL phase and who receives this information. The result was analyzed and evaluated together with an expert on digital product passports (DPP), working on a global standardization organization, to clarify the benefits and impacts associated with each case together with further needs of research and new processes needed in the future (Appendix F2b**).**

3. Result

This section presents findings from data collection. The literature review presented through a Prisma flow diagram in Figure 3.1 revealed a lack of research and guidelines on DBP management at EoL, with no studies specifically addressing this area, see Appendix A. The literature study highlights that the beginning of life for DBP is rather complete (Berger et al., 2023a; Carlsson & Nevzorova, 2023; Gutwald et al., 2024; Jansen et al., 2023; Naseri et al., 2023; Rufino et al., 2024; Soufi et al., 2023), while EoL lacks management guidelines. This was confirmed by each interview target, where even the car manufacturer who already launched a car with a belonging DBP explained that they were waiting for further delegated acts for this (Appendix D2). Consequently, the following chapter presents a result that relies primarily on material from interviews analyses, other oral communication and study visits with actors in the value chain.

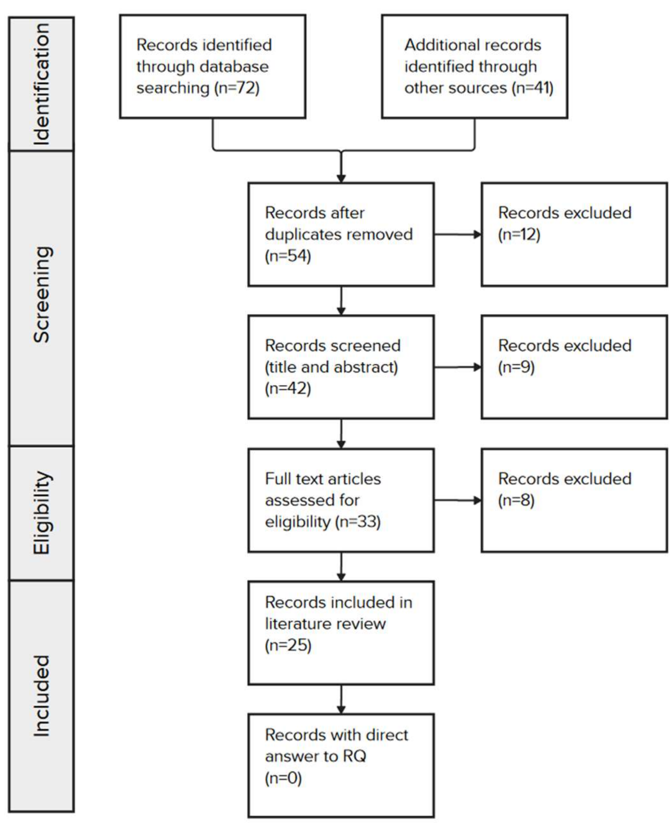

Figure 3.1: S*howing the result from the literature review in a Prisma flow diagram.*

The overall expectations of the DBP are positive, enabling higher efficiency and transparency of processes (Appendix D2; Appendix J2; Appendix G2; Appendix H2; Appendix I2a; Appendix I2b; Appendix K2; Appendix F2a). OEMs will most likely be the most affected actors, with lots of pressure to adjust to the new regulations (Dalhammar et al., 2024). But OEMs might benefit from greater control of the batteries and being able to monitor and predict services alongside warranty errands through DBP together with identifying possible improvements when developing the batteries (Berger et al., 2022; Baumgartner et al., 2024; Naseri et al. 2023; Appendix D2; Appendix J2). However, a majority of the interview targets agreed on the importance of DBP and creating a more circular flow of batteries and materials, benefiting repurposing and EoL treatment (Appendix G2; Appendix H2; Appendix I2a; Appendix I2b; Appendix K2; Appendix F2a).

3.1 How to manage and transfer DBP among actors up until EoL for DBP?

This section will answer the research question, *How to manage and transfer DBP among actors up until EoL for DBP?* To understand what system is required and how to end a DBP one must understand what needs exist and what events can happen within the system (Baumgartner et al., 2024; Appendix C2b). Therefore, the following section will provide insight into the value chain for EVBs, how DBP is to be implemented together with its actors and how the responsibility of the DBP is transferred. Suggested solutions enhancing the implementation of DBP in the value chain are discussed.

3.1.1 Value chain and adaptation to DBP

Figure 3.2 illustrates the life cycle of EVBs and DBP. The life cycle starts with the mining and extraction of raw materials followed by refining, leading to cell, modules and pack manufacturing (Basia et al., 2024; Naseri et al., 2023; Appendix J2). The battery regulation together with the ESPR, states that batteries can only be placed on the market or put into service on the Union market if all requirements are fulfilled and have an assigned, unique DBP available

(European Union, 2023; European Union, 2024). The requirement also applies to imported battery packs where the importer will have to ensure DBP for each battery. Customs' work will be significant to ensure that batteries that are imported have a DBP (Appendix I2b). The battery regulation is however not applicable for cells and modules but demands the suppliers to fulfill the demands on due diligence when assembling components to battery packs. This means that, if an EU car manufacturer imports complete battery packs or battery components to assemble into an EVB, they are responsible for the DBP, which includes creating, updating, and storing (Battery Pass Consortium, n.d.). This puts pressure on non-European companies that trade, produce or import batteries in Europe and must also comply with environmental and due diligence requirements (Melin et al., 2021). China also started developing a DBP of its own before the EU battery regulation was published. This aligns Chine's standards with the EU's, facilitating trade and promoting consistent transparency across international battery supply chains (World Economic Forum, 2023; The State Council Information Office of the People's Republic of China, 2020).

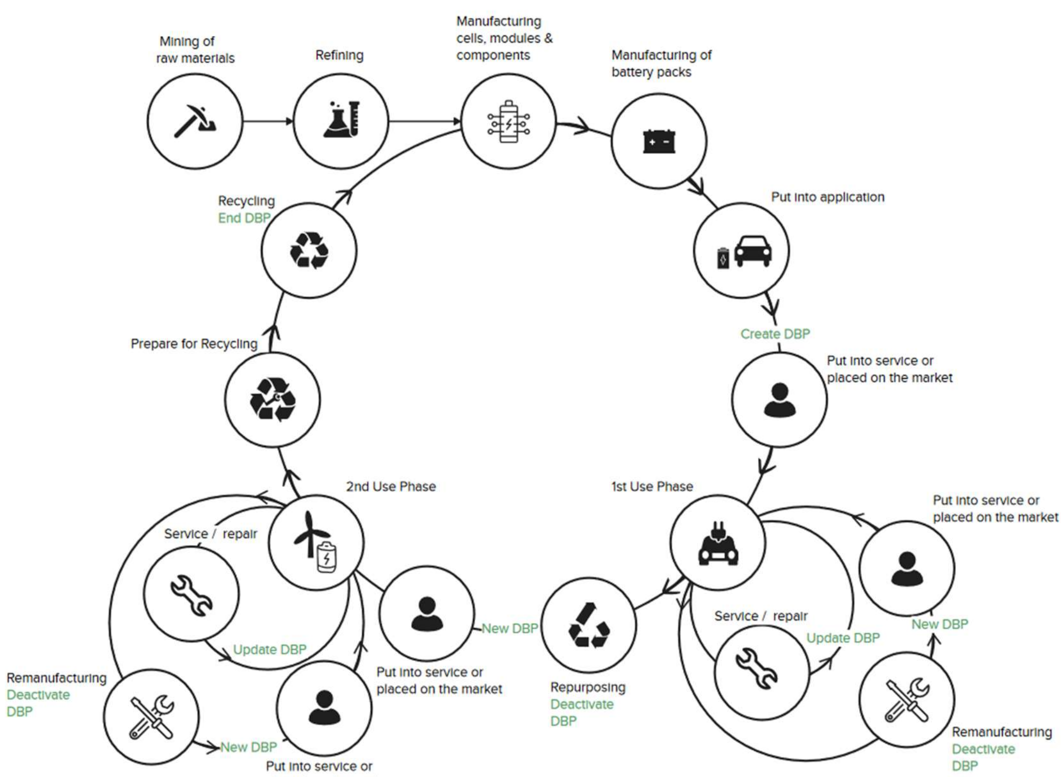

Figure 3.2: *The circular life cycle of EV batteries and DBP.*

To promote a sustainable life cycle, EVBs should undergo additional loops for repair, remanufacturing, or repurposing before recycling (Basia et al., 2024). Remanufacturing aims to restore the battery's capacity to 90% of the original nominal capacity. In addition, there is a requirement that all the cells in the battery pack must be in a uniform SoH with a deviation of a maximum of 3% (European Union, 2023). Rufino et al. (2024) note that it is still unclear from the battery regulation whether new data from remanufacturing will update the existing DBP as it should be done for reparations or if it should require a new DBP linked to the original (Rufino et al., 2024). However, the car manufacturer stated that at least, they need to do certain conformity assessments and quality assurance tests, which forces them to create a new pack ID for that specific battery and so also a new DBP (Appendix D2; The Battery Consortium, 2024).

EVB's aging during their first life depends on factors such as driving habits, temperature, and charging rates, making degradation patterns unpredictable. EVBs are considered at EoL when their capacity declines by 20–30%, meaning they still retain 70–80% capacity (Basia et al., 2024). Researchers suggest repurposing these batteries for less demanding uses, such as stationary BESS, instead of immediate recycling (Beckers et al., 2023; Hassini et al., 2024; Naseri et al., 2023; Rufino et al., 2024; Terkes et al., 2024). EVBs used for a second life in BESS have the potential to fully provide stationary storage by 2050. This can be achieved by reusing 45% of the EVBs for a second life (Aguilar et al., 2024). Which is only one reason to facilitate the repurposing of batteries before finally recycling. However, each battery's unique degradation and health status make sorting at EoL challenging, requiring standardized testing methods which often require disassembling battery pack into modules (Hassini et al., 2024; Naseri et al., 2023; Rufino et al., 2024). Additionally, the absence of clear standards for reuse highlights the need for quality and certification protocols to ensure safety and efficiency in second-life applications (Basia et al., 2024).

Information from the interview with the recycler indicates that the handling of the batteries takes place on module level. To the greatest extent, the battery comes disassembled in modules for recycling, which indicates that the modules may have been replaced for some reason, e.g. repair, remanufacturing or repurposing (Appendix H2). In cases where they receive complete battery packs, they are disassembled into modules. Since today, most EVs on the road are considered new cars, the quantity of EoL EVBs arriving to the recycling sites are mostly batteries of early failure, warranty or insurance company errands. The amount of used EVBs is expected to increase rapidly in the future in correlation to the normal aging of the battery (Berger et al., 2022). To be able to handle big amounts of EVB at the recycling sites, DBP information regarding battery composition, hazardous substances, dismantling guidance, etc. to gain efficiency and safety for the employees is crucial (Berger et al., 2022; Berger et al., 2023a; Ott et al., 2024; Appendix H2). Information regarding SoH and rest of useful life (RUL) could benefit future possibilities also for recyclers if acting as a service to delegate batteries with the remaining capacity to enter a repurpose loop rather than early recycling (Berger et al., 2023a; Weng et al., 2023)

During the visit to the battery recycling facility during the project, an observation was made that all modules were marked with a barcode when received at the recycling site to keep traceability. The barcode remains while the modules are unloaded and short-circuited to finally being scanned just before the module is shredded to become black mass. In this way, the recycler can inform each OEM and the Swedish Environmental Protection Agency about the number of batteries that have been recycled and the recycled content. The black mass is later transported outside of the Swedish border to undergo a hydrometallurgical process which is later reported back to the recycler with information about the recycling rates. Hydrometallurgical recycling dissolves valuable cathode metals in acids, separating them using solvent extraction (Sommerville et al. 2021). Although the new battery recycling site in Sweden is a step forward in managing waste batteries within Europe, one employee at the battery manufacturing site working with sustainability, expressed the belief that batteries will be sent back to Asia to a large extent even in the future because of China's technological lead (Appendix J2). China still has more advanced technologies for refining materials, producing battery components and has a well-developed recycling system compared to Europe (Melin et al., 2021).

The DBP is highly promoting the later part of the value chain (Berger et al., 2022), including repurposing and recycling to create circularity. Therefore, it is important that the DBP does not end too early in the process but lets the traceability of critical and scarce materials remain. The market and communication manager at a Swedish producer responsibility organization (PRO) is hoping for future corporations over the borders of the EU state members, so that even the small fractions of scarce materials can be collected at one centralized facility in Europe to handle larger material volumes effectively for recycling this material (Appendix K2).

3.1.2 Actors in the value chain

In the battery value chain, there are three identified groups of key actors presented and relevant for this master thesis. These groups of actors are responsible economic operator (REO), independent operators and public authorities (van Nieuwenhuijze et al., 2024). An REO is the company that puts the battery on the EU market or into service (Siska et al., 2023). This can be the manufacturer, who manufactures or brands the battery, or the importer, who introduces the battery into the EU from another country (Battery Pass Consortium, n.d.). It is within the responsibility of the REO to create a DBP and to ensure that it meets battery passport requirements. Additionally, the REO needs to have a copy of the most up-to-date version of the DBP, to ensure that the information is still accessible if potential failures occur or if bankruptcy is taking place (European Union, 2024; Appendix F2a). The DBP with its copy can also, through agreement, be handled by a digital product passport service provider (DPPSP), assigned by the REO. Alongside the responsibility of REO, there is the EPR, which implies that producers are required to take care of and handle their products after use. The REO needs to be informed when their products are no longer being used for their original purpose (European Union, 2023).

When a battery is to be repurposed by an actor who is not the OEM or REO, there must be an agreement between the two parties, OEM and repurposer (European Union, 2023). The agreement for repurposing was an important topic for both the car manufacturer and the repurposer interviewed (Appendix D2; Appendix G2). The battery needs to be transferred to the new actor who will be assigned as the new REO when the product is put on the market together with a new DBP linking back to the original DBP. To ensure the link between the original DBP and the new DBP for as long as original modules are to be repurposed, this master thesis proposes that the original DBP will have to be deactivated by the original REO. Deactivation means a marking of status where no further updates can be done on the original DBP but with the information of the new owner of the battery. Still, the original DBP is not ended but lies in the hands of the OEM which may disclaim all liability for that battery in case of an accident or similar. For a repurposer, information available in DBP will facilitate the sourcing of batteries by providing information about if there is enough capacity left in the batteries to be repurposed (Appendix G2). Valuable sets of information are inter alia, SoH, production date and RUL to estimate the number of charging cycles remaining before EoL (Baumgartner et al., 2024; Naseri et al., 2023).

The independent operators that are identified in the system are DPPSP, car workshops, traders, dismantlers, insurance companies and recyclers, among others. These are actors who play a crucial part in the value chain with the need for access to selected information and the obligations to report events and updates or services performed on the battery to REO (Berger et al., 2023c). For batteries and their belonging DBP the ownership of the product does not correspond to the ownership of the DBP (Naseri et al., 2023; Rufino et al., 2024; Appendix F2a).

The public authorities are amongst others the European Commission and their linked umbrella organizations and each member state's supervisory authority with the obligation to report that the legislation is being followed (Berger et al., 2022). Some public authorities will also have regulatory responsibility of putting legal requirements into action which regulate e.g. required environmental performance and mandatory recycled content. In Sweden, some of these public authorities are the Swedish Transport Agency, Swedish Environmental Protection Agency, the Swedish Energy Agency and the Chemicals Inspectorate. Although, it is not yet decided which authorities will have legal supervisory responsibility in Sweden (Appendix E2; Appendix I2a; Appendix I2b).

3.1.3 Responsibility for DBP and transfer of REO

Articles 77 and 78 of the battery regulation (European Union, 2023) assigns REO the duty of ensuring that all relevant data is recorded and kept accurate, complete and up to date in the DBP. These obligations apply even when the battery is in use outside the operator's direct ownership or control, see Figure 3.3. According to the car manufacturer, see Appendix D2, this is one of the biggest concerns in need of further delegated acts from the EU. Although it is stated that, when a battery is repurposed, responsibility and requirements shift. An agreement between the OEM and the repurposer is necessary, as the repurposer must create a new DBP for the repurposed battery, linked to the original DBP. This new DBP signifies that the repurposer has assumed the role of REO for the repurposed battery together with the EPR, while the original REO retains responsibility for the original DBP (Rufino et al., 2024). Ownership of the repurposed battery can be proven with a digital receipt, which may store or link to a copy of the original DBP for reference. However, since the battery is no longer in its original application, updates to the original DBP are not possible. This suggested solution on how to manage the transfer of REO is addressed by this master thesis project to address and clarify uncertainties about the responsibility of DBP mentioned by the Battery Pass Consortium (Battery Pass Consortium, 2023b).

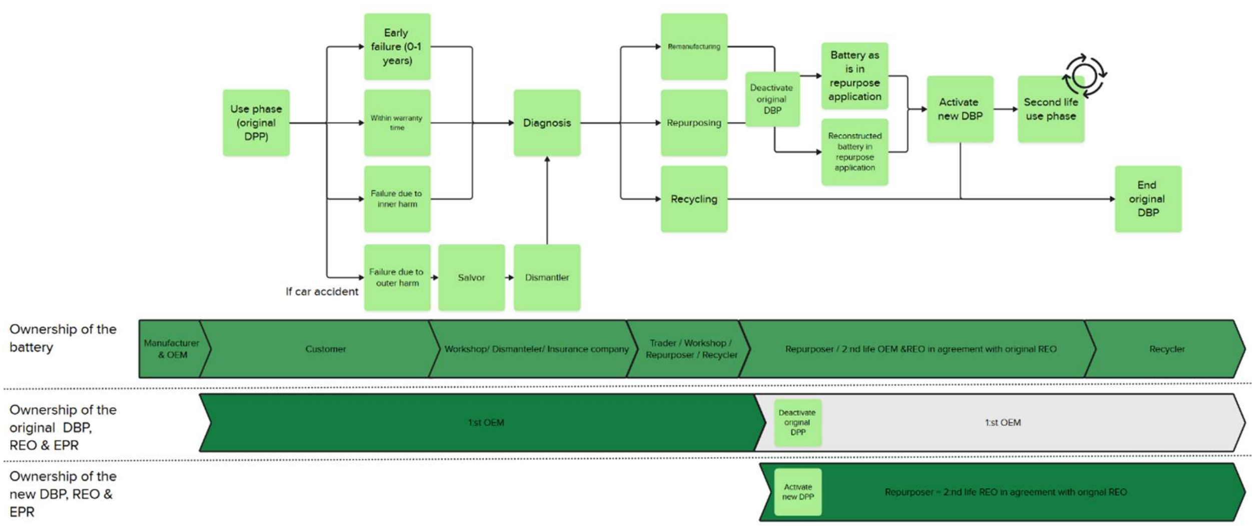

Figure 3.3: *Illustrating the ownership of the battery along the REO responsibility of the DBP and how it is being handled in case of repurposing of the battery.*

As just mentioned, the ownership of an EVB does not correspond to the ownership of the DBP (Naseri et al., 2023; Rufino et al., 2024). As a result of this, it is beneficial if the independent operators do not take REO responsibility for the DBP even though the battery may be in their possession. While the ownership of the battery is shifted amongst consumers and independent operators, the ownership of the original DBP remains by the original REO. This recommendation is based on how interview targets have been describing their and other positions and needs when transferring the responsibility of DBP and the battery. Figure 4.3 illustrates the life cycle of a battery, highlighting the roles of various actors and the management of the DBP through stages such as use, diagnosis, repurposing, and recycling (Ott et al., 2024). Economic benefits are assigned to the REO, typically the OEM or repurposer, ensuring that independent actors like salvage operators, dismantlers, or insurance companies are not linked to the DBP (Appendix J2; Appendix G2). This arrangement allows these intermediaries to focus on their specialized tasks, such as diagnosing or dismantling, without being burdened by regulatory obligations tied to the DBP.

By confirming DBP-related responsibilities with OEMs and repurposers, the system narrows down the responsibility to promoting efficient battery management. This structure ensures that REOs, who benefit economically from battery reuse or recycling, remain responsible for compliance and long-term stewardship. Independent actors, on the other hand, can contribute to the value chain without being constrained by administrative work. Still, if an update or likewise is performed on the battery the DBP needs to be updated by the independent operator. According to the Battey Pass consortium, guidelines addressing the procedure of how to update information in DBP without transferring REO, e.g. during repair needs to be clarified, which is further confirmed by Timms & King (2023) (Battery Pass Consortium, 2023b).

Together with the information gap in the guidelines and findings from interviews where a concern about the responsibility of the DBP is not linked to the ownership and control of the product, this master thesis proposes that independent operators, such as workshops, can update DBPs as follows. If an independent operator has an agreement and is authorized to update the DBP, this can be managed through an API provided by the REO. The API would allow the operator to access the necessary systems and perform the update, with clear tracking of who made the update and when. If the independent operator does not have access to an API, they would need to submit a request to the REO with details of the update. The REO would then be responsible for manually putting this information into the system. This approach protects the system from unauthorized changes but ensures necessary updates are made in a controlled manner. However, there is a risk that some updates may be missed. This demands a collaborative ecosystem that supports both economic and environmental objectives (Gianvincenzi et al., 2024; Naseri et al., 2023; Soufi et al., 2023). Findings from a study conducted by Dalhammar et al. (2024) predict that consumers are expected to reach out to authorized workshops to a greater extent in the future.

Table 3.1 further clarifies the responsibilities of the battery and its DBP at different stages in the battery life cycle, explaining the roles of various actors and the changes in ownership and responsibility. It covers events such as battery failure during the warranty period, repurposing, recycling, and remanufacturing by both authorized and non-authorized workshops. The table shows how ownership and responsibility shift based on the circumstances.

Table 3.1: C*larifying the responsibility of the battery and the DBP at certain events.*

Events where the responsibility of the battery and DBP might shift	**Ownership of the battery at the time of the event**	**REO & ownership of the DBP at the time of the event**	**Shifting ownership of the battery after the time for the event**	**Shifting REO & ownership of the new DBP after the time of the event**	**Outcome**
1. Battery fail (Low SoH, accident, inner failure) within and outside of warranty time	Consumer / OEM	OEM	Remanufacturing / Repurposing / Recycling	OEM	At remanufacturing, repurposing or recycling a new DBP has to be created linking back to the original DBP which stays in the hands of the REO.
2a. Remanufacture by an authorized car brand workshop	Consumer A	OEM	OEM / Consumer B	OEM	Consumer A receives another battery in its car while the battery later will be replacing another battery in the car of consumer B with a new DBP
2b. Remanufacture by a non-authorized car brand workshop	Consumer A	OEM	Non-authorized car brand workshop / Consumer B	Non-authorized car brand workshop	A new DBP has to be created linking back to the original DBP which stays in the hands of the REO while the new DBP is managed by the non-authorized car brand workshop.
3. Repurpose of the battery	Independent operator/ Repurposer	OEM	Repurposer	Repurposer	A new DBP has to be created linking back to the original DBP which stays in the hands of the REO while the new DBP is managed by the repurposer.
4. Recycling of the battery	Recycler	REO	Recycler	End DBP	

Ownership of a battery by consumers allows them the freedom to use it as they wish, reducing REO control. To strengthen REO control, some interview targets highlighted the benefits of implementing a closed-loop system and leasing batteries instead of selling them. Retaining ownership of the product enables the REO to maintain greater oversight and control throughout the battery's life cycle (Appendix J2; Appendix G2; Appendix F2b).

3.1.4 Solutions leading the way for sustainability

To balance data needs and confidentiality, the DBP should only include necessary information, e.g., material type and weight. Solutions like technical standards, legal confidentiality agreements and limited data disclosure can protect sensitive data. To minimize risks for insights into processing techniques or structural conditions, only material-level data should be shared (Battery Pass consortium, 2023a). Although, sharing detailed cell-level or primary data through the DBP raises confidentiality concerns (Berger et al., 2023c; Haupt et al., 2024; Ott et al., 2024), but is crucial for remanufacturers, second-life operators, and recyclers (Battery Pass consortium, 2023a; Appendix D2; Appendix J2). The importance is due to the benefits of being able to determine EoL battery value, improve recycling efficiency and reduce costs through easier access to information that can promote and more precisely recycling and calculate recycled content levels of cobalt, lithium, nickel and lead, which is mandatory (Appendix H2; Battery Pass Consortium, 2023a).

As a result of remanufacturing and repurposing, EVBs are often dismantled into components and modules, meaning recycling facilities typically receive modules rather than complete battery packs (Baumgartner et al., 2024; Appendix H2). Dismantling the modules from a battery is today done manually, a costly and timely process for the recyclers. The DBP is designed to improve battery traceability, extended to their module and cell levels. This ensures the availability of crucial information, such as material content and safety measures, which is vital for effective recycling (Battery Pass Consortium, 2023b). Despite this, the DBP currently operates only at the pack level, making it inaccessible for module-level use at recycling sites (Baumgartner et al., 2024; Berger et al., 2023b; Ott et al., 2024). Since the original battery does not exist, neither can the original DBP be active either (Appendix H2; Appendix F2). This creates uncertainty when parts of a battery are being further used while the rest is sent to recycling. Assigning the original DBP to individual modules would not provide accurate data on material content and other specifics, which highlights the need for better module-level traceability.

To solve the above-mentioned problem, this master thesis proposes enhancing the modularity of the DBP to correspond to the modularity of the battery. This means that each module would have a module identification (MID), holding data to facilitate repurposing and recycling of modules that have been removed from their original packs through a barcode. This can even be applicable on the cell level through identifier numbers to each battery cell (Bandini et al., 2023; Kies et al., 2023; Naseri et al., 2023). Although, for this project, traceability to a modular level is enough. The MID will consist of only a fraction of the information compared to DBP, including dimensions, weight, material content, manufacturing date, link back to original DBP and other static data. This will help to fulfill the initial aim of implementing DBP, to favor circularity.

MID will further provide insight into if modules of the DBP are still active or not through the links tracing back to the original DBP, see Figure 3.4. The status of the DBP could in this case be explained through three different states, activated, deactivated and ended. Where an activated DBP refers to an EVB used in the form and application of which it was created to perform. Deactivated DBP, meaning that the battery has been removed from its initial area of use or use phase due to remanufacturing, repurposing or recycling, and dismantled into components. Deactivated means that there are still active modules and MID linked to that DBP but the ability to update information in the original DBP is not possible anymore because the battery is not in its original use any longer. The DBP will stay deactivated as long as it has an active linking MID. When the last MID ends, so will the original DBP. Remanufacturing and repurposing are actions leading to the creation of a new DBP in need of deactivation of the original DBP. Recycling should be the only occasion where DBP can be ended. Further explanation of who can manage to end a DBP will be found in Chapter 3.2.

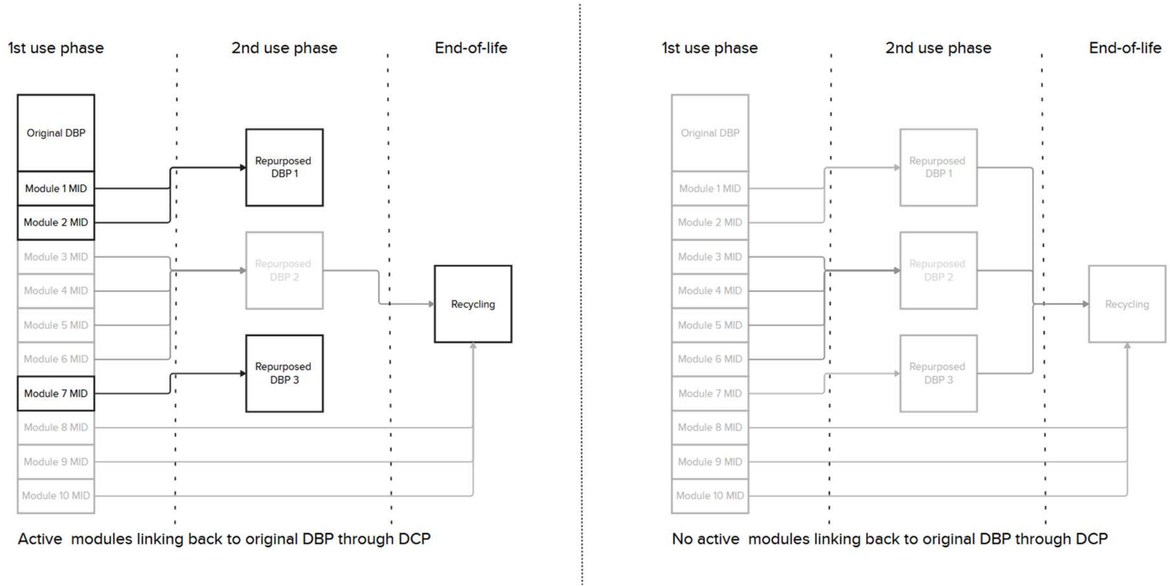

Figure 3.4: *Showing links between the original DBP and its modules through MID in different stages of the life cycle.*

3.2 Determine suitable actors to end DBP

This section treats the first objective, *Determine suitable actors to end DBP*. It also highlights when in the value chain it is most reasonable to end a DBP and possible solutions to how it is done.

From the interviews it is stated that the REO should be very sure that the products no longer exist on the market in order to remove the DBP, therefore it is practical if the REO could be informed when the product no longer exists (Appendix F2a). Several actors (Appendix I2a; Appendix J2; Appendix H2) express that the recycler would be a reasonable actor who would have the right to end the DBP. One of the interviewed employees at the Swedish Environmental Protection Agency further explains that this is reasonable since they are the ones who know when the product is being recycled (Appendix I2a). The global standardization employee on the other hand explains that the DBP is managed by the REO, which means that only they have the ability and access to end the DBP. The other employee at the Swedish Environmental Protection Agency agrees that the REO that puts the product on the market should be the one ending the DBP, but this means that the recycler could be a suitable actor that reports the occasion that the product no longer exists to the REO, stating that they are the only one with that knowledge (Appendix I2b). The interviewed recycler means that if the DBP ends before it has reached them, there is a risk that some information during the product's EoL would not be documented, there is also literature that implies that the DBP shall be active when the product enters recycling (Naseri et al., 2023; Ott et al., 2024). It is also mentioned that the DBP system should be as automatized as possible (Appendix C2a).

When creating a new DBP for repurposing, it shall be linked to the original DBP, but exactly how this will be implemented is not yet decided (Appendix F2a). One of the characteristics of the new DBP is to show which product the corresponding modules were attached to before. If the new DBP is linking back to an original DBP, it is recommended to not end that specific original DBP to keep the link active. An alternative to keeping the information is by copying and storing the data, which is safe and possible since the information in the original DBP will not be updated. It is still uncertain if it is possible to activate a DBP that has been ended, which is one of the reasons why it is important to be careful when ending a DBP.

The recycler raises the question if DBP should follow even further down the chain and explains that they are a mechanical processing operator and does not perform hydrometallurgical processes. That places demands on the entire process since you then need to have a substantial traceability of what you do, and you must be able to batch run and keep track of every single module that has been processed. It becomes complex as you go further down in the value chain, which is why the recycler sees themselves as the appropriate actors to handle the final stage of a battery's life cycle by confirming EoL and proper recycling of the battery.

As mentioned above in the interviews and literature, there is a demand from the recycler to receive information about each module, making their process easier. There is also a demand for the DBP to end when the product no longer exists, which happens when it is being processed at recycling sites. This project, therefore, proposes two alternative approaches for managing the DBP during its EoL phase:

Alternative 1: Two-step verification where REO together with Recyclers end DBP

The recyclers are recycling the battery and updating the DBP that the product no longer exists. The REO is still the owner and responsible for the DBP. This update will be done automatically at the recycling station when the DBP and MID are being scanned and the corresponding product is being sent to shredding. Through the scanning, the REO automatically receives continuous updates on which products that have been recycled. This step is where the product transitions to no longer being a product. Only after this confirmation, the REO is able to fully end the passport. When ending a DBP there are still uncertainties about what will happen with the DBP, if information is mandated to be archived for a certain period or if it can be deleted straight after. This presupposes that recyclers have a certificate, allowing them to update the DBP that the product has been processed and is no longer available. One selected authority will approve which recyclers will have the certificate to give permission to end a DBP and to access its sensitive information (Appendix E2; Appendix I2a; Appendix F2a). Suitable supervisory authorities will review the process through selective tests and will ensure that it is done correctly. If fraud is detected, the authorities have the right to retract the recyclers' certificate. Since every DBP and MID is being scanned, it ensures that every product is being treated and reported to the REO.

Together with the solution of MID, the recycler will receive information about each battery and module that enters their department. The DBP or MID shall therefore also be active when entering the recycling station and end when its corresponding product is shredded. As can be seen in the value chain under 4.1.1, each component and module of the battery finally ends up in recycling, which implies that this common end could be a part of the process when ending the DBP. If the final actor in the value chain, the recycler, ends the DBP, it could help to make the system more automatized in the way that the REO creating the original DBP does not have to be involved with the ending.

Alternative 2: REO can end DBP independently

The REO, responsible for and owner of the DBP, is the only one who has the right and ability to end the DBP when they are sure that the product no longer exists. The REO is responsible for ensuring that their products are treated in the right way after the use phase and for discovering when their products no longer exist and can end the DBP when this is stated. Suitable supervisory authorities will review the process through selection tests and ensure that it is done correctly.

To be able to review what is correctly done during the process of ending a DBP guidelines need to be determined and clarified. For Alternative 2 to be feasible there needs to be rules about when it is approved to end a DBP, relative to when its corresponding product ends. The DBP is intended to follow its product, meaning that if the product is recycled, there is no need for the DBP to stay active. As the recycler previously mentioned, it gets more complicated with the traceability the further down in the process you go. This strengthens the point that the DBP shall end when the product is being recycled and should not follow further in the recycling process. Table 3.2 highlights the differences and similarities between the two alternatives for ending DBP, if an X is marked under the Alternative, then this means that it applies to that case.

Table 3.2: *Clarification and comparison of the two alternatives for ending DBP.*

Subprocess	Alternative 1	Alternative 2
REO is responsible for ending DBP and the only actor that can do that	X	X
REO depends on another actor to end DBP	X	
Automized system when reporting information about products to REO	X	
REO is guaranteed to receive information about each of its products when they enter EoL at a recycling station	X	
Suitable supervisory authorities will review the process through selection tests	X	X
REO is guaranteed to receive information about its products from a credible source	X	

As can be seen in Table 3.2, Alternative 1 guarantees a more credible information and status flow. Since the REO is the only actor that has access to end the DBP, it is valuable for them to receive a continuous and accurate report about their product's state. Therefore, this thesis recommends ending the DBP according to Alternative 1.

3.3 Define handling procedures of EoL information

This section provides insight for the second objective, *Define handling procedures of EoL information.* It presents who will receive the information as well as who the sender is.

Receiving information when the products and their DBP have ended could be valuable for the REO, giving insight into how the product has been used (Appendix J2). The global standardization employee agrees and mentions that it could also provide information about when the battery was taken out of use and why, as well as that the DBP could provide a more realistic insight into how long the product has lived. The global standardization employee also highlights the question of who to trust when it comes to EoL information and how to verify that the information comes from a credible source. The recyclers are a reasonable actor to inform the REO who first placed the product on the market, when the products no longer exist (Appendix I2b). The Commission shall also be informed when products cease to exist, but which actor would be suitable for this is not yet decided (Appendix F2a). When the product, and its corresponding DBP ends, there seems to not be any interest in taking part in its information after the product has left the value chain (Appendix F2a).

The recycler in this project explains during the interview that they annually report to the Swedish Environmental Protection Agency and back to certain OEMs the amount of their batteries that they have recycled. They are believed to have a similar role when the DBP is established. The question will be the same, an OEM will not know that the recyclers have received their specific product and that it has entered their recycling process yet. That will be something that they report back, or write into a system, but to whom this system belongs is still uncertain. They further explain that there could be other demands placed on them, perhaps it should be reported with a different frequency than is done today and possibly more specific data for each battery that has been recycled.

Based on what is stated above, the source giving information about the products during their EoL shall be credible, the REO should receive information about their products and DBP, as well as the Commission shall receive information when products no longer circulate in the system. Therefore, this project recommends that the recyclers inform the REO when they have recycled their products. The reporting will automatically occur simultaneously when the products are being scanned when sent to shredding. The recycler shall have a certificate from a suitable supervisory authority, stating that they are a credible source. The REO, who is responsible for the DBP, shall inform the Commission about the status of their products. This could be done monthly or continuously when the REO has received information that their products no longer exist. These decisions can be applied to both Alternative 1 and 2 presented under section 4.2.

3.4 Identify possible loopholes and preventive actions

This chapter partly highlights the third objective, *Identify possible loopholes and preventive actions.* All identified gaps in the system of EoL management for DBP discussed previously in the result chapter can be considered loopholes with proposed actions on how they can be avoided. One example is the two-step verification process mentioned in 3.2 *Determine suitable actors to end DBP*, to prevent a sink of unused batteries in the use phase. Also, the MID introduced is to enhance traceability and not lose track of valuable materials through loopholes where modular data is not covered. Furthermore, not transferring REO and ownership of the DBP to independent operators will create a more stable system with less room for loopholes.

The EU battery regulation lacks clarity on defining the EoL management for DBP. If the DBP ends too early, traceability is lost, making it challenging to ensure proper recycling. Even though the REO has full responsibility and is the only one with full access rights to the DBP this master thesis suggests a two-step verification process. This aims to prevent an REO declaring EoL for a DBP without further notice. This is to make sure that batteries do not end up neglected during the user phase creating a sink of unused batteries which could happen if operators choose to close the DBP without actually ensuring the proper handling and processing of the battery (Appendix F2b).

The EPR, as highlighted during an interview with the Swedish Environmental Protection Agency, might favor EV manufacturers over environmental benefits (Appendix I2a). OEMs and REOs mandated to manage waste batteries make it challenging for repurposing businesses to access batteries without agreements, raising market entry barriers. This situation may result in batteries being recycled prematurely, benefiting OEMs by increasing recycled content in new batteries but reinforcing a linear usage model. Promoting a circular approach through full battery utilization, such as second-life applications for stationary energy storage, could significantly impact sustainability. Market barriers may also apply to small and medium-sized companies which may face difficulties in digitalization and sourcing required supply chain data for DBP (Haupt et al., 2024).

Finding a balance between recycling to increase recycled content and repurposing batteries to support circularity is crucial. DBP could facilitate this by identifying which batteries are better suited for reuse and which contain critical materials warranting recycling and reintegration into their original applications. For instance, NMC batteries, designed for automotive use, are rich in critical materials such as cobalt and nickel efficiency (Fallah & Fitzpatrick, 2023). NMC batteries are often given priority for recycling to recover these valuable resources since some argue that NMC batteries are not always well-suited for BESS due to differing performance requirements and charging cycles (Appendix I2a). On the other hand, LFP batteries, which lack nickel and cobalt, may be more suitable for reuse in stationary BESS (Fallah & Fitzpatrick, 2023). Their composition aligns better with the needs of such applications, supporting both environmental goals and resource efficiency.

4. Discussion

The result of this project is based on interviews and recently published articles regarding batteries and EoL for DBP. Having newly published papers regarding DBP makes the information more credible since the battery regulation was published in July 2023. On the other hand, all studies published in this new area of research with not yet set guidelines for performance make these results based on assumptions and estimations. New guidelines and delegated acts are coming from the EU, and the results of this report are based on literature that was available at the time. The lack of information in the literature regarding the EoL of DBP shows that the research area is underdeveloped, which is reasonable since the DBP enters into force in February 2027. The interviewed stakeholders all covered different areas of the battery value chain, however, if more stakeholders in the same area of expertise were interviewed it would give a broader and more diversified picture of the value chain. Another limitation linked to the interview targets is that all are located in Sweden. For further understanding and a greater perspective, actors outside of the Swedish borders, but inside of the EU still, could have been interviewed or potentially reached through a survey or likewise. Despite this, the results can still be viewed as credible since they adopt an existing system for batteries and follow the most up-to-date regulations.

Since batteries are the first product category requiring a DPP, solutions developed for EVBs may inspire other product categories. EVBs are heavy and difficult for consumers to handle, typically requiring professional service workshops for management. This characteristic helps to ensure that EVBs remain within a controlled system and are predominantly managed by economic actors. In contrast, smaller batteries, such as those for light means of transport, are easier for consumers to manage independently, increasing the risk of them falling out of control. These batteries may end up with uncertified recyclers who process them without proper overview. Therefore, the system outlined in this report is specifically tailored to EVBs and its results may not be universally applicable to a broader system that includes all battery types. For a general DBP to function effectively across all battery categories, further evaluation and adaptation would be necessary.

The results emphasize the importance of showcasing that materials are being recycled, aligning with the growing interest in sustainable practices. However, it is crucial to acknowledge the limited technical maturity of material recycling and its reintegration into battery production within Europe. While material recycling for batteries is an emerging and promising industry, it is not yet fully established, with uncertainties surrounding its development. DBPs hold significant potential for advancing sustainability in battery production, but the current limitations in material recycling maturity and DBP technology underline the need for continued development and innovation. To fully harness these benefits, the industry must bridge the gap between the availability of data and its practical application, ensuring that advancements in recycling processes and digital tools translate into actionable and impactful outcomes.

For the DBP to function effectively, it is essential to establish multiple collaborations and agreements. No single company can fully implement or sustain a DBP system on its own, underscoring the need for industry partnerships over the border. Furthermore, the concept must be tested in real-world scenarios to understand its practical implications and determine how it will evolve. This is still the beginning of the electrification journey; one can expect a significant increase in variations and generations of battery modules in the future. The solution presented in this report is based on current conditions, but an uncertain future will ultimately determine how applicable and robust our recommendations prove to be.

5. Conclusion

This thesis addressed the gap in the research for the EoL management for DBP. To achieve a more sustainable transition for the usage of batteries inside of the EU, a complete and functional system with high traceability of scars materials is crucial, according to the battery regulation. Therefore, to complete the DBP system, which would enable the traceability of materials used in batteries, this thesis has investigated and answered the question; *How to manage and transfer DBP among actors up until EoL for DBP?*

Both from literature and interviews, it is stated that to achieve full traceability of the value chain, the information needs to be documented from the extraction of materials until the recycling of the battery, even when it has been dismantled into modules. Since the DBP follows the complete battery pack, this thesis therefore suggests implementing a MID. The MID makes it possible for recyclers to obtain valuable information about each module that enters the recycling, facilitating the treatment of each product. The MID links back to the original DBP and when all modules are recycled the DBP can end.

The REO creating the original DBP stays the owner and responsible for the DBP during its whole existence, which also means that they are the only ones that have the right to end and delete the DBP. Therefore, independent operators in the value chain will never take REO responsibilities, on the other hand, they are obliged to update DBPs when needed for the battery. This thesis further suggests that the DBP shall end when the corresponding product has been recycled. The recyclers shall inform the REO when this occurs and the REO will after that end the DBP.

The gap of research for EoL management for DBP mostly depends on the requirement for DBP will be first in February 2027, meaning that the majority of DBPs that are in need of ending will be relevant first within a couple of years after the implementation has taken place. This thesis highlights possible loopholes in the system but cannot be further investigated without practical pilot studies. While a fully comprehensive solution for EoL management cannot yet be predicted due to the absence of further delegated acts, the results provided in this report offer guidance and can be seen as a prediction based on the current landscape of EoL management for DBPs.

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Appendixes

Appendix A

Table of research papers found the literature review, proving the research gap.

Author, year, country	Title	Research area/aim/ Research questions	Battery category	Parts of the value chain discussed	Suggested solutions for EoL for DBP?
Bai, YC; Muralidharan, N; (...); Belharouak, I, 2020, USA, Germany	Energy and environmental aspects in recycling lithium-ion batteries: Concept of Battery Identity Global Passport		Consumer electronics, electric vehicles, and renewable energy storage	Early speculation and benefits, encouraging implementing battery passport (2020)	NO
Bandini, G., Buffi, A., Caposciutti, G., Marracci, M., & Tellini, B. (2023), Italy	An RFID System Enabling Battery Life Cycle Traceability	DBP system leverages Ultra-High-Frequency (UHF) Radio Frequency Identification (RFID) technology to enable circularity and sustainability in battery management.	EV batteries	Whole life cycle	NO
Basia, A; Simeu-Abazi, Z; (...); Zwolinski, P, 2024, France	A Conceptual Framework Based on Current Directives to Design Lithium-Ion Battery Industrial Repurposing Models	LIB repurposing		LIB repurposing (second-life)	NO
Basic, F., Seifert, C., Steger, C., & Kofler, R, 2023, Austria	Secure Data Acquisition for Battery Management Systems	Secure BMS processing from the local to the cloud level	EV batteries	Transferring of data during the phase from BMS to the cloud	NO

Baumgartner, Rupert J., Katharina Berger, and Josef-Peter Schöggl, (2024), Austria	Digital Technologies for Sustainable Product Management in the Circular Economy	Investigate the potential of digital solutions for SPM	EV batteries	SPM, CE	NO
Beckers, C., Hoedemaekers, E., Dagkilic, A., & Bergveld, H. J., 2023, The Netherlands	Round-Trip Energy Efficiency and Energy-Efficiency Fade Estimation for Battery Passport	Presents an algorithm and demonstrates the estimate round-trip energy efficiency of a battery pack		User phase	NO
Berger, K., Rusch, M., Pohlmann, A., Popowicz, M., Geiger, B. C., Gursch, H., ... & Baumgartner, R. J. (2023), Austria	Confidentiality-preserving data exchange to enable sustainable product management via digital product passports - a conceptualization.	How to exchange confidential data via DPP	EV batteries		NO
Berger, K., Baumgartner, R. J., Weinzerl, M., Bachler, J., Preston, K., & Schöggl, J. P. (2023)	Data requirements and availabilities for a digital battery passport – A value chain actor perspective	Value chain actors' needs and requirements for a sustainable battery management	EV batteries		NO
Berger, K., Schöggl, J. P., & Baumgartner, R. J. (2022). Austria	Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases	SRQ 1: Who are the potential users of an EVB digital battery passport?	EV batteries	Whole life cycle of the battery. NOT the DBP	NO
Carlsson, R., & Nevzorova, T. (2023, September), Sweden	Managing Circular Electric Vehicle Battery Life Cycle Using Standards	An overview of standards that cover the whole circular electric vehicle battery life cycles	EV batteries	Whole life cycle	NO

Crocetti, L., Di Rienzo, R., Verani, A., Baronti, F., Roncella, R., & Saletti, R. (2023), Italy	A Novel and Robust Security Approach for Authentication, Integrity, and Confidentiality of Lithium-ion Battery Management Systems	Protect BMS's from cyber-attacks by proposing safety measures to BMS		BMS usage	NO
Dalhammar, C., Richter, J., & Montenegro, P. (2024, June), Sweden	Drivers and Barriers for “Circular” Consumer Electronics in the European Union	Expect outcomes of the "policy mix" = ESPR & Bat. regulation			NO
Gianvincenzi, M., Marconi, M., Mosconi, E. M., & Tola, F. (2024). Italy	A Standardized Data Model for the Battery Passport: Paving the Way for Sustainable Battery Management	Conceptualize a data model that ensures compatibility with various software applications across the battery life cycle	Various battery types	The whole life cycle	NO
Gutwald, B., Baumann, N., Funk, F., Reichenstein, T., Albayrak, B., & Franke, J. (2024, June), Germany	Sustainable manufacturing practices: A systematic analysis and guideline for assessing the industrial Product Carbon Footprint	Provide guidelines for determining the Product's carbon footprint			NO
Haupt, J., Cerdas, F., & Herrmann, C. (2024), Germany	Derivation of requirements for life cycle assessment-related information to be integrated in digital battery passports	Conflict areas of DBP together with requirements of actors		LCA-related information into DBP	NO

Hassini, M; Redondo-Iglesias, E and Venet, P, 2024, France	Battery Passports for Second-Life Batteries: An Experimental Assessment of Suitability for Mobile Applications	Second-Life Batteries	EV batteries	Second-life usage	NO
Heldt, L. Ekaterina, P.. 2024, Sweden	"When upstream suppliers drive traceability: A process study on blockchain adoption for sustainability."	Insights from an upstream (vs downstream) perspective and investigates blockchain's implementation.		Upstream supply chain and supply chains in general	NO
Jansen, M., Meisen, T., Plociennik, C., Berg, H., Pomp, A., & Windholz, W. (2023). Germany	Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems	Identify the requirements for a DPP system to achieve scalability		The whole life cycle except EoL for DPP	NO
Kies, A. D., Siegert, F., Ackermann, T., Krauß, J., Grunert, D., & Schmitt, R. H. (2023). Germany	Product-specific Identifiers and Data Aggregation for Enabling Traceability in Battery Cell Production. Procedia CIRP	Introduce a concept for realizing a traceability system in battery cell production		Cell production	NO
Naseri, F., Gil, S., Barbu, C., Çetkin, E., Yarimca, G., Jensen, A. C., ... & Gomes, C. (2023).	Digital twin of electric vehicle battery systems: Comprehensive review of the use cases, requirements, and platforms	Use case for ex. repurposing, second-life, and recycling	EV batteries		NO
Neri, A., Butturi, M. A., Sauer, H. L., Lolli, F., Gamberini, R., & Sellitto, M. A. (2024)., Italy, Brazil	Distributed Ledger Technology selection for Digital Battery Passport: A BWM-TOPSIS approach	Finding the best fir DLT platform for developing DBP		Storage of DBP data platforms	NO

Niemi, T., Kaarlela, T., Niittyviita, E., Lassi, U., & Röning, J. (2024). Finland	CAN Interface Insights for Electric Vehicle Battery Recycling	How to extract data from integrated battery monitoring systems in the recycling process of electric vehicle batteries	EV batteries	Lifecycle data necessary for Recycling phase	NO
Ott, J., Schoeggl, J. P., & Baumgartner, R. J.r, 2024, Austria	End of life focused data model for a digital battery passport	Looks at a suitable way to set up a battery passport to support the EoL of lithium-ion batteries.			NO
Otte, S., Sufian, N. N. A. M., Schabel, S., & Fleischer, J. (2024), Germany	Identification of Relevant Parameters for Traceability in the Continuous Mixing Process in Battery Cell Production	Traceability during the mixing process of the cell production			NO
Popowicz, M., Pohlmann, A., Schöggl, J. P., & Baumgartner, R. J. (2024), Austria	Circular and sustainable battery design – The case of digital product passports as information providers during the design phase	Identifying DPP parameters of interest when designing batteries		Design phase	NO
Plotnikov, M., & Schier, A. (2023), Germany	Concept About Shared Digital Twin of EV Batteries to Improve the Data Exchange in the Context of Battery Transport	Transport information of batteries	EV batteries	Transport	NO

Siska, V., Al-Akrawi, A., & Zackrisson, M. (2023), Austria, Sweden	Building a Sustainable Battery Supply Chain with Digital Battery Passports	Outline the concept of the battery passport, including the status of the relevant regulations, standards and initiatives.	Li-ion battery	Whole value chain	NO
Soufi, C., Mesbahi, T., & Samet, A. (2023, October), France	Digital Battery Passport as an Enabler of Environmental Impact Assessment in Electric Vehicle Applications	Implementation technologies of DBP.	EV batteries		NO
Rufino, CA Jr; Sanseverino, ER; (...); Zanin, H, 2024, Brazil, Germany, Italy	Towards to Battery Digital Passport: Reviewing Regulations and Standards for Second-Life Batteries	Who will own the batteries at the end of their life?	EV batteries	Second-life usage	NO
Terkes, M., Demirci, A., Gokalp, E., & Cali, U., 2024, Turkey, Norway, U.K.	Battery Passport for Second-Life Batteries: Potential Applications and Challenges	Second-life applications	3 selected models	Standards, regulations, second-life application areas, recycling process	NO
Timms, P. D., & King, M. R., 2023, U.K.	Complexity in the delivery of product passports: a system of systems approach to passport life cycles	Digital product passport 'ecosystem'		Engineering, use, re-use, and EoL processes	NO

Walden, J., Steinbrecher, A., & Marinkovic, M. (2021),	Digital Product Passports as Enablers of the Circular Economy	Early studies looked at the concept of a digital product passport as a tool for implementing and scaling the circular economy.		Circular economy	NO
Weng, A., Dufek, E., & Stefanopoulou, A. (2023), USA	Battery passports for promoting electric vehicle resale and repurposing	Defining: Remaining Useful Life (RUL) to predict repurposing	EV batteries	Repurposing more easily through RUL	NO

Appendix B

General questions asked to all interview targets:

- What is the most important thing that DPP can bring?
  - How do you think DPP will impact your business, operations and work?
  - How easy is it for various actors to integrate DPP into their processes?
  - How do you view DPP, and do you believe it is a good path towards a more sustainable society for Sweden and the world?

- What are the biggest challenges regarding the regulations for DPP?
  - Do you see any risks or loopholes with DPP?
    - What are the largest challenges related to the regulations, or do you identify gaps in the directives that need addressing?

- How often does the information in DPP need to be updated, and how is it ensured that it remains current?
  - When does responsibility for DPP end, and how does one secure updates?
  - How should data be protected and updated throughout its life cycle?
  - What is important to think about when ending a DBP?
    - What would be a suitable procedure?

Appendix C1 - CIT expert interview protocol

Scoping interview protocol with CIT experts

- We understand that you worked with DPP in the past. Can you tell us a little about your experiences? How long? / When did these projects start?
  - How has DPP worked in the past in those projects you have been involved with?
  - How often does the information in the DPP need to be updated, and how is it ensured that it is kept current in previous projects?
  - Who owns the data in a DPP?
  - Has there been confidential data? And how is it protected?
  - How has DPP been received by the user? Creator?
    - How easy is it for different actors, especially SMEs, to integrate DPP into their processors?
  - Can you identify any lessons learned from the DPP work in these areas that might be relevant to the battery industry?

- How is end-of-life handled for the DPPs you have been involved in?
  - When a DPP has ended:
    - How is this data stored?
    - Has there been an interest in going back into the "archive"?
  - Do you think there is anything extra important to consider at EoL?

- Do you think it would have been possible to standardize DPP across different product categories/manufacturers? Benefits/Disadvantages?

- Do you have something that you think might be particularly important for us to think about during the work?

Appendix C2a - CIT expert 1 interview summary

This is a summary of the interview with a CIT expert involved in several DPP projects, lately connected to furniture and textiles.

The discussion focuses on the challenges and opportunities of DPP, particularly in relation to batteries and electronic products, as well as their potential to enhance sustainability and circularity across various industries.

One of the key points discussed is the need for standardization and interoperability among different systems and stakeholders to ensure that DPP can function effectively. This includes the development of open standards and technical systems capable of managing diverse product bases and volumes of information.

The discussion also highlights the importance of understanding the current state and baseline for different industries and products before implementing DPP. This may involve site visits and analysis of existing processes and systems to identify areas where DPP can enhance sustainability and circularity.

Another critical point raised is the need to develop standards for expressing circular properties, such as repairability and recyclability, in a machine-readable format. The interview target expresses the need for everything to be as time-consuming as possible to not become a hindrance for companies. If as much as possible could be automated, it would be beneficial. While this presents a challenge, DPP needs to function efficiently.

Appendix C2b - CIT expert 2 interview summary

This is a summary of the interview with a CIT expert involved in several DBP projects, lately connected to batteries.

The conversation revolves around the topic of DPP and its implementation in various industries. The expert shares her experiences and insights from working on projects related to DPP, including the Keep 3 project, which is part of the larger Trace for Value project.

She explains that DPP is a digital document that contains information about a product's life cycle, from production to end-of-life. She highlights the benefits of DPP, including increased transparency, improved product safety and enhanced customer trust. However, she also notes that implementing DPP can be challenging, particularly for small and medium-sized companies. The conversation also touches on the topic of data management and the need for a standardized system for collecting and storing product data. She further mentions that the European Commission is working on developing a framework for DPP but notes that it is still in the early stages. Together with the understanding what system is required and how to end a DBP one must understand what needs exist and what events can happen with the system

In terms of the potential impact of DPP on businesses, she suggests that it could lead to increased costs and administrative burdens, particularly for smaller companies. However, she also notes that DPP could provide opportunities for businesses to differentiate themselves and improve their sustainability credentials. The conversation concludes with a discussion on the potential risks and challenges associated with implementing DPP, including the need for data security and the potential for loopholes in the system. The interview target emphasizes the importance of ongoing testing and evaluation to ensure that DPP is effective and efficient. Adding that no one will be able to create a functioning system by themselves, collaborations over the industrial borders are needed.

Appendix D1 - Car manufacturing interview protocol

Interview protocol with the car manufacturing employee

- How do you work with traceability today?
  - Do you have any ongoing projects/thoughts regarding the introduction of Digital Product Passport (DPP) into your businesses?

- What events can lead to a battery being taken out of order today? (In the future, lead to DPP EoL)
- How are batteries treated if they have been in an accident/exposed to extreme events etc.? Low SoH? Early faults within the warranty period? What is currently happening with your unsold batteries?

- On what occasions do you do refurbishment or remanufacturing?
    - When you repair or refurbish a battery in your battery centers are you changing part number?
    - Do you intend to create a new DPP and refer to the original DPP? If so, what do you do with the old DPP?
- How are batteries treated in the latter part of your value chain?
- Meaning dismantling, preparation of recycling, etc. Do you have established partners for this? How will you secure your flow of EoL batteries and the recycled content?

- (Linked to DPP) Which steps in the value chain do you consider to be part of your responsibility and when does it end? Consider the following steps: Use phase within warranty, 1st life repair/refurbish, Refurbish/repurpose for 2nd life, Recycling, accidents within and without warranty
    - When will you transfer the DPP to the next economic operator? How do you ensure that they get access and can authenticate the DPP?
  - What kind of information is it that you pass on to the next player in the value chain?
  - How do you ensure that confidential data and company secrets are not disseminated?
  - Will you be forced, according to new laws, to disclose information that was previously classified?

- Do you have interest in continuing to get access to the DPP updates of the batteries that have been transferred to the next economic operator (within warranty period, without warranty)?

Appendix D2 - Car manufacturing interview summary

This is a summary of the interview with the End-of-Life Battery & Circularity Manager at a car manufacturing company.

The interview started off by discussing the company's approach to DBP and its implications on the automotive industry. This car manufacturer has already launched the DBP with one of their cars, which provides a unique identifier for each battery pack and tracks its history from production to EoL. Although, they do not have any ideas of how to end a DBP yet, according to the interview target. It is still a long way in the future he explains and still a lack of research and guidelines on DBP management at EoL, with no studies specifically addressing this area, so they are waiting for further delegated acts from the EU.

The overall expectation of the DBP is positive enabling higher efficiency and transparency of processes. It will help the business to become more sustainable by providing full material traceability and enabling the company to track the origin of raw materials. He also noted that the DPP will contribute to the company's sustainability targets and help to reduce the environmental impact of battery production. In the longer timeframe, the belief is that DBP also can benefit from greater control of the batteries and being able to monitor and predict services and warranty errands through DBP together with identifying possible improvements when developing the batteries. The interview target emphasized the importance of traceability in the battery supply chain, particularly when it comes to repairs and recycling. He noted that they, as a company, have a system in place to track repairs and updates to the battery passport, but this becomes challenging when batteries are repaired outside of the company's ecosystem.

The conversation also touched on the topic of EPR, where manufacturers are responsible for collecting and recycling batteries at the end of their lives. The interview target explained that the car manufacturer has partnerships with recyclers and is working towards closing the loop on battery recycling, for example in China where he is explaining that recycling sites often are placed in connection to cell production.

When talking about how they treat EVB in their life cycle through repairs, remanufactures, reuse and recycle the car manufacturer stated the idea is to perform repairs on batteries and they keep rotating between cars within warranty time. He states, "We want to provide the same state of health or much better state of health bags to our customers, but we want them to be repaired." When doing repairs there is no need to change pack ID and create a new DBP. When doing remanufacturing on the other hand, they need to do certain conformity assessments and quality assurance tests, which forces them to create a new pack ID for that battery and so also a new DBP. The discussion also covered the topic of unsold batteries and whether they would require a DPP. At their factory, a DBP is created for every battery produced, regardless of whether the car is sold or not.

When repurposing their batteries it was very clear that the battery needs to be transferred to the new actor who will be assigned as the new REO when the product is put on the market together with a new DBP linking back to the original DBP. This was to protect the brand image in case of an accident where someone had made changes to the battery or something similar. The concern about sharing confidential data was discussed and he stated that they stick to certain data governance principles and to their own DPO approvals. Some data are required to be shared according to the regulation, but they don't disclose anything that is affecting their IP.

Finally, he highlighted the companies' bigger challenges in implementing the DBP, particularly when it comes to third-party workshops and independent repair shops. He emphasized the need for delegated acts to clarify the regulations and ensure that all stakeholders are on board with the new requirements.

Appendix E1 - Swedish Vehicle Authority interview protocol

Interview protocol with the Swedish Vehicle Authority employee

- How did the Swedish Transport Agency come to be established, and why did it begin maintaining a registry of all vehicles in Sweden?
    - Who has access to what data?
        - How do you ensure the correct parties receive the appropriate data? Workshops, Vehicle owners, Swedish Transport Agency & OEMs, etc.
        - What responsibilities do the different stakeholders have?
        - How can parallels be drawn to data stored in DPP?
    - Do you think a similar independent entity would be required for DPP for batteries in the future?
    - Could DPP for vehicle batteries be integrated into your existing vehicle registries?
    - Do you currently have any ongoing projects related to DPP?

- How is communication handled between you and OEMs when a new vehicle is produced and needs to be registered?

- Who owns the vehicle, and how is ownership transferred among actors in the value chain in the case of an accident? When introducing DBP, how will that affect?
    - Will the person responsible for the vehicle also be responsible for the DPP?
        - Who is responsible for ensuring the data in the DPP remains relevant?

- Would it be valuable for you to know what happens to batteries no longer in vehicles?

- Can you describe the car scrapping process today and draw parallels to how it might be affected by the implementation of DPP for batteries?
    - When a vehicle is decommissioned/scrapped, who is the sender and recipient of this information, and how is it processed?
    - How do you ensure that a scrapped vehicle cannot continue to be used?
    - How is data on scrapped vehicles stored today?

- To conclude, do you think DPP for batteries could be managed similarly to the registry that you have today?

Appendix E2 - Swedish Vehicle Authority interview summary

This is a summary of the interview with an employee at The Swedish Transport Agency, working with regulations for cars and previously being involved in electric cars due to the battery regulation.

He began by explaining the vehicle registration, battery passports, and EoL vehicles. The discussion highlights the agency's role in registering vehicles, including electric vehicles, and the use of digital systems to track ownership and registration of the vehicle.

The Swedish Transport Agency is responsible for registering vehicles in Sweden, including electric vehicles. When implementing DBP he does not think they will be taking a very big part of that record. Today, their registries contain static data and are not often updated. For example, they do not keep track of individual components for each vehicle, so they cannot identify which battery is located in what car.

He is describing how dismantlers today have a certificate to mark vehicles EoL. He is reasoning about the correlation of DBP predicting that one selected authority will have to approve which recyclers have the certificate to give permission to end DBP and access to its sensitive information.

Appendix F1 - Global standardizing organization interview protocol

Interview protocol with global standardization organization where the questions referring to DPP User Stories V3 published by Cirpass 2 (2024).

User Story 9:

- In the automotive industry, for EV batteries, is the car manufacturer the REO in this user story?
- Would it be possible for someone who put a battery on the market not to be the REO after the car with its battery has been sold?
- During the usage phase, is it the REO's responsibility to update dynamic data?
- In user story 9, #12-14, can this be assumed to happen in-house in the example? If DPPSP were hired, would these tasks fall under DPPSP?
    - How will this be controlled? Random checks? By whom?
- The car manufacturer mentioned that dynamic data could be read remotely from the battery via the car. Or could it become mandatory for car owners to approve this type of reading?

User Story 11:

- "Transfer of ESPR-related legal responsibility does not necessarily lead to the creation of a 'new DPP' needing to be linked to the old DPP", as expressed in Article 10(d).
- Why? In which cases is this unnecessary?

User Story 13:

"An REO may decide to stop providing access to the DPP for a product when the "expected lifetime" has expired".

- With this assumption, does ESPR mean that a battery still in use beyond its "expected lifetime" can have its DPP terminated (even though the product is still in use)?
- What happens if a DPP is deleted when the product's lifespan is over, but the product continues to operate?
- Could the deletion of a DPP, as soon as it is legally permissible, complicate traceability? Is there a benefit to being able to track a product even when it is no longer in use or within its lifespan?

"DPP can no longer be accessed, updated, or otherwise utilized. The REO may still retain a copy of the DPP in their systems for their needs".

- Is there no requirement to store DPP data for a certain number of years after the DPP is terminated and the product no longer exists?

- Does this not apply to, for example, an old DPP for a product that has been and is still being used for repurposing purposes? (For example, an old EV battery is now in a battery storage system).
- Can these DPPs only be deleted once all components in the original DPP have been recycled?
- Is there an obligation for the REO to produce data for a deleted DPP of a product that no longer exists?
- When an original DPP is terminated, can a "backup copy" keep the DPP operational?
- If a DPP and a backup copy are deleted from the Registry and Web Portal, but a backup copy remains with the REO for internal use, do customers have the right to access it?

User Story 9+13:

- In the Cirrpass2 scenario, where a DPP is to be deactivated, the REO expresses a desire to terminate the DPP. What happens before and leads to this step? Why does the REO want to terminate the DPP?
- Discuss the correlation.
- Is 13 a subsequent step to 9? Can these be done simultaneously? If not, when is each step performed?

User Story 7+8:

- When information in the DPP is updated: Can it become too burdensome for the REO to double-check all information entering the DPP?
- (US9) When a DPP is terminated: Why is it optional to report this to the REO? In which cases might the REO not want to know that a DPP is no longer active?
- What happens if the REO ceases to exist, but the product and its DPP remain? Who becomes responsible for terminating or approving the DPP's termination?

- How did you develop the user stories?
- If you were to estimate, how far from reality do you think they are? (Especially EoL: 9, 11, 13)
- How has your interaction with the EU been? Are they aligned with your user stories?
- Is there anything specific you think needs to be worked on and developed concerning EoL?
- Anything important you think we should keep in mind in the rest of our project?

Appendix F2a - Global standardization organization interview summary

This is a summary of the interview with the head of global affairs at a global standardization organization.

The interview target explains that the overall expectations of the DBP are positive enabling higher efficiency and transparency of processes. As well as the importance of DBP, creating a more circular flow of batteries and materials, benefiting repurposing and EoL treatment.

He further explains that it is within the responsibility of the REO to create a DBP and to ensure it meets battery passport requirements. Additionally, the REO needs to have a copy of the most up-to-date version of the DBP, to ensure that the information is still accessible if potential failures occur or bankruptcy. The DBP with its copy can also, through agreement, be handled by a DPPSP, assigned by the REO. Along the responsibility as REO, there is the EPR, which implies that producers are required to take care of and handle their products after use. The DBP is managed by the REO, which means that only they have the ability and access to end the DBP.

He describes that the ownership over the DBP does not correspond to the ownership of the battery. Ownership of a battery by consumers allows them the freedom to use it as they wish, which reduces REO control. Implementing a closed-loop system and leasing batteries could strengthen the REO's control and enable greater oversight over their products. He further explains that the REO should be very sure that the products no longer exist on the market to remove the DBP, therefore it is practical if REO could be informed when the product no longer exists.

When creating a new DBP in the repurpose stage, the new one shall be linked to the original DBP, but exactly how this will be implemented is not yet decided. One of the characteristics of the new DBP is to show which product the corresponding modules were attached to before. If the new DBP is linking back to an original DBP, it is recommended to not end the original DBP in order to keep the link active. An alternative to keep the information from the original DBP is by copying and storing the data, which is safe and possible since the information in the original DBP will not update. It is still uncertain if it is possible to activate a DBP that has been ended, which is one of the reasons why it is important to be careful when ending a DBP.

The interview target explains that there is an uncertainty when parts of a battery are being further used while the rest is sent to recycling. Since the original battery does not exist, neither can the original DBP be active either. He also highlights the question of who to trust when it comes to the EoL information and how to verify that the information comes from a credible source. One selected authority will approve which recyclers have the certificate to give permission to end DBP and access to its sensitive information.

He mentions that receiving information when the products and their DBP have ended could be valuable for the REO, giving insight into how the product has worked, when it was taken out of use and why, as well as that the DBP could provide a more realistic insight into how long the product has lived. The Commission shall also be informed when products cease to exist, but which actor would be suitable for this is not yet decided. When the product and its corresponding DBP ends, there seems to not be any interest in taking part in its information after the product has left the value chain.

Appendix F2b - Global standardization organization evaluation summary

Summary of the evaluation interview:

The purpose of the meeting was to discuss the concept and results of this master thesis. Starting off, the students presented the value chain where the interview target confirmed the complexity of the battery value chain, which involves multiple stakeholders, including manufacturers, recyclers, and regulators. The following is a discussion held around the results presented.

Deactivation is essentially a status marking within the system. It does not truly represent an end but rather a pause where no additional information can be added, akin to being "put on a shelf." The product remains linked to other components and is "active" in a sense. This raises questions about the product's identity, such as whether the engraved QR code needs to be altered or if it can retain its original code, which inherently links back to the initial REO. Maintaining the original identity has inherent value for traceability but also creates challenges since the old QR code won't connect to the new product passport unless the previous REO acts as a service provider and redirects it, which complicates the process.

For independent actors updating battery passports, technical clarity is lacking. Questions arise about whether REOs should establish APIs accessible to recyclers or if recyclers should submit updated suggestions to the REO, leaving the latter responsible for approval. This introduces the risk of untrustworthy updates. A solution proposed is that independent operators with agreements with REOs gain API access, while others submit update logs for REOs to integrate, preventing unauthorized access. Still, this poses risks of overlooked updates.

Repurposing agreements between OEMs and operators also faces legal challenges. Warranty periods play a key role—unauthorized modifications during this period may void the warranty, but post-warranty, the OEM cannot stop reuse. DPPSP akin to service facilitators, are not active stakeholders but support the REO as needed, akin to email or hosting services.

When ownership of a battery changes, such as during an accident where it transitions between owners like insurers, dismantlers, and recyclers, the REO retains responsibility until the battery reaches remanufacturing, repurposing, or recycling. Digital receipts for ownership transfer are supported as they can link to the original passport for reference, though updates are not possible after the battery leaves its original application.

Ultimately, only the REO can finalize a DPP, although recyclers can recommend closure after processing. Authorities could perform spot checks and mandate regulatory measures to prevent early closures. Certification systems are necessary to ensure that only approved recyclers handle sensitive information in product passports. While some REOs may prefer self-recycling for material recovery, ensuring standardized practices remains critical.

Traceability is pivotal, with examples like BMW using RFID tags on individual cells to maintain tracking through production stages. This highlights the need for traceability information rather than individual product passports for each component. Identifying items down to the cell level aligns with modern traceability methods. The EU Commission suggests that only REOs, not recyclers, should finalize product registrations within the EU registry.

To make sure that batteries do not end up neglected during the user phase, creating a sink of unused batteries which could happen if operators choose to close the DBP without actually ensuring the proper handling and processing of the battery.

Appendix G1 - Repurposing of BESS interview protocol

Interview protocol for the repurposer of BESS

- How do you create energy storage today and who will DBP affect that?
    - Who are your customers? Even if you sell to a company, do you retain responsibility for the BESS?
    - What is your warranty period?
        - If your BESS requires service or remanufacturing, how is this handled?
    - What is your perspective on today's batteries moving towards cell-to-pack designs when you rely on modules for your storage solutions?

"The transfer of ESPR-related legal responsibilities to a new REO can only occur if there exists a contractual agreement with the previous REO or if the previous REO has gone out of business" according to the battery regulation.

- Do you have an existing agreement with car manufacturers? What does it entail?
- Currently, when do you take over legal responsibility for the batteries you purchase? How will this procedure be managed when adding DBP?

- How well do you know the batteries that arrive at your facility before you purchase them?
    - Is any diagnosis done before you receive them?
    - What is the most common reason for you to take over a battery?
- At the end-of-life for BESS, how do you currently ensure that the products are recycled?
    - How do you receive information that your products are no longer in use or have been recycled?
        - Is this information valuable to you?
            - When do you consider your responsibility for the DPP to end?
- If you are the REO and responsible for the DPP, and the only entity capable of terminating the DPP, how do you determine when you can deactivate it?
    - How do you ensure that you are aware of whether your products are still in use?

Appendix G2 - Repurposing of BESS interview summary

This is a summary of the interview with the CEO of a company which is repurposing used EVB for BESS.

The speaker explains the value chain of EVB, describing how the battery is transferred among actors like salvage operators, dismantlers, or insurance companies and finally second-life batteries, which have been used in electric vehicles, can be repurposed for energy storage systems. They test and categorize these batteries by dismantling them into modules and determining their remaining capacity and suitability for other applications. The conversation highlights the complexities of recycling and reusing electric vehicle batteries, including tracking and documenting the history of each battery module.

The speaker's business provides energy storage solutions to industries and energy companies, including the design, installation, and maintenance of energy storage systems. They also partner with a dismantler for battery testing and validation services. When diffracting the ownership of the battery and the ownership of the DBP, the repurposer explained that it was not a problem for them. They always rented their products to their consumers and kept the maintenance through a service agreement leading to taking back the product when it was exhausted. This assured the control of the batteries. If a breach outside the contract was committed, the contract was terminated.

The interview target also described the process of repurposing EVB today and how they expect it to be modified when adopting DBP. The battery needs to be transferred to him as the repurposer who will be assigned as the new REO when the product is put on the market together with a new DBP linking back to the original DBP. He described that modules from one EVB are not always used together but are divided into different battery packs. If modules are not usable, they are sent to recycling.

He is overall positive about DBP, hoping for standardization and regulation in the industry to ensure safe and efficient processes through the information that can be provided. DBP, he thinks, will facilitate his work as a repurposer, knowing what batteries he is provided with which will create a more circular flow of batteries, materials and EoL treatment.

Appendix H1 - Recycler interview protocol

Interview protocol for the recycler.

- Tell us about your processes
    - What important information about a battery do you need to know before recycling it?
    - If you only receive modules from batteries, how do you think these could be linked to the DPP? Do you need the original DPP for every module/component you receive?
    - When you receive batteries as waste, do you want them to still have an active DPP?
    - Would you then take over ownership and responsibility for it?

- How is the level of digitization in your facilities?
- What opportunities do you see for adapting your facilities to handle DPP during the EoL and recycling phases?
    - Could the DPP QR code replace the barcode you currently use in your facilities?
    - Would it be possible to sync the QR code so that when it is scanned upon entering the shredding process, the DPP is also terminated?

- Which actor in the value chain do you think is best suited to terminate a battery passport?
    - Should you be involved in this process, in your opinion? OR
    - If it becomes your responsibility to handle the EoL for DPP and terminate them, how would you like that process to look?
    - Would it work for you to notify the OEM, who would then inform the EU Registry?
    - OR should you notify the EU Registry directly?

- In terms of producer responsibility and producer responsibility organizations, what role will you have in this context?

    - Will you have agreements with producers to recycle their specific batteries, or how does that work?
- Must you be able to account for which batteries are included in the black mass you send for further processing? What type of information should you provide when selling recycled materials? Which DPPs are involved in that batch of black mass?
    - After sending the black mass for hydrometallurgy, do you know what happens to those materials?
- Can you obtain specific data on what percentage of a battery has been recycled?
    - How far back in the material's life cycle must the black mass be traceable? (eg., extraction, usage, and multiple recycling cycles)
    - How do you document this information?

Appendix H2 - Recycler interview summary

This is a summary of the study visit followed by an interview at the recycling site.

The interview is held with the business and prior technical specialist, discussing how DBP could be used to track and manage batteries throughout their life cycle, from production to recycling, with a focus on recycling. It is said that the handling of the batteries takes place at the module level. To the greatest extent, the battery comes disassembled in modules for recycling, which indicates that the modules may have been replaced for some reason, e.g. repair, remanufacturing or repurposing.

The interview target describes how they use DBP to track the batteries they receive for recycling and how they can use the information in DBP to improve efficiency and reduce costs for their recycling process. This is because DBP can help determine EoLbattery value through easier access to information that can promote and more precisely recycle and calculate recycled content levels of cobalt, lithium, nickel, and lead, which is a mandatory work task at the recycling site. He is therefore positive towards DBP enabling higher efficiency and transparency of their processes. This also applies to the fact of using DBP as a tool to create a more circular flow of batteries and materials, benefiting repurposing and EoL treatment.

The batteries received today are mostly insurance errands where batteries have been in an accident or warranty errands. The prognosis is saying that the amount of EVBs handled by this, and other recycling sites is expected to increase rapidly in the future in correlation to the normal aging of the battery. To be able to handle large amounts of EVB accepted at the recycling sites, DBP information regarding battery composition, hazardous substances, dismantling guidance, etc. to gain efficiency and safety for the employees is crucial. All this will make a great improvement over the current situations where arriving batteries are handled with no pre-knowledge. He explains that it is important that the information is available also on the module level and not only on the pack level. Receiving information about each module will facilitate the treatment when entering the recycling station. Currently, each module that arrives at recycling does not carry any information by itself, information of the module can only be found on the corresponding battery pack. Dismantling the modules from a battery is today done manually, a costly and timely process.

The recycler in this project explains during the interview that they annually report to the Swedish Environmental Protection Agency and to certain OEMs the amount of their batteries that they have recycled. They believe to have a similar role when the DBP is established. The question will be the same, an OEM will not know that the recyclers have received their specific product and that it has entered their recycling process yet. That will be something that they report back, or write into a system, but to whom this system belongs is still uncertain. They further explain that there could be other demands placed on them, perhaps it should be reported with a different frequency than it is done today or more ID specifically what has been recycled.

The recycler is reasoning about when DBP should be ended and states that if the DBP ends before it has reached them, there is a risk that some information during the product EoL would not be documented. Therefore, recyclers would be a reasonable actor who would have the right to end the DBP. This could be implemented in their work of today since they are already scanning every module as they enter the shredded to become black mass. The black mass is exported out of the Swedish borders to undergo hydrometallurgical processes.

Appendix I1 - Swedish Environmental Protection Agency interview protocol

Interview protocol for the Swedish Environmental Protection Agency.

- How do you view DPP, and do you think it is a good tool for a more sustainable society for Sweden and the world?
    - What are the biggest challenges regarding the regulations / do you see any loopholes in the regulation that need to be covered?
    - What role will you have with DPP?
        - Can the Swedish Environmental Protection Agency be the ones who approve who have the right to perhaps end a DPP or be the ones who notify the REO about when a DPP should be ended?
        - Who do you consider having the right to / be the most suitable to end a DPP?
        - Will you be some sort of supervisory authority?
        - What does the collaboration look like between the Swedish Environmental Protection Agency, other authorities, and the industry to promote the introduction of Digital Product Passports?
            - How do you view the number of actors (in the value chain) who are involved? Positive/negative with more?
        - Advantages/disadvantages if a third independent party were to be involved? Instead of end-to-end communication between actors.

- In what situations is REO transferred for DPP?
    - E.g. By accident:
    - Dismantler
    - Insurance company
    - Trader / Repurposer
    - Recycling station
        - At repurpose

- Can you briefly explain the concept and meaning of producer responsibility?
    - What is the main purpose of producer responsibility??
    - How is producer responsibility handled? Do you need to distinguish between DPP and the product?
        - That is, when the DPP is moved to the next REO, is the producer's responsibility then also moved?

            - E.g. In case of reuse where the battery is put on the market a second/third time e.g. BESS, is it still the one who first put the battery on the market who has the producer responsibility or is this moved to the next who is the new REO?
    - o How is DPP and producer responsibility transferred?
        - How will the above steps take place if there is a requirement for the OEM to take back their products at EoL?
            - How will producer responsibility benefit multiple phases of use and reuse?
                - o (or will it be an actor that relies on recycling used batteries?)
                    - E.g. repurpose: Must these actors then be connected to OEM OR
                    - Will the OEM have to manage repurposing in-house?
            - If you think for OEMs who want to increase their recycled content, producer responsibility is good because they want to be able to recycle their products.
- In terms of producer responsibility, you "extend" the responsibility for the OEM. When you talk about responsibility/ownership and control, we have understood from a car manufacturer that it creates some insecurities. E.g. Volvo is responsible even when the car has been sold, and control is in the hands of the owner. After all, the owner can choose any workshop and as soon as he chooses a workshop that is not an authorized brand workshop, Volvo completely loses control of the car and the battery.
    - o What is your view on that?
    - o Will there be further clarification in the regulation on how control can increase
            - If you intend to recycle, producer responsibility can make this difficult. From an environmental perspective, it is preferred to have more initiatives for recycling and the use of products and batteries to their full capacity.
                - o What do you think about this?
                    - Environment / Business glasses on
- Can you briefly explain the meaning of producer responsibility organization?

- Will it be relevant for recycling stations to own a DPP?
    - o When in the recycling process should a DPP be ended?
        - o E.g. when:
            - Prepare for recycling

            - The recycling station receives batteries/modules?
            - The battery is in black mass?
                - Must recyclers be able to report which batteries/DPP are part of a black mass?
        - Can you reclaim something classified as waste so that it is no longer seen as waste and allow it to be reused? What is ok? What is not ok?
            - What does the regulation say about a battery that is classified as waste instead of being recycled being reused as a spare part in a car?
                - If it is possible to "revive" a battery, how should such a DPP be treated?
                    - (Depending on when in the recycling phase the DPP ends, maybe the DPP hasn't even ended yet?)
                    - SCENARIO: If Stena receives a battery that they judge can be reused, either sell it or recycle it themselves. Do they then have the opportunity to do so?

- How do you handle DPP when individual components belonging to a DPP are reused and others are recycled?
    - E.g. by repurposing or remanufacturing?
    - According to producer responsibility, does this mean that even components that are replaced or "leftover" must be sent back to the producer?
        - One scenario: Volvo buys batteries from LG and puts them in a car, after the use phase the battery is taken apart by someone who wants to build BESS for repurposing where only certain modules are used. Other modules, should these be sent to LG or Volvo according to producer responsibility?
            - Is the scenario above possible following producer responsibility?
    - Batteries that are manufactured for a specific car manufacturer, are they "put on the market" by the battery manufacturer or is it first done by the car manufacturer? Since it was already predetermined where the battery would end up.

- Which actor in the value chain do you think is most suitable to end a DPP?
        - Do you think you should be involved in this? (e.g. that DPP ends in connection with the end-user leaving the battery for recycling. (two actors needed to terminate?)) OR
            - Alternative third party? (the one who owns the database where DPP is?)

- The EU registry where all data must be stored and updated, you will have something to do with it?
    - The battery regulation states that you can remove DPP after the "expected lifetime" of the battery. Does that mean you can archive DPP for batteries that are still in use??
    - If modules for a battery are reused, does the old DPP have to be active as long as modules from the original pack are still "alive" even though they are in a new battery pack that has a new DPP?
    - Will the data from DPP ever be permanently deleted? Or will you be able to have access
    - Is this correct: In ESPR, there will be a registry so you can see more. But that type of registry will not exist, as far as I know, for batteries, but everything simple is available locally

- What would an ideal case look like if you had to decide? End of life for batteries and DPP
- Do you have something that you think might be particularly important for us to think about during the work toward EoL for DPP?

Appendix I2a - Swedish Environmental Protection Agency 1 interview summary

This is a summary of the interview with the Swedish Environmental Protection Agency, on the battery regulation adaptive work for the government.

The interview focus was on the implementation of the EU's Battery Regulation and DBP in Sweden. The DPP will track the battery's life cycle, from production to recycling, containing information about the battery's performance, maintenance and repair history.

The Swedish Environmental Protection Agency will potentially oversee the implementation of DBP but nothing is yet decided, other authorities are also in the discussion of contributing with their area of expertise. Manufacturers on the other hand will provide necessary information for the DBP. He is wondering if recyclers potentially will update the DBP when batteries have been recycled. This is reasonable since they are the ones who know when the product is being recycled. Although one authority must approve what recyclers will have this ability, even though he cannot say anything about if it will be their responsibility or not. Regarding PRO, most probably the Swedish Environmental Protection Agency will be involved in approving these in the future, but still, it is not yet decided. Implementing the DPP poses challenges, including the need for a common standard, detailed information from manufacturers, and updates from recyclers. But he is also positive about the change, hoping it will create a more circular flow of batteries and materials. The conversation also touches on the topic of EPR, which refers to the obligation of manufacturers to take back and recycle their products at the end of their life cycle. He worked a lot with that in recent times. Although I did not really think about the consequences of EPR before. After a bit of conversation, he states that the EPR might favor EV manufacturers over environmental benefits due to promoting recycled content rather than several use phases. If OEMs and REOs are mandated to manage waste batteries, it is challenging for repurposing businesses to access batteries without agreements, raising market entry barriers. This situation may result in batteries being recycled prematurely, benefiting OEMs by increasing recycled content in new batteries but reinforcing a linear usage model.

He also discusses the different uses of different chemistry of batteries. For instance, he says, NMC batteries, designed for automotive use, are rich in critical materials like cobalt and nickel efficiency. Leading to NMC batteries are often prioritized for recycling to recover these valuable resources since some argue that NMC batteries are not always well-suited for BESS due to differing performance requirements and charging cycles. On the other hand, LFP batteries, which lack nickel and cobalt, may be more suitable for reuse in stationary storage systems. Lastly, he is describing how it works with the EU battery regulation stating that the new rules have been published, but the part about repurposing and EoL for DBP has not been finalized yet. The topic is complex, particularly regarding producer responsibility and reuse. To go through with a working DBP he highlights the need for close collaboration between different stakeholders to ensure a successful implementation.

Appendix I2b - Swedish Environmental Protection Agency 2 interview summary

This is a summary of the interview with an employee at the Swedish Environmental Protection Agency. The employee works within the resource efficiency unit regarding questions about waste prevention circular economy, sustainable consumption and production.

The interview target explains the importance of DBP and how it could create a more circular flow of batteries and materials, benefiting repurposing and EoL treatment. She further explains that the REO that puts the product on the market should be the one ending the DBP but means that the recycler could be a suitable actor that reports the occasion that the product no longer exists to REO, stating that they are the only one with that knowledge.

The REO shall by themselves store all data that the DPP contains. The thought is that the Commission shall establish a centralized registry where all the DPPs will have a unique label. The registry shall contain all existing DPPs. It is also thought that the registry eventually shall be connected with the customs authority's registry. This makes it possible for the customs authority to check if there are valid and active DPPs for products that are imported into the EU.

The expected lifetime of the DBP is not expressed in the ESPR, it only says that it shall exist at least as long as the product exists. All of this is described in the delegated acts for that specific product group. The employee expresses that she does not know what happens the day that the product becomes waste if the DBP ends simultaneously, as well as if the actor putting the product on the market receives information when the product becomes waste. The battery regulation is however not applicable for cells and modules but demands the suppliers to fulfill the demands on due diligence when assembling components to battery packs. Individual modules that are being sent to recycling have been discussed but have not heard that a solution has been found. However, the original DBP cannot describe products fully if parts from them have been picked out, since those modules are not in use anymore.

A continuing problem is with market controls and that there must be supervision around everything with the new legislation. Still do not know which authority will be given this responsibility, whether it will be the Swedish Environmental Protection Agency or another authority. It could be the Swedish Environmental Protection Agency; they work a lot with waste issues and material recycling. Waiting for Regeringskansliet to come up with some kind of regulatory letter, or for there to be some change in their instructions as to what questions they should handle.

Appendix J1 - Battery manufacturing interview protocol

Interview protocol for battery manufacturing

- What are the most important/current sustainability-related issues that you are driving today? How do you see this evolving in the longer term?
- What are your current priority preparations ahead of the Battery Regulation's requirements for digital product passports coming into effect?
- Are there any products in your portfolio today where you will act as the REO?
- Regarding data collection to populate the DPP with content – what types of data do you currently find most difficult to access? Why? What strategies do you have to address this?
- How are used batteries handled today during and after their first life?
    - How do you currently produce batteries/modules? Based on demand?
- What information about your batteries during their usage phase is valuable to you?
        - Is it important for you to get information when one of your batteries' DPP is terminated?
        - During recycling and EoL for DBP, how do you imagine this process working?
            - Who is best suited to terminate a product passport?
            - Would it be beneficial for you to be involved in some way?
- How do you think the new guidelines for producer responsibility and producer responsibility organizations will affect your way of working today?
- Do you have the ability to establish a closed loop for your batteries so that you know where the recycled material you use originates?
    - What is your view on your products potentially being reused? Versus being recycled to increase recycled content.
        - Are you aware of any reuse of your batteries today?

Appendix J2 - Battery manufacturing interview summary

This is a summary of the interview with two employees in the Sustainability department of a battery manufacturing company, followed by a round tour of the facilities together with the production manager, manager of application and a quality engineer.

The production manager and the sustainability experts at the company talked about due diligence and the challenges of getting the raw data from mining and extraction of raw materials outside of Europe. They explained that those are the first steps before refining and later cell, modules and pack manufacturing.

As of today, the battery module manufacturer saw the complexity of the regulation and potential costs associated with implementation, in need of a standardized approach to DPP and data management. On the other hand, they saw benefits, ensuring data accuracy and security. They really thought the implementation of DBP will impact the supply chain, particularly for companies importing cells from countries like China with the pressure to increase transparency, safety, and sustainability in the battery industry.

Representatives from the company shared their experience with other actors in the industry who shared their perspectives on the technical, administrative and economic aspects of DPP implementation. They emphasize the importance of collaboration and knowledge-sharing across industries. As well as industry standards and certifications, such as ISO 26262, in ensuring safety and reliability together with a centralized system to manage data required for DPP.

Although the new battery recycling site in Sweden is a step forward in managing waste batteries within Europe, one employee at the battery manufacturing site, working with sustainability, expressed the belief that batteries will be sent back to Asia to a large extent even in the future because of China's technological lead. China still has more advanced technologies refining materials, producing battery components and has a well-developed recycling system compared to Europe. Wherever the recycling takes place, they are arguing that the recycler would be a reasonable actor who would have the right to end the DBP. When that is done, they as an OEM think that it would be useful to receive information of when the products and their DBP have ended to provide insight into how the product has worked since this is not information that comes back to them today. Customers are free to do whatever they want when they have bought their batteries, so it is hard to have any control over what happens when the batteries are sold. The only way to gain control is by leasing the batteries, one of the sustainability employees thinks.

Appendix K1 - Swedish PRO interview protocol

Interview protocol for the employee at a Swedish PRO

- Can you tell us about your operations? What types of batteries do you handle?
- What role do you take in relation to OEMs/producers vs. recyclers?
- Do you currently have agreements with car manufacturers to act as their PRO?
    - In these discussions, have you also considered opportunities for reusing batteries?
- The purpose of DPP seems to be to monitor collection rates, increase them for batteries, and ensure they remain within Europe. What will your responsibility be in this?
    - Are you the ones who will report this type of statistic? To whom?
    - What role do you think you will play in the introduction of DPP?

- Producer Responsibility Organization: What does this mean for you today?
    - How will the new battery regulation change this?
    - Do you think you will be involved in owning DPPs?

- When you receive batteries intended for reuse or recycling, do you make the decision yourselves, based on agreements and trust from the REO/OEM? Or do you need to contact the REO for a decision on what to do with the batteries?
- How will you collaborate with producers in the future?

    - Which actor in the value chain do you think is most suitable to terminate a DPP?
    - How do you think the end of life of DBP would work to function smoothly?

Appendix K2 - Swedish PRO interview summary

This is a summary of the interview with an employee at a Swedish PRO working as a market and communications manager.

During the interview the organization's role in handling electronic waste, particularly batteries was discussed. This PRO operates a collective system for handling electronic waste, including batteries, and has a contract with municipalities to collect electronic waste, which is then sold to recycling facilities. Mainly they are handling smaller batteries which can be handled by consumers when taken out of their applications. The PRO started to collect EVB as well during the last year but saw that the request from car manufacturers to act as a PRO lacked demand and need. Also, the handling of EVB comes with higher risk and higher costs than for smaller batteries, so after a while they decided not to go through with it. EV batteries require special handling and transportation, and the organization has a system in place for tracking the origin of the batteries they collect, which they report back to the producers of which they have an agreement.

The conversation also touches on the topic of DBPs and how they might be used to track the origin and composition of batteries. The PRO expresses interest in exploring the potential of DBPs but notes that there are still many unanswered questions about how they would work in practice. He suggests that a system for verifying the destruction of batteries, potentially through a two-step verification process involving both the producer and the recycler, might be beneficial.

Overall, he is very excited about the DBP, explaining that they are as a company not there yet in terms of digitalization in their business. Although, he sees the potential in DBPs and is open to exploring new roles and responsibilities in the context of DBPs. However, he notes that this would require further discussion and clarification on the specifics of how such a system would work. He is hoping for future corporations over the border of the EU state members so that even the small fractions of scarce materials can be collected at one centralized facility in Europe to handle larger material volumes effectively for recycling this material.