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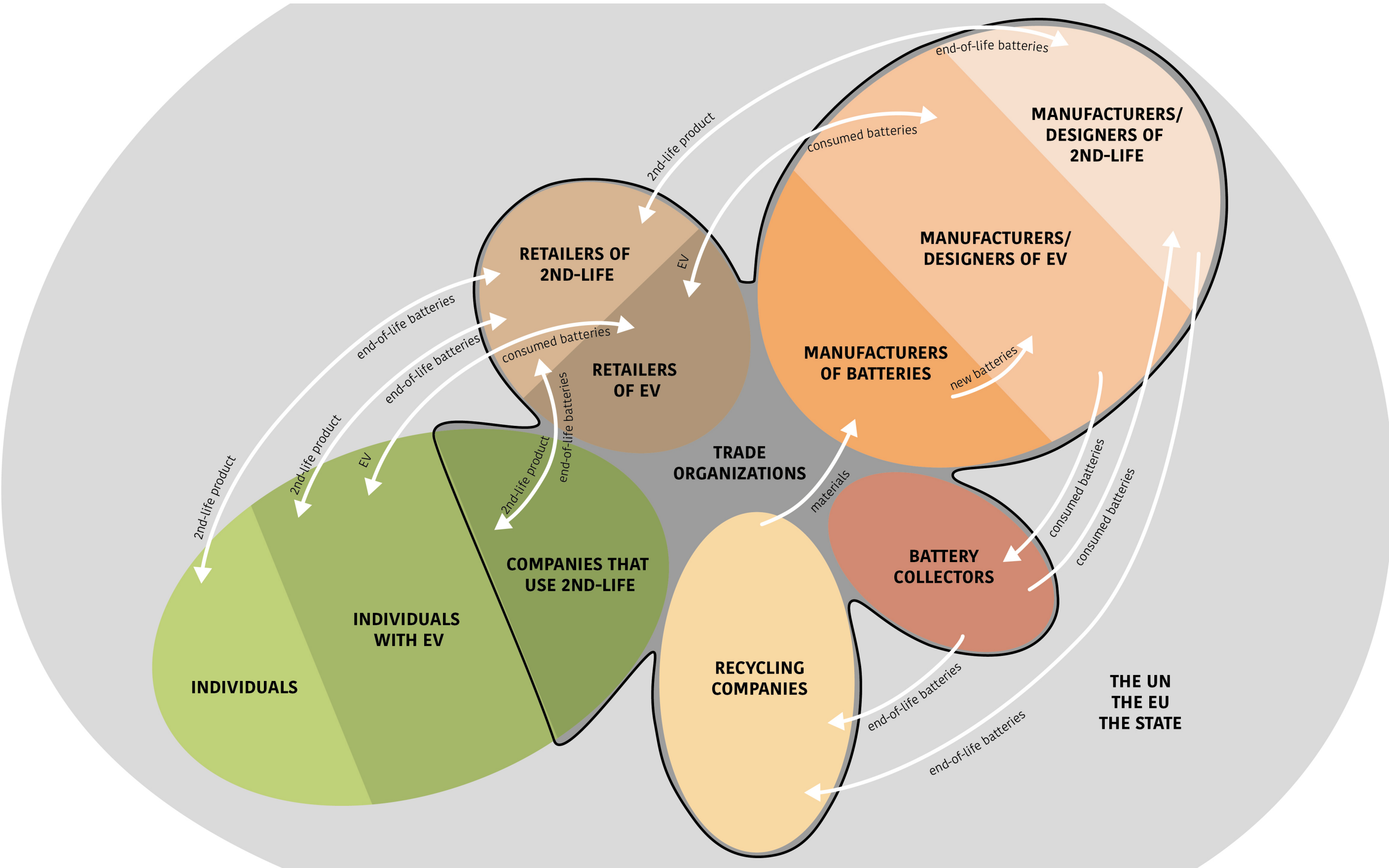

How to reuse consumed batteries from electric vehicles

Master's thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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ABSTRACT

Society is moving away from using finite resources and therefore the automotive industry faces a huge transformation. The vehicles of the future will be driven by electrical power and the use of lithium-ion batteries will increase dramatically. However, after some years of use, the lithium-ion batteries can only perform 80% of their maximum effect and that is not enough capacity in order for the batteries to be considered useful in these vehicles. The Swedish battery producer has a responsibility to recycle all batteries that are produced, but recycling batteries that still have 80% capacity left would be a waste of resources. Reusing these batteries in second-life applications would be a better alternative. However, there is a noticeable lack of knowledge of how to utilise the entire capacity of the battery and such knowledge has to be developed and spread in order to create a sustainable use of electric vehicles and their batteries.

The aim of the project was to contribute to creating a market for the reuse of batteries from electric vehicles.

The project has had both a system oriented approach and a user centered approach and the project has followed a design process.

The final result is divided into two parts, content and call-to-action. Content includes the system needed in order for the reuse of consumed batteries to work, guidelines for which standards that should be implemented and design suggestions for how consumed batteries can be reused in second-life applications. For both the system and the guidelines, the main target groups are decision makers such as trade organizations and higher authorities. For the design suggestions, the target groups are companies and individuals that could benefit from reusing consumed batteries in their business or in their home. Call-to-action includes a short-film that describes the issues and a website that gathers all information in one place in order for the stakeholders to be able to take part of it. The main target group for the short-film is trade organizations and the target group for the website is basically everyone, since all can benefit from this information.

Keywords: electric vehicles, consumed batteries, second-life products, reuse, recycle, sustainability, circular economy

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Gothenburg 3rd of June
Rebecca Sandberg & Emelie Sedén

TERMINOLOGY

- *Electric vehicle* - an electric car
- *Electric trucks* - other bigger electric vehicles
- *Consumed* - there is capacity left
- *End-of-life* - there is no capacity left
- *Batteries* - lithium-ion batteries
- *Consumed batteries* - consumed lithium-ion batteries from electric vehicles that have consumed 20% of their maximum effect and are not able to drive electric vehicles anymore
- *Second-life products* - products that reuse consumed lithium-ion batteries from electric vehicles
- *Reuse* - using something again
- *Reuse of batteries* - using consumed lithium-ion batteries from electric vehicles again
- *Recycling* - making use of materials from waste
- *Recycling of batteries* - making use of materials from end-of-life lithium-ion batteries

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1

INTRODUCTION

This chapter presents the background, the aim and research questions, the objectives, the demarcations and finally the report structure.

1.1 BACKGROUND

Society is moving away from using finite resources such as oil, gasoline and diesel (Naturvårdsverket, 2018), and therefore the automotive industry faces a huge transformation. The vehicles of the future will be driven by electrical power and the use of lithium-ion batteries in electric vehicles will increase dramatically (Gil-Agusti, Zubizarreta, Fuster & Quijano, 2014).

However, after some years of use, the lithium-ion batteries that drive the electric vehicles can only perform 80% of their maximum effect and that is not enough capacity in order for the batteries to be considered useful in these vehicles (Guenther, Schott, Hennings, Waldowski & Danzer, 2013). In Sweden, the battery producer has a responsibility to collect and recycle all batteries that are produced (Naturvårdsverket, 2018). However, these batteries still have 80% capacity left and recycling these batteries right away would be a waste of resources. When the batteries are no longer useful in electric vehicles, they have potentials in being used in second-life applications such as different grid solutions. If these batteries goes directly to recycling, the grid solutions need to produce new batteries. This means a negative impact on the environmental since the manufacturing of batteries contributes to a big negative environmental impact (Casals, Garcia, Aguesse and Iturrondobeitia, 2017). If the batteries instead are reused in the second-life applications, this environmental impact of producing new batteries could be avoided. So the consumed lithium-ion batteries from electric vehicles should firstly be reused in second-life applications and later be recycled, this since it utilizes more of the capacity of the batteries and also because it reducing the number of newly produced batteries (Canals Casals, Amante García and Cremades, 2017).

There are two problematic issues with reusing consumed batteries from electric vehicles. The first one is that the huge amount of consumed batteries that will follow the development of electric vehicles is viewed as a future problem and therefore, it is not being taken seriously enough at the moment. Most manufacturers and designers of electric vehicles have their main focus on the first stage of the electric vehicle's lifecycle, which is to create the best and most advanced electric vehicle on the market. The later stage of the electric vehicle's lifecycle, when the batteries do not have enough capacity left to be considered useful in electric vehicles, has not been taken into enough consideration. The manufacturers and designers of electric vehicles seem to think that it is someone else's problem to solve in the future, since they do not have any plan for what to do with the consumed batteries.

Once it has been acknowledged that a plan for what to do with the consumed batteries is needed, the second problematic issue is to solve how the consumed batteries should be taken care of and how the system should work, and this is where complexity comes in. Today, a system for how to take care of and reuse these batteries is missing. There are some ideas of how to reuse the consumed batteries from electric vehicles in second-life applications such as different grid solutions (Cready et al. 2003; Williams and Lipman 2010; Wolfs 2010), but not enough effort has been put into this part of the batteries' lifecycle. There is a noticeable lack of knowledge of how to utilise the entire capacity of the battery and such knowledge has to be developed and spread in order to create a sustainable use of electric vehicles and their batteries. Without a system for how this new market with reusing consumed batteries from electric vehicles in second-life applications should work, we will in some years face a problematic situation with a huge mountain of batteries that no one knows what to do with.

However, there are a lot of challenges with creating a working system within the reuse of consumed batteries from electric vehicles. One of the challenges is the many involved stakeholders within this new system such as the many different companies and organisations that all have their own wills. All these stakeholders need to collaborate in order for the system to be implemented (Mathur, Deng, Singh, Yih and Sutherland, 2019). This, since the different stakeholders are part of different stages in the life cycle of the battery and therefore they are dependent on each other in order for the system to work. No single actor or producer can implement this new system by itself and therefore, collaboration is the key.

Apart from the challenges, there are also great opportunities with creating this new market. Reuse of consumed batteries from electric vehicles is often seen as an opportunity to delay disposal and recycling of these batteries, as well as an opportunity to squeeze value out of existing resources (Olsson et al., 2018). However, the low volumes of batteries on the market today mean that the possibilities of such a business are small, but in the next few years, the volumes of consumed batteries from electric vehicles on the market are expected to increase greatly and therefore, possibilities of these businesses will increase as well.

Recycling companies also see new opportunities, this by making themselves natural intermediaries between the end user of the electric vehicle and a second life for the battery. However, in order for a consumed battery to be useful, it needs some degree of repurposing i.e. adapt the consumed battery for use in a different purpose (Olsson et al., 2018). Some third-party entrepreneurs are currently trying to establish second-life battery businesses, with repurposing as the main part of their business models. Some energy storage suppliers also work with giving consumed batteries from electric vehicles a second life by refurbishing them for new applications.

So there are economic gains associated with both reuse and recycling of batteries from electric vehicles, but the greatest economic gain is created by first reusing, then recycling (Mathur et al., 2019). This, since there are economic gains in both the remaining capacity and in the materials of the batteries.

1.2 AIM AND RESEARCH QUESTIONS

The aim of this project was to answer the following research questions:

- How could consumed batteries from electric vehicles be reused in second-life applications?
- Which are the relevant stakeholders and what are the possible relationships between them?
- How to explain the complex issues with reusing batteries from electric vehicles in a clear way in order to make people aware of its extent?

On a larger scale, the aim was to contribute to creating a market for the reuse of batteries from electric vehicles and to inspire companies and organisations how to take care of the values of these consumed batteries by firstly reuse and then recycle the batteries.

1.3 OBJECTIVES

The two main objectives of this project was first to deliver reliable and knowledge based information about the problematic issues regarding the reuse of batteries from electric vehicles and then to come up with a proposal in terms of a system for how the reuse of consumed batteries could work.

Included deliverables in these main objectives was firstly a short-film that explains the complex issues in a clear way, this to make people aware of the extent of the issues and to inspire higher authorities, the UN, the EU and the State of Sweden, to take action. As an addition to the short-film, the project was to deliver a website consisting of a system image, guidelines and design suggestions for how the different stakeholders can take action against the issues. Both the short-film, the system image, the guidelines and the design suggestions were based on the gained knowledge about the issues.

1.4 DEMARCATIONS

The project was limited to countries with an infrastructure such as the infrastructure in Sweden. This demarcation was made because the system of reusing consumed batteries from electric vehicles requires transportation, which means that the system is dependent on well working roads, railways, harbours and other parts of the infrastructure that are involved in transportation.

1.5 REPORT STRUCTURE

After the introduction there is a description of the project process. This chapter describes the process of the project and what different choices that were made, but it also includes a more specific description of which and how different methods have been used.

The next chapter is a theoretical chapter that is called circulating batteries. Here, the result from both the theoretical and empirical studies is presented. The chapter includes relevant information about lithium-ion batteries, a general description of circularity and how circularity can be used in different companies and also.

After the theoretical chapter, the result is presented more thoroughly. The result is divided into two parts where the first one is called content and the second one is called call-to-action. Content includes the system image, the guidelines and the design suggestions and call-to-action includes the short-film and the website.

The three last chapters of the report are discussion, conclusions and further development. These chapters discuss and draw conclusions about the project on a more general level and discusses what the next steps would be for this project.

2 PROCESS

This chapter presents the process of the project. The project has had both a system oriented and a user centered approach. The system oriented approach was used in the beginning when creating the system image and the guidelines and the user centered approach was used later in the project when creating the design suggestion for *At home*.

2.1 PROJECT STRUCTURE

The project started by planning all activities involved in the project. A broad research was done in order to gain as much knowledge as possible about the problematic issues with reusing consumed batteries from electric vehicles. This research involved a literature study, several expert interviews and user studies. The process of the project is described in the picture below, see figure 1.

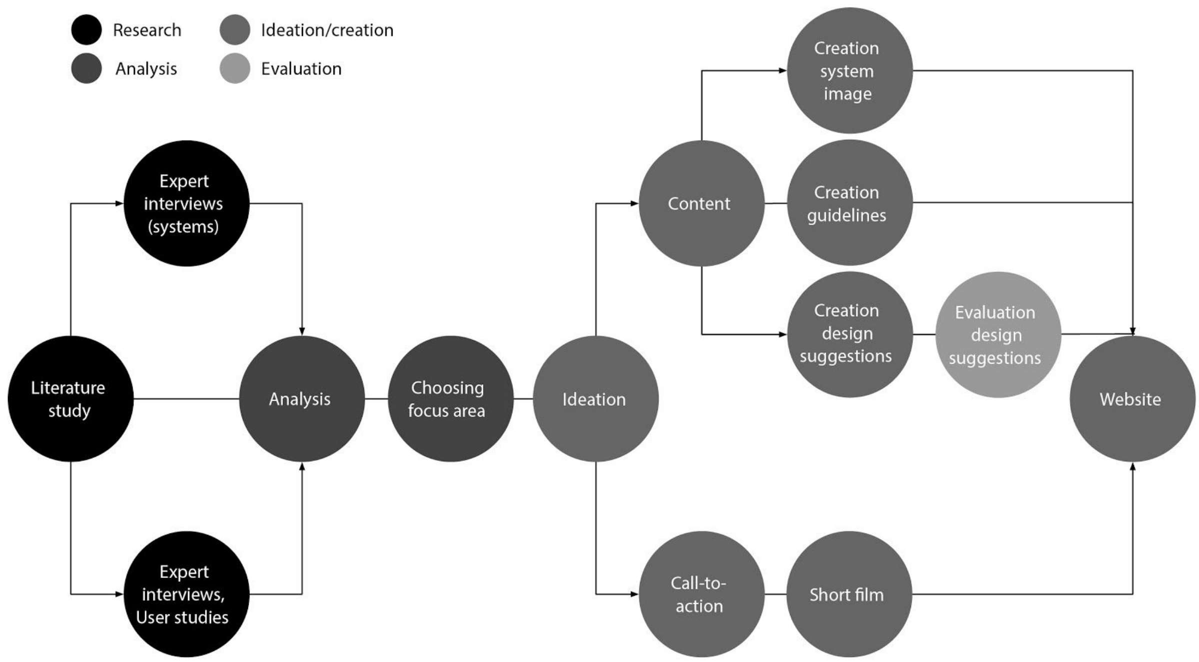


Figure 1: The project process

All gathered data was analysed and from this, a focus area was chosen and three main research questions were stated.

The next step was the ideation phase which was divided into two parts, see the ideation phase in figure 1. One of them was called content and the other one was called call-to-action. Content includes the system image, the guidelines and the design suggestions and call-to-action includes the short-film and the website. The design suggestions were evaluated and refined and one of them was further developed into a more detailed design suggestion. All these parts were based on the literature study, the expert interviews and the user studies.

Since this project has been a completely new area, the research phase stretched across the entire length of the project. This, because new information and knowledge was constantly needed.

2.2 DATA COLLECTION AND CHOOSING FOCUS AREA

A broad literature study (Bligård, 2015) was done to gain broader knowledge of the area to be investigated. Three research questions were stated; "How could consumed batteries from electric vehicles be reused in second-life applications?", "Which are the relevant stakeholders and what are the possible relationships between them?" and "How to explain the complex issues with reusing batteries from electric vehicles in a clear way in order to make people aware of its extent?". In order to answer the first research question the broad literature study included studies of circularity in relation to batteries, how batteries work and potential areas to reuse batteries.

The research phase continued by doing expert interviews. The experts that were interviewed were: Hans Eric Melin, founder of Circular Energy Storage Research and Consulting, Dr Christian Ekberg Professor Nuclear Chemistry, Chemistry and Chemical Engineering and Anders Grauers, associate Professor at Chalmers within electrical engineering and system-and control engineering and part of the project of electrifying the mine of Aitik, see table 1. A total of five interviews were conducted, where two of the interviewees, Hans Eric Melin and Anders Grauers, were interviewed twice. The purpose of these expert interviews was to get deeper knowledge about the areas of batteries, chemistry, battery reuse, materials, recycling of batteries and potential areas that could be users of second-life applications based on consumed batteries.

All expert interviews were done because the literature study did not provide enough information about the area of reusing batteries and therefore, complementary information was needed. The interviews were all semi-structured, with some structured, predetermined questions in the beginning of the interviews and some complementary questions in the end of the interviews. The interviews were held via email.

More specifically, Hans Eric Melin was interviewed in order to gain more knowledge in the area of reusing consumed batteries in second-life applications and Dr Christian Ekberg was interviewed in order to get more information about recycling of batteries. The interview guides with Melin and Ekberg are presented in Appendix IV and III. Anders Grauers was interviewed in order to gather knowledge about mines since mines was considered an area that could potentially benefit from second-life applications based on consumed batteries. The interview guides with Grauers are presented in Appendix V.

Table 1. List of expert areas and experts

Expert area	Expert
Batteries and reuse of batteries	Hans Eric Melin
Recycling of batteries	Dr Christian Ekberg
Mines	Anders Grauers

In addition to the expert interviews, user studies were conducted, see table 2. The user studies included observations, interviews with users and a survey. The hidden observations (Wikberg-Nilsson, Ericson and Törlind, 2015) were done by visiting two construction sites in the city of Gothenburg to investigate possibilities and challenges with introducing batteries in their business. Two additional semi-structured interviews were held with two male construction workers working on the construction sites, see Appendix II. This, to get more detailed information about the possibilities and challenges with introducing batteries on construction sites and to understand the user perspective. Lastly, a survey (Bligård, 2015) was sent out via Facebook in order to gain knowledge about how individuals would like to use batteries in their everyday life. 58 individuals that differed in age, gender and educational background answered the survey, 50% were younger than 25, 35% were between 25-40 years old and 15% were older than 40. 60% were women and 40% were men and lastly 67% had an educational background within technology/science and 33% had other educational backgrounds. This variation was considered sufficient to be able to do an analysis upon the answers and to later draw some conclusions from. The full version of the survey is presented in Appendix I.

Table 2. List of user study areas and method

Area of user studies	Method
Construction sites	Observations of, and interviews with construction workers
At home	Survey sent to individuals
Public areas	Survey sent to individuals

However, it was realised that the project was very broad. After analysing the gathered information using the method AIM (Alänge, 2009), restricted areas where access to electricity is limited were investigated, this according to the primary brief that was given in the beginning of this project. AIM is a method where qualitative data is analysed by dividing different identified aspects into different groups and then comparing these groups with each other (Alänge, 2009). AIM is preferable when a specific question or a problem is to be analyzed and post-it notes is a good tool to use when analysing and then presenting the analysis. The restricted areas, *Construction sites*, *Mines* and *Harbours*, were chosen. This since all have high emissions so an electrification of these restricted areas would also mean a big decrease in emissions.

Although, it was realised that the project would become very technical with this limitation. There would not be much design, form, colour and user perspective as wanted. Because of this, it was instead decided that the overall perspective would be the focus area of this project. It was realised from the research that no one had looked at the overall perspective before, and that information on this area was missing and much needed.

So when choosing the overall perspective as the focus area, the limitation was set to look at ten areas and create guidelines for each area. The ten areas became divided into two groups; areas for second-life and systems. Areas for second-life included *At home*, *Public areas*, *Construction sites*, *Mines*, *Harbours* and systems included *Circularity*, *Transportation*, *Manufacturing and disassembling*, *Collection of consumed batteries* and *Recycling*. The first five areas were chosen since it was found from research that it was these areas that could benefit the most from reusing batteries from electric vehicles. The second five areas were chosen since it was found from research that standards were needed to be set for these system areas in order for the new market with reusing consumed batteries to work. The guidelines were aimed as a help to create working systems and working implementations of batteries. Of these ten areas, design suggestions were to be made on the five areas for second-life; *At home*, *Public areas*, *Construction sites*, *Mines* and *Harbours*. This, to give more concrete examples to the stakeholders within these five areas of how they could reuse batteries. For the system areas, suggestions of standards and recommendations should be made for each area.

2.3 CONTENT AND CALL-TO-ACTION

When going into the ideation phase, it was realised that the three research questions differed a lot from each other and that the result had to be divided into two parts. The first question; “How could consumed batteries from electric vehicles be reused in second-life applications?”, was more product focused and had a user oriented approach. The second question; “Which are the relevant stakeholders and what are the possible relationships between them?”, had a system oriented approach and the third, and lastly the question; “How to explain the complex issues with reusing batteries from electric vehicles in a clear way in order to make people aware of its extent?”, was more how the message could be spread. Therefore, the ideation phase was divided into content and call-to-action. Content was the result itself and was primarily connected to the first and second research questions; “How could consumed batteries from electric vehicles be reused in second-life applications?” and “Which are the relevant stakeholders and what are the possible relationships between them?”. Call-to-action was how the result was to be mediated and was primarily connected to the third research question; “How to explain the complex issues with reusing batteries from electric vehicles in a clear way in order to make people aware of its extent?”.

2.4 SYSTEM IMAGE

To investigate and clarify which different stakeholders that are involved in the system, what their roles are and what relationships they have between each other, it was decided to create a system image. This system image was based on the information gained from research. By analysing the gained information from the data collection according to the method AIM (Alänge, 2009), the stakeholders were identified along with their roles and relationships. To visualize this, the system image was created. The system image was first created through sketching by pen and paper using brainwriting (Österlin, 2010) and then digitally in Illustrator. To better explain the system image, complementary texts were written. The system image is the result of the second research question and is presented in chapter 4.1.

2.5 GUIDELINES

When the guidelines were to be created for the different areas, the method AIM (Alänge, 2009) was used to further analyse the gathered data from research, the expert interviews and the user studies. Design suggestions were to work as guidelines for the areas for second-life; *At home*, *Public areas*, *Construction sites* and *Mines*, see chapter 5, and standards and recommendations were to work as the guidelines for the system areas; *Circularity*, *Transportation*, *Manufacturing and disassembling*, *Collection of consumed batteries* and *Recycling*, see chapter 4.2. The reason why *Harbours* was removed from the areas for second-life could be read in chapter 2.6. The reason why the areas for second-life only have design suggestions was since they were not in need of standards in the same way as the systems.

The result from the analysis was compiled into design suggestions for the areas for second-life, see chapter 2.6, and standards and recommendations for each of the system areas.

2.6 CREATION OF SECOND-LIFE APPLICATIONS

When moving on to the ideation process of the design suggestions for the areas for second-life, the methods brainstorming (Wikberg-Nilsson, Ericson and Törlind, 2015), brainwriting (Österlin, 2010), benchmarking (Nilsson, 2016) and sketching were used. The first two methods were used to get a large quantity of ideas, which was desired to boost the creativity and to get a lot of ideas to choose from later on. Benchmarking (Nilsson, 2016) was used to investigate what existing products and services that are on the market today in order to take inspiration of what already has been invented. The findings from research, the expert interviews and the user studies were the basis for the creation of the design suggestions.

From this ideation process, it was realised that *Harbours* was a difficult area to generate ideas about when it comes to reusing consumed batteries, this since there were so many factors that were outside the scope of this project. These factors were for example the many different battery types on the vessels, the lack of economic incentives, that the vessels in harbours often come from different countries and that each vessel should be able to go to harbours in different countries. All this made the implementation of batteries even more complex for *Harbours* than the other areas for second-life. Without an implementation of standards, it was found hard to implement any sort of second-life application. Therefore, it was chosen to remove *Harbours*.

This choice left four areas for second-life to generate ideas around; *At home*, *Public areas*, *Construction sites* and *Mines*. These were taken further into a new round of ideation and the method Scamper (Wikberg-Nilsson, Ericson and Törlind, 2015) was used.

Out of the four areas for second-life, it was decided to keep the three areas *Public areas*, *Construction sites* and *Mines* on a speculative level and to only take the design suggestion *At home* to a sketch level. *At home* was chosen because it was the area where the most people could benefit from the solution, since basically anyone could be the user of this product.

It was realised though, from both the ideation and the analysis of the gathered information of *Mines*, that there already were good solutions in progress to remake the diesel trucks into electric trucks with overhead wires. Therefore, there was no need for reusing consumed batteries from electric vehicles in conjunction with the trucks or the charging stations of the trucks in the mines. Ventilation and lighting were not in need of any solution with consumed batteries either. At quarries, no ventilation or lighting is used and at underground mines, they already have well established electric systems for all lighting and almost all ventilation. The ventilation, that was not part of any well established electric system, demanded too much capacity from the consumed batteries in order for it to be favourably to use them. So there was no suitable area for reusing consumed batteries in the mines. Although, it was decided to keep the design suggestion for *Mines*, but instead of generating new ideas for electrifying mines, the one that already existed was used as the design suggestion. This, due to the time limit of the project and the fact that it is a well working idea worth spreading.

To find what needs people have for electricity in their everyday life, a survey (Bligård, 2015), see Appendix I, was sent out via Facebook and it was answered by 58 persons, for more detailed information about this survey, see chapter 2.2. This survey were the basis for the creation of the design suggestions for *At home* and *Public areas.* For *Construction sites*, the study visit of the two construction sites that included observations and interviews was the basis for the creation of the design suggestion.

For the area that was chosen to develop the furthest, *At home,* different design suggestions were created by using brainstorming (Wikberg-Nilsson, Ericson and Törlind, 2015), brainwriting (Österlin, 2010) and sketching. The design suggestions were evaluated and analysed and one of them was chosen to work further on. From this, specifics regarding functions, shape, details and colours of the *At home* design suggestion were decided. Calculations were also made on the sizes, weights and capacities of the batteries in order to know if the ideas were reasonable. The design suggestion was later created in CATIA.

For the design suggestions for *Public areas, Construction sites* and *Mines,* the design suggestions were created by using brainstorming (Wikberg-Nilsson, Ericson and Törlind, 2015), brainwriting (Österlin, 2010) and sketching as well but specifics regarding functions, shape, details and colours were not decided. However, these concepts were evaluated by interviewing people working within the different areas. This in order to find out what people within the different areas thought about the design suggestions for respective area. The evaluations are described more in detail in chapter 2.7.

2.7 EVALUATION

To evaluate the design suggestions, examination was used (Bligård, 2015). Examination means that different stakeholders that are more or less involved in the development project are asked to respond to an idea or a concept. This by having an interview, a focus group or by sending out a survey. The stakeholders could be potential users of the product or service, marketers, sellers or developers.

For the design suggestions for *Public areas*, *Constructions sites* and *Mines*, different stakeholders and people working within these areas were interviewed via email. The design suggestion was explained and they were asked to express their thoughts and comments about the idea, the pros and cons and if they thought they would benefit from the design suggestion.

When evaluating the design suggestion that is designed for *Public areas*, six different companies and administrations within the city of Gothenburg were contacted via email. The different contacted companies and administrations were; the business unit of service and development at Göteborgs Stads Leasing AB, the local government and the real estate department at Göteborgs Stad, Göteborgs Energi, the district administration of Västra Hisingen, the unit for soil and water protection in the environmental administration at Göteborgs Stad and Fastighet Göteborg. The design suggestion was explained and workers at these companies and administrations were asked to express their thoughts and comments about the idea. The interview guide is presented in Appendix IX.

For the *Construction sites* design suggestion, Serneke construction company was contacted via email. The design suggestion was explained and three persons that work at Serneke were asked to express their thoughts and comments about the idea. The interview guide is presented in Appendix X.

For the *Mines* design suggestion, Anders Grauers that is part of the project of electrifying the mine of Aitik was interviewed, see Appendix V.

For *At home*, the evaluation was divided into three aspects. Those aspects were; the economic aspect, the charging function and the semantics. A survey (Bligård, 2017) was sent out via Facebook to individuals in order to evaluate the economic aspect of the product. The economic aspect was important to evaluate since this is a product that the user are to invest in, and even though it becomes economically beneficial for the user to have this product with time, the initial cost has to be considered. The individuals that answered the survey differed in age, gender and educational background. There were 32 individuals that answered the survey, 27% were younger than 25, 21% were between 25-40 years old, 30% were between 40-60 years old and 24% were older than 60. 46% were women and 54% were men and lastly 53% had an educational background within technology/science and 47% had other educational backgrounds. This variation was considered sufficient to be able to do an analysis upon the answers and to later draw some conclusions. The full version of the survey is presented in Appendix VI.

When evaluating the charging function on the *At home* design suggestion, structured interviews were held with people owning an electric vehicle. The interviewees was friends of family or friends and the interviews were held via phone or email. Six persons were interviewed, see table 3, and the interview questions are presented in Appendix VIII.

Table 3. List of interviewees regarding the charging function

Interviewee	Age	Frequency of use	Car brand
1	48	Every weekend	Tesla
2	60	Every weekend	Tesla
3	40	Every day	Tesla
4	44	Every day	Tesla
5	64	Every day	Tesla
6	42	Every day	Tesla

To evaluate the semantics of the *At home* design suggestion, a semantic scale was used, see Appendix VII. Digital images of the three different versions were shown to individuals in a predetermined order; first the metal version, then the tree version and at last the red one. The individuals were asked to rate the semantics directly after they had seen each version, this to only focus on one version at a time. The individuals that rated the semantics were students at

Chalmers, family members and friends and they differed in age, gender and educational background. There were nine individuals that rated the semantics, see table 4.

Table 4. List of interviewees regarding the semantics

Interviewee	Age	Profession
1	50	Hockey coach
2	48	Nurse
3	24	Car mechanicer
4	67	Civil engineer
5	62	Education
6	28	Design student
7	27	Design student
8	23	Economy student
9	22	Teacher student

Regarding the evaluation of the power banks, the need for this solution was already found in the first survey that investigated the needs for electricity in everyday life. This, in combination with the fact that power banks are already commonly used and considered as a good solution for bringing electricity when "on the go", was considered as sufficient information to not perform any separate evaluation on the power banks of the design suggestion. The survey could be seen in Appendix I.

This division of the evaluation of the *At home* design suggestion was done because it was outside the timeframe of this project to be able to build a mock-up or prototype of the product. Therefore, it was not possible to evaluate all aspects simultaneously, it was better to evaluate the four aspects separately.

2.8 SHORT-FILM

To spread the message of the problematic issues with consumed batteries from electric vehicles and to answer the third research question in the project, a short-film was created. Many people know that the issues exist but no one is taking it seriously enough. Therefore, the idea was to publish the short-film on social media in order to spread the message about the problematic issues with consumed batteries in an efficient way.

To create a well-thought-out short-film, the purpose, aim, target group, call-to-action, feeling, expression and distribution of the short-film were listed. A collage (Wikberg-Nilsson, Ericson and Törlind, 2015) was created for the feeling and expression of the short-film, a storyboard (Babich, 2017) was made over the desired footages and a script was written.

The footages for the short-film were filmed by phone and a stand helped stabilise the footages. These footages were then put together in iMovie into a short-film of approximately one minute.

The audio for the short-film was recorded in Linderoth's studio in Gothenburg and the voice of the storyteller was female. A background soundtrack was also decided upon to complete the feeling and expression of the short-film. The short-film is presented in chapter 6.

2.9 WEBSITE

The idea with having a website was to gather all information in one place. The website is to work as a platform where the different stakeholders can find inspiration and information about how they can reuse consumed batteries and how they can improve this new market.

Collages (Wikberg-Nilsson, Ericson and Törlind, 2015) were created to get the right feeling and expression of the website. Then the pictures, the guidelines, the design suggestions, background information, information about the group and contact information were compiled into a working website by using the online service Wix. The system image was also to be on the website along with its complementary texts, so that all stakeholders could get a chance of understanding the system for battery reuse. The website is presented in chapter 7.

3

CIRCULATING BATTERIES

This chapter presents the results from the theoretical and empirical studies which was the basis for the whole project. The result from the user studies and the result from the theoretical studies are intertwined and the theoretical background is divided into two parts. The first one describes relevant information about lithium-ion batteries in electric vehicles and the second one describes how reusing is part of a circular economy.
This research was done in order to gain needed information about the area of reusing batteries.

3.1 BATTERIES

In this chapter, general information about lithium-ion batteries is presented in order to get a better understanding of the opportunities and challenges of reusing and recycling lithium-ion batteries from electric vehicles.

3.1.1 Construction and function

The lithium-ion battery in an electric vehicle consists of one or more cells that contains stored energy and that energy becomes available in electric form when the electric vehicle is connected to the battery. The cell is the smallest unit that can generate electricity and it consists of a positive cathode, a negative anode and an electrolyte (Wu, 2015).

When the lithium-ion battery is connected to a conductor, electrons move from the negative anode through the conductor to the positive cathode. This movement is called electrical current and electrical energy is then emitted. The current tries to equalize the potential difference, that is, the difference in charge between the poles. The potential difference between the anode and the cathode is called the voltage and is measured in the unit volts [V]. When all electrons have moved from the negative anode to the positive anode, the battery can no longer move the electrons through the conductor, which means that the battery needs to be charged (Wu, 2015).

3.1.2 Charge and discharge

Lithium-ion batteries are rechargeable batteries, or secondary batteries as they are also called, and they can be recharged by connecting a conductor that drives back the current in the opposite direction. However, recharges wear out the battery and therefore secondary batteries have a fixed life span. The life span is measured in cycles, that is, how many times the battery can be fully charged and fully discharged before it is worn out. The charging process of a lithium-ion battery is not completely “chemically” reversible and after repeated charging/discharging, the battery will accept less and less charge until a lower limit of the capacity (defined as failure) is reached (Wu, 2015). For lithium-ion batteries in electric vehicles, this limit of failure is set to 80% of the nominal capacity and this is when the lithium-ion batteries reach the end of their functional first life in electric vehicles (Ambrose & Kendall, 2016).

When this exactly occurs depends on many factors, including:

- Consumer behavior when charging and discharging, and other usage patterns such as driving styles (Hawkins, Gausen and Strømman, 2012) (Faria et al., 2014).
- Technical specifications of the battery, including the powertrain efficiency (Ellingsen et al., 2014).
- Climate, in specifically high or low temperatures (Faria et al., 2014). The ideal working temperature range of the lithium ion battery is 20-45℃. When the temperature drops, the battery capacity also drops and when the temperature gets below 5℃, the capacity of the battery is rapidly reduced (Zhou, Guo, Huang, Jiang, and Wu, 2017). Also, if the temperatures is above 50 °C for a short period, it could present a safety hazard (Neubauer & Wood, 2014).

3.1.3 Hardware and software of a battery pack

The battery in an electric vehicle is called a battery pack and it consists of modules, with a number of cells, and a battery management system (BMS). The cells and modules work together in the battery pack, but they can be disassembled into separate working units (Kushnir, 2015).

The hardware in a lithium-ion battery is the battery pack itself, which is assembled by the battery cells through series or parallel connection, this to supply the desired voltage and capacity. When the battery is in operation, the cells discharge. Ideally, the remaining charges in all battery cells are equally large and they become empty simultaneously. However, it may occur that the discharge occurs unevenly or that a cell continues to be discharged when it is empty, which destroys the cell. To avoid this, a software system is needed to balance the cells. Therefore the software BMS exists, which is an abbreviation for battery management system. This system is found in lithium-ion battery packs in electric vehicles. In addition to balancing the cells, the BMS is also a safety measure as it ensures that the battery pack only works within its safe action area. This, by for example protecting against excessive currents, protect against too high voltages during charging, protect against too low voltages during discharge and/or use, protect against operation during too high temperatures and protect against operation during too low temperatures. It is also possible to build in so that the BMS system can communicate with the product, so that for example the person driving the electric vehicle can see the charging status, the remaining driving time, the battery temperature and eventual error codes (Liu, Li, Peng and Zhang, 2018).

3.1.4 Handling of batteries

Handling of lithium-ion batteries is regulated in the battery regulation (SFS 2008:834). The batteries should be stored in a cool and dry environment, without being exposed to direct sunlight, since this increases the durability of the batteries. However, if the temperature is below zero degrees, crystals can form which destroys the batteries. The packaging of the lithium-ion batteries should protect against short-circuits since this could cause the battery to self ignite and cause fire. Handling the batteries according to (SFS 2008:834) also decreases the risk of “thermal rush”, which means that the battery’s liquid electrolyte starts to burn due to an uncontrollable increase in temperature. These regulations apply during transport as well.

3.1.5 Transport of batteries

The transport of lithium-ion batteries is a big challenge, since lithium-ion batteries are classified as hazardous goods. This means that transport is costly and highly regulated (Olsson et al., 2018). When batteries are to be transported, the sender has the responsibility of the packaging. The logistic company transporting the lithium-ion batteries expects that the batteries are protected in the best way possible, this since the batteries are exposed to knocks, vibrations and/or pressure during the transport (Packbud, 2019).

When transporting batteries, there are rules produced by IATA that have to be followed (Myrdal, 2016). Some logistics firms will not transport consumed lithium-ion batteries and air freight is not allowed at all for lithium-ion batteries from electric vehicles (Olsson et al., 2018). This, since lithium-ion batteries with a capacity of 100 watt-hours or more are classed as hazardous goods class nine and are therefore not allowed to be transported by air (Myrdal, 2016). Hazardous goods need to be transported by road in special trucks labeled with hazardous goods. The UN has developed regulations and recommendations regarding hazardous goods in terms of classification rules, packaging methods, labeling requirements and requirements for information in transport documents for lithium batteries (Myndigheten för samhällsskydd och beredskap [MSB], 2019).

According to a transport manager at Schenker AB, who we unfortunately do not have the name of, the weight is the determining factor for how much one can load in a truck during transport. The maximum load is 36 000 kg and since lithium-ion batteries in electric vehicles are heavy, the weight limit during transport might become problematic when transporting these batteries. However, each truck is equipped with a pallet truck that the driver uses during on-and offloading, which facilitates for the transportation of lithium-ion batteries from electric vehicles. Schenker transports both old and new batteries, and both are classified as hazardous goods. One interesting aspect is that trucks containing hazardous goods are not allowed to use all roads. For example, they are not allowed to drive through tunnels due to safety reasons and are therefore often forced to drive a detour. This could become an obstacle when implementing a system for reuse of consumed batteries from electric vehicles.

Transportation is generally a very expensive part of both battery reuse and recycling and that brings up the question of where the markets should be located, both for the manufacturing of electric vehicles, the manufacturing of second-life products and recycling. There might be a need for a global market for consumed batteries from electric vehicles, since for example there may be many electric vehicles in a developed country like Sweden but a low use for energy storage. The consumed batteries from Swedish electric vehicles could be more valuable in second-life products elsewhere (Olsson et al., 2018).

3.1.6 Standards regarding batteries

Innovative products and services are constantly evolving. When these are to be marketed, meetings arise between suppliers and customers in new markets without fully established rules. Concepts, standards, and agreements regarding responsibility can be missing. It is common that already established rules only cover parts of the innovative features of the new product or service. Then, uncertainty prevails and the market works worse than it could and this is why standards are of such great importance (Vinnova, 2018).

According to Business Sweden (2017), standards promote cross-border trade and facilitate for businesses to export. In the globalized world of today, standards that unite across industries and national borders are needed to create uniform guidelines, simpler routines, cheaper flows and heightened quality.

Standardization facilitates market-adapted competition on equal terms, clarifies functional requirements and simplifies the reporting of technical properties, which, overall, reduces costs for the industry. standards and norms also facilitate and simplify manufacturing, purchasing, installation and maintenance for users (Swedish Standards Institute, n.d.).

There are three different levels of standards according to Swedish Standards Institute:

- SIS - Swedish Standards Institute
- CEN - European Committee for Standardization
- ISO - International Organization for Standardization

There are some standards regarding lithium-ion batteries. The standard (ISO 12405-4:2018) regards test specifications for lithium-ion traction battery packs and systems. This standard provide specific test procedures for lithium-ion battery packs and systems specially developed for propulsion of road vehicles. The standard (EN/IEC 62619:2017) regards safety requirements for secondary lithium cells and batteries for use in industrial applications. Lastly, the standard (EN/IEC 62133-2:2017) regards safety requirements for portable sealed lithium-ion batteries for use in portable applications.

3.1.7 How if affects the project

A circular economy is needed in order for the reuse of consumed batteries from electric vehicles to work. There are some circular business models that could be used in the reuse of consumed batteries from electric vehicles. Both direct reuse, refurbishment, remanufacturing, and/or recycling (Ellen MacArthur Foundation, 2015) could fit into the system of reusing consumed batteries that is to be developed in this project. However, there are both organizational barriers and cognitive barriers that needs to be overcome in order for companies to transition into this new circular market. The technological barriers are harder to overcome and here, standards needs to be implemented. There are some standards today regarding lithium-ion batteries, (ISO 12405-4:2018, EN/IEC 62619:2017 and EN/IEC 62133-2:2017), but they mainly concern safety aspects. Other aspects like for example the size of the battery, the technology used in the battery, how the battery is assembled/disassembled need standards as well, this to facilitate a system where several stakeholders are involved in the reuse of lithium-ion batteries from electric vehicles. Here, the project need to find a way to affect the creation and implementation of standards. Also, as circular business models becomes more common and the development of both lithium-ion batteries and electric vehicles goes forward, these barriers will decrease, which is positive for the project. Together with the implementation of standards and cooperation between different stakeholders, there are great opportunities in reusing consumed batteries from electric vehicles in second-life applications, both economically and environmentally (Olsson et al., 2018).

Creating standards for the types of cells, physical shape and chemistry of batteries from electric vehicles to decrease the technological barriers would also facilitate the handling, transportation, recycling and reuse of batteries that will all be part of the system that will be created in this project. The recycling and reuse of consumed batteries from electric vehicles could become more efficient and profitable, which is important since an economic incentive is necessary in order to start a business. International standards are also important if the market with reusing batteries should be global.

Keeping track of the batteries is going to be a big challenge for the reuse of consumed batteries from electric vehicles, but introducing blockchain might solve this. It is also an interesting idea since it could create economic incentives to create this system without going through the higher authorities. This, since the stakeholders will be economically motivated to be a part of this system and therefore, the standards that are to be created by the higher authorities might not play an as important role as before.

The producer responsibility (Olsson et al., 2018) is one interesting aspect that could be seen as an opportunity for the system of reusing consumed batteries from electric vehicles in this project, this since it makes the producers responsible for the later stage of the batteries' lives. However, there are some legal issues that need to be sorted out in order for the producer responsibility to work efficiently (Olsson et al., 2018).

Lastly, there is an ongoing discussion weather recycling or reuse is the best option for consumed batteries from electric vehicles, but for this project, a combination of the two would be beneficial. Reuse and recycling are complementary to each other and the largest sustainability benefit can be reached if batteries from electric vehicles are first reused and then recycled.

3.2 REUSING IS PART OF A CIRCULAR ECONOMY

A circular economy means that material is recycled or reused over and over again. It is the core of sustainable development and the opposite of today's way of producing and consuming goods. In today's linear economy, material is extracted in order to produce products that are then thrown away or burned up. In a circular economy on the other hand, resources can be saved and waste can be reduced (Naturskyddsföreningen, 2019).

In order to get there, people's way of consuming, recycling and reusing needs to be changed. These are the important steps according to Naturskyddsföreningen (2019):

- Reduce consumption of new things
- Reuse more
- Design products and packagings smarter
- Recycle more material
- Take advantage of the energy of what cannot be recycled and therefore must be incinerated

With direct reuse, refurbishment, remanufacturing, and/or recycling, the waste can be eliminated (Ellen MacArthur Foundation, 2015). Extending the life of a battery through remanufacturing and reuse slows down the resource cycle and recycling closes the resource loop (Bocken, de Pauw, Bakker and van der Grinten, 2016). Reuse and recycling are complementary to each other and the largest sustainability benefit can be reached if batteries from electric vehicles are first reused and then recycled.

3.2.1 Challenges and barriers

From a business model perspective, the challenges and barriers for second life and recycling of lithium-ion batteries used in electric vehicles can be divided into three categories: organizational, cognitive and technological (Olsson, Fallahi, Schnurr, Diener and Van Loon, 2018).

When transitioning into a circular business model for reusing consumed batteries from electric vehicles, there are organizational barriers that may manifest in different forms. The new business model might conflict with existing assets and capabilities (Chesbrough &

Rosenbloom, 2002), (Hadjimanolis, 1999) and (Tripsas & Gavetti, 2000), there could be costs for customers or other stakeholders when switching into the new business model (Amit & Zott, 2001), there could be complications of developing a new business model in parallel to existing one(s) (Mezger, 2014), it can be difficult to manage multiple business models simultaneously (Markides & Charitou, 2004) and there might be inertia due to uncertainty about the effectiveness of a new business model (Andries & Debackere, 2007).

There will also be cognitive barriers when transitioning into a new business model for reusing consumed batteries from electric vehicles. Cognitive barriers are related to the decision makers being uncertain about how promising future circular business models will be. The decision makers may be reluctant to invest in new business models that conflict with their up-and-running businesses. People are often so used to the existing business models that they find it difficult to see how the new business model is going to work. There could also be a lack of management leadership to envision business model innovation and to figure out the required structures, capabilities and processes for the new business model (Olsson et al., 2018).

Technological barriers are related to the lack of standards regarding the battery chemistry, which makes preparing them for second life and recycling costly and complex. This also causes an uncertainty of how the consumed batteries will perform after first life (with respect to capacity loss). The lithium-ion batteries that are used in electric vehicles are made by many different manufacturers with many different constructions, which include variations in type of cell, physical shape and chemistry. The batteries are not labelled with their specific chemistry, so the different actors do not know which kind of batteries they receive. In addition, each lithium-ion battery has a tailored battery management system. Because of this, large costs are often associated with reuse. One way of solving this and simplifying the process of reuse is to introduce standards in regards of chemistry, packing and labeling could simplify the process, but since standards could interfere with competition between manufacturers, this is a sensitive issue (Olsson et al., 2018).

In addition to the organizational, cognitive and technological challenges, another challenge is the batteries themselves. The earlier life of a battery is in many cases unknown in terms of where it has been and for how long it has been used. This causes an uncertainty regarding the remaining capacity and the condition of the battery. This uncertainty exists since there currently is no established system of how to keep track of the batteries. This creates a challenge in the future system of reusing consumed batteries since the different stakeholders are dependent of having access to such information in order to make the right choice of what to do with the batteries. Therefore, in order to create and implement a working system for the reuse of consumed batteries from electric vehicles, either a stakeholder or a technology is needed to check the remaining capacity and the condition of the batteries.

3.2.2 Opportunities

As stated in the background, reuse of consumed batteries from electric vehicles is often seen as an opportunity to delay disposal and recycling of these batteries, as well as an opportunity to squeeze value out of existing resources. However, the low volumes of batteries on the market today mean that the possibilities of such a business are small, but in the next few years, the volumes of consumed batteries from electric vehicles on the market are expected to increase greatly and therefore, possibilities of these businesses will increase as well (Olsson et al., 2018).

Recycling companies also see new opportunities, this by making themselves natural intermediaries between the end user of the electric vehicle and a second life for the battery. However, in order for a consumed battery to be useful, it needs some degree of repurposing. Some third-party entrepreneurs are currently trying to establish second-life battery businesses, with repurposing as the main part of their business models. Some energy storage suppliers also work with giving consumed batteries from electric vehicles a second life by refurbishing them for new applications (Olsson et al., 2018).

So there are economic gains associated with both reuse and recycling of batteries from electric vehicles, but the greatest economic gain is created by first reusing, then recycling (Mathur et al., 2019). This, since there are economic gains in both the remaining capacity and in the materials of the batteries.

3.2.3 Reuse of batteries in second-life products

Some companies in Europe and the US, that are focused on electric vehicles, have tried to create different energy storage system based on consumed batteries from electric vehicles. These systems are used as for example back-up power and auxiliary capacity but also to reduce stress on the grid and to decrease the peak demands during electric vehicle charging. Another way to make use of the energy storage systems, according to the report written by Melin (2018), is time-shift management. This means to charge when energy is cheap and discharge when it is expensive.

Chinese automotive manufacturers have together with a telecom infrastructure company found another application to reuse consumed batteries from electric vehicles. They have replaced lead-acid batteries in the backup systems of base stations with consumed batteries from electric vehicles (Melin, 2018).

In Scandinavia, similar solutions of energy storage systems exist. Jönköpings Bildemontering is using consumed batteries from electric vehicles to store solar energy. This stored energy supplies 25% of the company's energy consumption (Weibull, 2018). Tesla also has an energy storage product to store solar energy for at home. However, Tesla does not use consumed batteries in these products, they use new ones. The product is called Powerwall and is priced at 75 000 Swedish crowns (Tesla, 2019).

A third example is the company Box of energy that had energy storage products that stored residual energy from solar and wind power plants in batteries. They started off using new lithium-ion batteries in their products but had plans to use consumed batteries for electric vehicles in the future. Unfortunately, the company filed for bankruptcy in 2018 before they got the chance to try using consumed batteries in their products (Box of energy, 2015).

Challenges with reusing batteries

There are aspects that challenge the idea of reuse. One challenge with reusing consumed batteries from electric vehicles is that it is hard to keep track of the batteries and it is hard for the different actors to know the history of the battery. The history of where it has been, for how long it has been used, remaining capacity and the quality of the battery. One technology that could solve this is blockchain. A blockchain is a distributed (decentralized) database, that is, a database that is stored in many copies - one on each node (computer) in a peer-to-peer network. The many copies and a sequence of cryptographic hash functions make it difficult or impossible to subsequently manipulate the database's change history. Each event in the database (each database transaction) is stored by adding a so-called block to the database, and a sequence of blocks is therefore called a blockchain (Thors, 2019). Using blockchain could be a way to keep track of the consumed batteries.

Another challenge (or possibility) with creating a system for reuse of batteries from electric vehicles is the producer responsibility. The actor that puts the battery on the market has a producer responsibility, which means that the actor has a responsibility for providing a system for collection and recycling when the battery becomes waste. If the battery turns into a new product, that responsibility can be transferred to a new actor. However, it is not always entirely clear which actor that has the producer responsibility, and this uncertainty about legal issues could discourage actors from engaging in the system of giving consumed batteries from electric vehicles a second life (Olsson et al., 2018).

Reuse or recycling?

Reuse of batteries from electric vehicles get more and more attention. Many companies and researchers are developing different kind of solutions, such as grid solutions, to take care of these batteries in a second life application, however, Tesla is thinking differently. Tesla’s development manager JB Straubel argues that reuse of these batteries in energy storage solutions is not a good alternative (Blomhäll, 2017). This since different applications require different battery properties. According to Straubel, it is better to choose appropriate, new produced batteries for energy storage systems in those applications and recycle lithium-ion batteries from electric vehicles instead.

Hans Eric Melin, founder of Circular Energy Storage Research and Consulting, does not agree with Straubel. In the expert interview that was held with Melin, he argues that "There is a lot of existing solutions with electric car batteries in energy storage. It is clear that if you have the possibility to choose, you optimize your BMS (battery management system) for the right application. But generally speaking, energy storage is rarely as demanding as a battery for a vehicle so it is not a problem".

3.2.4 Recycling of batteries

Extraction of raw materials, metals in this case, requires a lot of energy and has a huge negative impact on the environment. Especially extraction of lithium and cobalt that are two often used materials in electric vehicle batteries. Recycling and/or reusing these metals would result in great environmental benefits (Zachrisson-Winberg, 2018). The extraction of the materials used in lithium-ion batteries also includes very bad working conditions and in many times child labor (Walt, Vivienne and Fortune, 2018). Recycling and/or reusing these metals would result in great benefits for social sustainability as well.

Recycling technologies can be roughly categorized in three techniques: hydrometallurgical, pyrometallurgical and mechanical processes (Boyden, 2014). In most cases, a combination of these recycling techniques is used (Winslow, Laux and Townsend, 2018). Hydrometallurgy is a chemistry-specific leaching-intensive process that can recover lithium, aluminum, and other high-value materials (Hendrickson, Kavvada, Shah, Sathre, Scown, 2015). Pyrometallurgy is a thermal treatment process, that includes pyrolysis, smelting, distillation, and refining (Boyden, 2014). High-value materials such as nickel, cobalt and copper can be recovered (Hendrickson et al., 2015). Mechanical processes have two purposes, to dismantle the battery and to liberate components. These processes include methods such as crushing, shredding, magnetic separation, air ballistic separation and sieving (Boyden, 2014).

Literature concludes that with 'state of the art' recycling, a large fraction of materials can be recovered: over 90% of lithium, cobalt, manganese, nickel, copper and aluminum (Ordoñez, Gago and Girard, 2016) (Zeng, Li, and Singh, 2014). In current practice, however, recycling rates are much lower (Zeng et al., 2014) (Heelan et al., 2016).

The European Union's Battery Directive (European Commission, 2006) states that 50% of the weight of an lithium-ion battery from an electric vehicle shall be recycled. According to the Swedish Environment Protection Agency, in Sweden that is obtained. However, current legislation does not create incentives for further recycling.

Challenges with recycling of batteries

Due to the uncertainty about future battery chemistries and volumes, investments in recycling processes are not easily accomplished. Energy density is improving, new battery chemistries are developed and battery prices are falling. The cost and availability of different materials affect the battery prices and the content of the batteries. This presents a great challenge for the recycling companies since recycling depend on what materials that are used. The cost of virgin-materials and the technological development also affect the profitability of recycling and the demand for recycled material (Olsson et al., 2018).

Another big challenge today with the recycling of lithium-ion batteries from electric vehicles is the volume of batteries on the market. In Asia, where the volumes are the biggest, there are three different companies working with recycling of lithium-ion batteries, Brunp and Ganfeng in China and Posco in South Korea. However, in Europe and North America there are at the moment no recycling possibilities for lithium-ion batteries. Christer Forsgren from Stena Metall considers recycling of lithium-ion batteries as non-profitable today since the volumes of these batteries are still to small (Kristensson, 2018). Additionally, the existing recycling processes are very energy-consuming according to Forsgren (Kristensson, 2018). However, in a few years, there will be a larger volume of consumed lithium-ion batteries on the market and thereby effective recycling processes are possible to be applied (Blomhäll, 2017).

In contrast to Forsgren and Blomhäll, Hans Eric Melin, founder of Circular Energy Storage Research and Consulting, means that the possibilities exists in Europe and North America today as well, he said in the expert interview that they just have the wrong attitude to it. In Europe, batteries are seen as waste and recycling is a way to reduce the cost for that waste. In Asia, they are more focused on working to deliver material to the fast-growing manufacturing industry.

Ongoing research

Researchers from Chalmers University of Technology have developed a method to take care of the lithium from lithium-ion batteries (Nohrstedt, 2017). During the recycling process, the metals in the batteries are separated first mechanically and then chemically. According to the researchers, there is an expensive method but very effective though. They consider that this recycling method enables 95% of the lithium to be reused in new batteries. Christian Ekberg, professor in chemistry, chemical engineering, industrial material recycling and nuclear chemistry is developing a method for recycling lithium-ion batteries so that lithium can go back into battery manufacturing. The method is on the right track, but according to Ekberg, he has not found a way to avoid all residues. Rare Earth Elements (REM) and lithium can not be recycled yet. He is not familiar with the asian recyclers but means that the biggest reason why recycling of batteries is not existing Europe is due to the cost of the process (Nohrstedt, 2018).

CONTENT

The two following chapters present the content, which means the result of the first and second research questions; “How could consumed batteries from electric vehicles be reused in second-life applications?” and “Which are the relevant stakeholders and what are the possible relationships between them?”. Content includes chapter 4 and 5, which consist of system image, guidelines and design suggestions for the areas for second-life.

4

SYSTEM

This chapter presents the system image and the guidelines. The system image describes the system needed in order for the reuse of consumed batteries from electric vehicles to work and the guidelines describe standards and recommendations that need to be implemented in order for the system to work.

4.1 SYSTEM IMAGE

From the result from the theoretical studies and the user studies, a system image was created to get a better understanding of the overall system, see figure 2. This system image was also the basis for creating the guidelines, the design suggestions and the short-film. In order for this system to work, it is a prerequisite that circular business models regarding renting out and sharing products are well established.

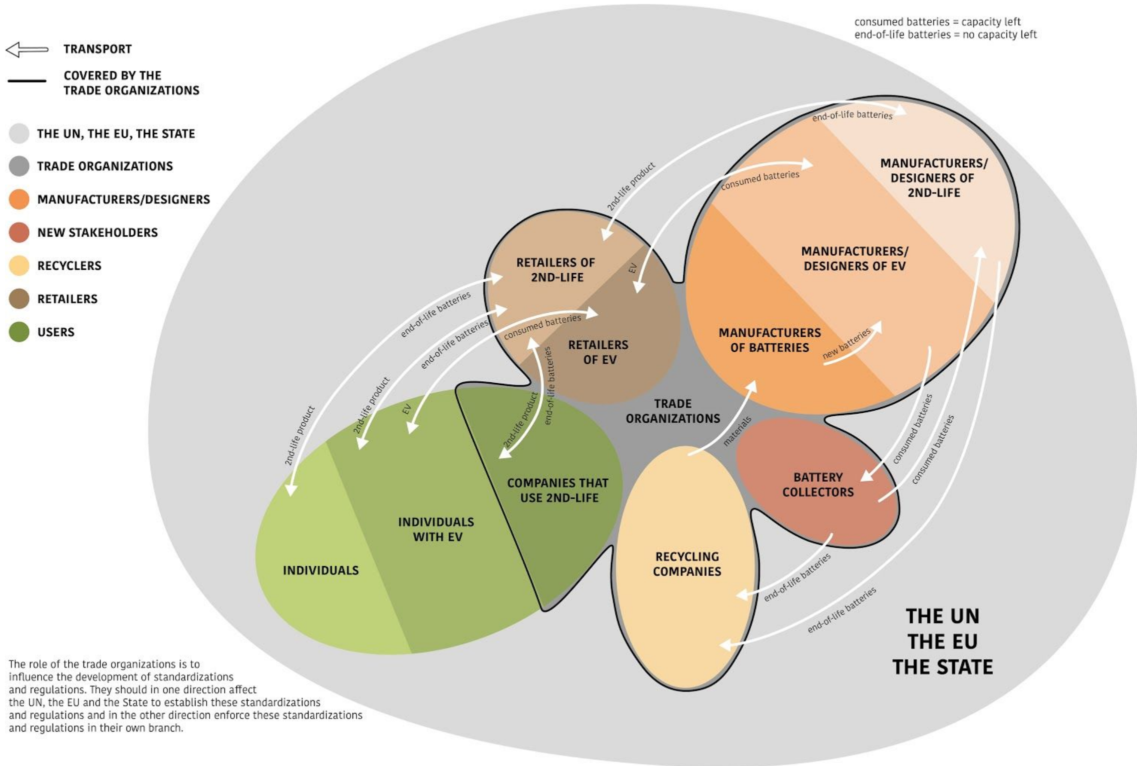


Figure 2: EV=electric vehicles, 2nd-life=second life solutions

Reusing consumed batteries from electric vehicles opens up a whole new market and this market can be described as a system consisting of different stakeholders. Each one of the stakeholders has a specific role and there are also relationships between the different stakeholders.

As seen in figure 2, the stakeholders have been divided into five groups; manufacturers/designers, new stakeholders, recyclers, retailers and users. The manufacturers/designers consists of the manufacturers of batteries, the manufacturers/designers of electric vehicles and the manufacturers/designers of second-life products. The new stakeholders consists of the battery collectors. The recyclers consists of the recycling companies. The retailers consists of the retailers of electric vehicles and the retailers of second-life products. Lastly, the users consists of the companies that use second-life products, the individuals with electric vehicles and the individuals. The groups were chosen since it was found from the research that these groups are required in order for the system to work. The stakeholders within the groups were chosen since they were considered, based on the research, that they were the most relevant stakeholders.

Beyond these groups, there is transportation of both materials, batteries, electric vehicles and second-life products between the different stakeholders in the groups. The transportation is visualized as white arrows in figure 2. The black text on the arrows describe what is being transported between the different stakeholders. It should also be noted that "consumed batteries" stands for batteries that still have capacity left and that "end-of-life batteries" stands for batteries that have no capacity left. The black line that covers almost all stakeholders in the groups, with the exception of individuals with electric vehicles and individuals, represent the different trade organizations. The trade organizations in this project are: Sveriges Byggindustrier, BIL Sweden, Svemin, Transportföretagen, Återvinningsindustrierna, Batteriföreningen, Innovationsföretagen and Biluthyrarna Sverige. Sveriges Byggindustrier is a trade and employer organization for 3,600 construction companies operating in the Swedish construction market (Sveriges byggindustrier, n.d.). BIL Sweden is the Swedish trade organization for manufacturers and importers of passenger cars, trucks and buses (BIL Sweden, 2019). Svemin is the trade organization for mines, mineral producers and metal producers in Sweden (Svemin, n.d.). Transportföretagen is the main gathering point for the transportation companies in Sweden (Transportföretagen, n.d.). Återvinningsindustrierna is a trade organization for recycling companies that has chosen to actively work with the environment and ethics in its operations with the aim of creating a recycling that is long-term sustainable (Återvinningsindustrierna, n.d.). Batteriföreningen is a trade organization for the Sweden's leading suppliers, i.e. manufacturers and importers of batteries (Batteriföreningen, 2019). Innovationsföretagen is the trade and employer organization for Sweden's architectural consulting companies and engineering consulting companies (Innovationsföretagen, n.d.). Biluthyrarna Sverige is an association for all companies that work with car rental and other car sharing (Biluthyrarna Sverige, 2017). Together they cover all the involved companies of this project which are construction companies, mining companies, all companies that sell or rent out services that involves electric driven vehicles, manufacturers of batteries, manufacturers of electric vehicles, recycling companies, companies that develop and design second life products and companies that are transporting batteries. Finally, the whole system is covered by the higher authorities such as the UN, the EU and the State. In this case, Sweden is the State.

Beyond transportation of materials, batteries, electric vehicles and second-life products there are also exchanges of information and knowledge between the different stakeholders within the system. These exchanges exist everywhere in the system and all stakeholders are involved in these. These information and knowledge exchanges can appear when stakeholders are in direct contact with one another, for example when buying or selling products, or it can appear through indirect contact, for example by creating standards. The exchanges can also appear through another stakeholder, for example when the higher authorities give information to the different industries through the trade organizations. However, it was chosen not to visualize this flow of information and knowledge in the system image, this simply because the system image would get much harder and more complicated to interpret.

4.1.1 Roles

Every stakeholder has its specific role and the different roles are presented below, together with the roles of the trade organizations and the higher authorities.

Manufacturers/designers

The manufacturers/designers consists of the manufacturers of batteries, the manufacturers/designers of electric vehicles and the manufacturers/designers of second-life products.

Manufacturers of batteries

The role of the manufacturers of batteries is to manufacture lithium-ion batteries for electric vehicles. They should use as much recycled material as possible, especially when it comes to rare materials such as lithium and cobalt. The working conditions during the manufacturing process should be good. The virgin materials that are being used in the manufacturing of electric vehicle batteries should be responsibly extracted and extracted during good working conditions as well. The battery producers have a responsibility to collect and recycle all batteries that are produced (Naturvårdsverket, 2018).

Manufacturers/designers of electric vehicles

The role of the manufacturers/designers of electric vehicles is to design and manufacture electric vehicles. They should use as much recycled material as possible in their manufacturing process and the working condition during the manufacturing process should be good. The virgin materials that are being used in the manufacturing of electric vehicles should be responsibly extracted and extracted during good working conditions as well. The manufacturers/designers of electric vehicles are according to the producer responsibility (Naturvårdsverket, 2018) responsible for the maintenance and scrapping of electric vehicles. An example of maintenance is to change the battery when it has consumed its maximum effect. The life of the electric vehicles are usually longer than that of the batteries, so in that case new batteries should be put in the electric vehicles and the vehicles can then be reused. Once they have changed the batteries, they are responsible for delivering the consumed batteries to the battery collectors.

The manufacturers/designers of electric vehicles should also have circularity in mind when it comes to the batteries and there are three levels on how much circularity they can implement in their businesses:

- **First**: Make sure that the purchased batteries are produced responsibly and that they are made of as much recycled material as possible. They should place the batteries in their electric vehicles in such a way as to facilitate disassembling.
- **Second**: In addition to the above, companies can also take back consumed batteries from self-produced cars, and either; send them to recycling companies for recycling and contribute to the reuse of old battery materials in new batteries or sell the consumed batteries via the battery collectors to manufacturers/designers responsible for giving the consumed batteries a second life in other products.
- **Third**: In addition to what is stated in the two paragraphs above, the companies can also take back consumed batteries from other cars brands as well as from their self-produced cars, and either; send them to recycling companies for recycling and contribute to the reuse of old battery materials in new batteries or sell the consumed batteries via the battery collectors to manufacturers/designers responsible for giving the consumed batteries a second life in other products.

Manufacturers/designers of second-life products

The role of the manufacturers/designers of second-life products is to design and manufacture second-life products that contains consumed batteries from electric vehicles. They purchase the consumed batteries from the battery collector. They should use as much recycled material as possible in their manufacturing process and the working conditions during the manufacturing process should be good. The virgin materials that are being used in the manufacturing of second-life products should be responsibly extracted and extracted during good working conditions as well. The manufacturers/designers of second-life products are responsible for the maintenance, upgrades and scrapping of second-life products, an example of maintenance is to change the battery when it has been fully consumed. The manufacturers/designers of second-life products have a producer responsibility towards their products. Once they have changed the battery, the manufacturers/designers of second-life products are responsible for delivering the consumed battery to the battery collector.

Retailers

The retailers consists of the retailers of electric vehicles and the retailers of second-life products.

Retailers of electric vehicles

The role of the retailers of electric vehicles is to sell or rent out electric vehicles. They are responsible to inform the buyers how it can be identified that the batteries have consumed their maximum effect and that the users can return the electric vehicles to the retailers if they want to change the batteries or scrap the electric vehicles. The retailers work as the intermediary between the user and the manufacturers/designers and are responsible for sending the electric vehicles back to the manufacturers/designers of electric vehicles when they should change their batteries or when the electric vehicles should be scrapped. So the battery-changes themselves take place at the manufacturers/designers of electric vehicles and not at the retailers of electric vehicles. Once the batteries have been changed, the retailers of electric vehicles are responsible for the users getting back the electric vehicles. This is done either by the retailers delivering the electric vehicles to the users or that the users come to the retailers to pick up the electric vehicles. The submissions of the electric vehicles works the same way. When the users want their electric vehicles maintained or scrapped, either the users deliver the electric vehicles to the retailers or the retailers come to the users to pick up the electric vehicles.

Retailers of second-life products

The role of the retailers of second-life products is to rent out second-life products to different users. They are responsible to inform the users how the products work, how they can be upgraded, how to do with maintenance and what to do with the products at their end-of-life. The upgrades, maintenance and scrapping are all done through the retailers. When the users want an upgrade, maintenance or for the products to be scrapped, they contact the retailers. The submissions of the second-life products work either by the users delivering the products to the retailers or by the retailers coming to the users to pick up the products. The retailers then transport the products to the manufacturers/designers of second-life products where the upgrade, maintenance or scrapping takes place. If an upgrade or maintenance is done, the retailers are responsible for delivering the products back to the users. This is done either by the retailers delivering the upgraded/maintained second-life products to the users or that the users come to the retailers to pick up their upgraded/maintained second-life products. If the products have reached their end-of-life and the users want them scrapped, the manufacturers/designers of second-life products instead transport the products to the recycling companies in order for the batteries to be recycled.

Users

The users consist of the companies that use second-life products, the individuals with electric vehicles and the individuals.

Companies that use second-life products

The role of the companies is to use second-life products in their businesses and to follow the guidelines for how they can use them. By implementing second-life products, and therefore drawing attention to the subject of reusing consumed batteries from electric vehicles, they help to push the implementation of standards at the higher authorities. They are responsible for contacting the retailers of second-life products when products need an upgrade, maintenance or need to be scrapped.

Individuals with electric vehicles

The role of the individuals that own or rent electric vehicles is to use electric vehicles and second-life products at their home. The second-life products should be used according to the guidelines. They are responsible for contacting the retailers of electric vehicles when their electric vehicle needs maintenance or needs to be scrapped. They are also responsible for contacting the retailers of second-life products when their second-life product needs an upgrade, maintenance or needs to be scrapped.

Individuals

The role of the individuals is to use second-life products at their home according to the guidelines. They are responsible for contacting the retailers of second-life products when their second-life product needs an upgrade, maintenance or needs to be scrapped.

New stakeholders

The new stakeholders consists of the battery collectors.

Battery collectors

The battery collectors is a new stakeholder whose role is to collect consumed batteries from the manufacturers/designers of electric vehicles. The battery collectors only receive or pick up the consumed batteries from the manufacturers/designers of electric vehicles, they do not receive the whole electric vehicle. So the extraction of the battery takes place at the manufacturers/designers of electric vehicles. The tasks for the battery collectors are to determine the condition and remaining capacity of the consumed batteries. If there is enough capacity left in order for the batteries to work in second-life products, the batteries are classified as "consumed batteries" and are sold to the manufacturers/designers of second-life products. If there is not enough capacity left in order for the batteries to work in second-life products, the batteries are classified as "end-of-life batteries" and are transported and sold to the recycling companies in order for the batteries to be recycled.

Recyclers

The recyclers consists of the recycling companies.

Recycling companies

The role of the recycling companies is to recycle end-of-life batteries from electric vehicles. They should try to recycle the batteries so that as much of their material as possible could be used in the production of new batteries. They are responsible for maintaining good working conditions during the recycling process. The recycling companies buy the end-of-life batteries from the battery collector and from the manufacturer/designer of second-life products. They then sell the materials from the recycling process to the manufacturer of batteries, so that the materials could be used in the process of producing new batteries for electric vehicles. The materials are either transported to the manufacturers of batteries by the recycling companies, or the manufacturers of batteries come to pick up the material at the recycling companies.

Other stakeholders

The other stakeholders consists of the trade organizations and the higher authorities.

Trade organizations

The role of the trade organizations is to absorb the information from everything, for example from the short-film, their own industry and their own employees and then take this information and put pressure on the higher authorities; the UN, the EU and the State of Sweden. This, to affect the development of standards. They should also provide the higher authorities with important insights about the industries that will be affected by these standards. Once the standards have been set, the role of the trade organizations is to help implementing the standards in their industry. They should also pass on information and be of support for their own industry at eventual questions or problems.

The higher authorities

The role of the UN, the EU and the State of Sweden is to set the standards for the market of consumed batteries from electric vehicles. They have a very important role since the implementation of standards is the key to making this new market to work.

4.1.2 Relationships

The different stakeholders have specific relationships to one another and the different relationships are presented below.

Trade organizations → The higher authorities

The trade organizations should affect the UN, the EU and the State of Sweden to establish the standards for the consumed batteries market. They should also provide the higher authorities with important insights about the industries that will be affected by these standards. This relationship already exists but not when it comes to the reuse of consumed batteries from electric vehicles.

Trade organizations → The stakeholders covered by the trade organizations

The trade organizations should implement the standards for the consumed batteries market in their own branch. This relationship already exists as well but not when it comes to the reuse of consumed batteries from electric vehicles.

Manufacturers of batteries → Manufacturers/designers of electric vehicles

The manufacturers of batteries sell new batteries to the manufacturers/designers of electric vehicles which means that new batteries are transported to the manufacturers/designers of electric vehicles. This is an already established relationship.

Manufacturers/designers of electric vehicles → Retailers of electric vehicles

The manufacturers/designers of electric vehicles sell electric vehicles to the retailers of electric vehicles which means that electric vehicles are transported to the retailers of electric vehicles. This part of the relationship is an already established one. However, the new part of the relationship is that the manufacturers/designers of electric vehicles are also responsible for the maintenance of the electric vehicles. Once they have been repaired/maintained, the electric vehicles are being transported from the manufacturers/designers of electric vehicles to the retailers of electric vehicles. The retailers of electric vehicles are then responsible for delivering the maintained electric vehicles back to the users.

Manufacturers/designers of second-life products → Retailers of second-life products

The manufacturers/designers of second-life products sell second-life products to the retailers of second-life products which means that second-life products are transported to the retailers of second-life products. The manufacturers/designers of second-life products are also responsible for the maintenance and upgrade of second-life products and once they have been upgraded/maintained, the second-life products are being transported from the manufacturers/designers of second-life products to the retailers of second-life products. The retailers of second-life products are then responsible for delivering the upgraded/maintained second-life products back to the users. This relationship is new since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Retailers of electric vehicles → Individuals with electric vehicles

The retailers of electric vehicles sell or rent electric vehicles to the individuals with electric vehicles which means that electric vehicles are transported to the individuals. Selling electric vehicles is an already established relationship but the new part of it is that the individual can rent the electric vehicle as well.

Retailers of second-life products → Companies that use second-life products

The retailers of second-life products rent out second-life products to the companies that use second-life products in their businesses which means that second-life products are transported to these companies. This relationship is new since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Retailers of second-life products → Individuals with electric vehicles

The retailers of second-life products rent out second-life products to the individuals with electric vehicles which means that second-life products are transported to the individuals with electric vehicles. This relationship is new since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Retailers of second-life products → Individuals

The retailers of second-life products rent out second-life products to the individuals. This means that second-life products are transported to the individuals. This relationship is new since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Individuals with electric vehicles → Retailers of electric vehicles

The retailers of electric vehicles take back electric vehicles from the individuals with electric vehicles for maintenance or at the end of the vehicle's life. Maintenance could be for example changing the batteries of the electric vehicles. In both cases, the batteries of the electric vehicles that are taken back have enough capacity left to be perceived as consumed batteries. This means that electric vehicles containing consumed batteries are transported to the retailers of electric vehicles. The next step is for the retailers of electric vehicles to transport the electric vehicles containing consumed batteries to the manufacturers/designers of electric vehicles, which in their turn take out the batteries and send them to the battery collectors. This relationship is partially new, today one can submit cars for maintenance at workshops connected to the company that manufactured the car. However, the new aspect is that it should go through the retailer.

Companies that use second-life products → Retailers of second-life products

The retailers of second-life products take back second-life products from the companies that use second-life products. The batteries of the second-life products that are taken back have been consumed to such extent that they are perceived as end-of-life batteries. This means that second-life products containing end-of-life batteries are transported to the retailers of second-life products. The next step is for the retailers of second-life products to transport the second-life products containing end-of-life batteries to the manufacturers/designers of second-life products, which in their turn send the batteries to the recycling companies in order for the batteries to be recycled. This is a new relationship since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Individuals with electric vehicles → Retailers of second-life products

The retailers of second-life products take back second-life products from the individuals with electric vehicles. The batteries of the second-life products that are taken back have been consumed to such extent that they are perceived as end-of-life batteries. This means that second-life products containing end-of-life batteries are transported to the retailers of second-life products. The next step is for the retailers of second-life products to transport the second-life products containing end-of-life batteries to the manufacturers/designers of second-life products, which in their turn send the batteries to the recycling companies in order for the batteries to be recycled. This is a new relationship since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Individuals → Retailers of second-life products

The retailers of second-life products take back second-life products from the individuals. The batteries of the second-life products that are taken back have been consumed to such extent that they are perceived as end-of-life batteries. This means that second-life products containing end-of-life batteries are transported to the retailers of second-life products. The next step is for the retailers of second-life products to transport the second-life products containing end-of-life batteries to the manufacturers/designers of second-life products, which in their turn send the batteries to the recycling companies in order for the batteries to be recycled. This is a new relationship since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Retailers of electric vehicles → Manufacturers/designers of electric vehicles

The retailers of electric vehicles receive electric vehicles from the user group to be maintained or scraped, and the retailers of electric vehicles transports these electric vehicles containing consumed batteries to the manufacturers/designers of electric vehicles. This means that electric vehicles containing consumed batteries are transported to the manufacturers/designers of electric vehicles. If the batteries in the electric vehicles are to be changed, this takes place at the manufacturers/designers of electric vehicles. The consumed batteries are then transported to the battery collectors. This relationship is partially new, today one can submit cars for maintenance at workshops connected to the company that manufactured the car. However, the new aspect is that it should go through the retailer.

Retailers of second-life products → Manufacturers/designers of second-life products

The retailers of second-life products receive second-life products from the group users to be maintained, upgraded or scraped, and the retailers of second-life products transport these second-life products containing batteries to the manufacturers/designers of second-life products. The batteries of the second-life products have been consumed to such extent that they are perceived as end-of-life batteries. If the batteries in the second-life products are to be changed, this takes place at the manufacturers/designers of second-life products. The end-of-life batteries are then transported to the recycling companies in order for the batteries to be recycled. If the second-life products are to be upgraded, this takes place at the manufacturers/designers of second-life products but nothing is done with the batteries. The batteries remain as they are in the second-life products and later the whole products get delivered back to the users. This is a new relationship since there are no second-life products containing consumed batteries from electric vehicles on the market today.

Manufacturers/designers of electric vehicles → Battery collectors

The manufacturers/designers of electric vehicles sell consumed batteries to the battery collectors. It is then the task of the battery collectors to control how much of the capacity that is left in the batteries. If there is enough capacity left, the batteries are perceived as consumed and the battery collectors sell the batteries to the manufacturers/designers of second-life products for them to be reused. If there is not enough capacity left, the batteries are perceived as end-of-life and the battery collectors sell the batteries to the recycling companies in order for the end-of-life batteries to be recycled. This relationship is new since there is no stakeholder today with a role that resembles the role of the battery collectors.

Manufacturers/designers of second-life products → Recycling companies

The manufacturers/designers of second-life products sell end-of-life batteries to the recycling companies in order for the batteries to be recycled. The batteries have been consumed to such extent that they are perceived as end-of-life batteries. This relationship is new since there is no stakeholder today that manufactures second-life products containing consumed batteries from electric vehicles.

Battery collectors → Manufacturers/designers of second-life products

The battery collectors collect consumed batteries from the manufacturers/designers of electric vehicles and the consumed batteries that have enough capacity left are being sold to the manufacturers/designers of second-life products. The manufacturers/designers of second-life products are to use these consumed electric vehicle batteries in their second-life products. This relationship is new since there is no stakeholder today with a role that resembles the role of the battery collectors and since there is no stakeholder today that manufactures second-life products containing consumed batteries from electric vehicles.

Battery collectors → Recycling companies

The battery collectors collect consumed batteries from the manufacturers/designers of electric vehicles and the consumed batteries that do not have enough capacity left are perceived as end-of-life batteries. These end-of-life batteries are being sold from the battery collectors to the recycling companies, in order for the batteries to be recycled. This relationship is new since there is no stakeholder today with a role that resembles the role of the battery collectors.

Recycling companies → Manufacturers of batteries

The recycling companies recycle end-of-life electric vehicle batteries and sell the recycled material to the manufacturers of batteries. This is an already established relationship.

4.1.3 Final comments

This system image has been made to make the flow of products and materials as natural as possible. The users get their electric vehicles or second-life products from the retailers and it is therefore natural for the users to contact the retailers when they want an upgrade, maintenance or to scrap their vehicles/products. It is also easier for the user to be able to contact one and the same actor for several different matters, instead of having to contact different actors for different matters. This is also helpful when building relationships, both business to business and business to customer.

The retailers already have a relationship with the manufacturers/designers because they are selling/renting out their products and it is therefore natural for the retailers to send back products to the manufacturers/designers that need upgrades, maintenance or need to be scrapped. It is also the best option that the manufacturers/designers are the ones to extract the batteries from the vehicles/products, since they are the ones who built them and therefore should know how to disassemble them.

The battery collector is a new stakeholder that was from the beginning considered necessary, this because it was needed a stakeholder specialized on measuring the capacity of the batteries. It is necessary that someone sorts out which batteries that can be reused and which batteries that should be recycled. However, this special competence does not exist among any of the manufacturers/designers today but as well as having a separate stakeholder, the manufacturers/designers could become this stakeholder if this special competence is gained. The recycling companies is nothing new, but they are much needed in order for the system to work.

In order for this system to fully work, standards are necessary and creating these is a task for the higher authorities. But, since it basically not is possible to give orders to the higher authorities, it has been decided that the trade organisations shall put pressure on this to happen. The trade organizations are also the ones to help implement the standards in their industries once they have been set.

When it comes to the safety risk of transporting batteries, both lithium-ion batteries themselves and products containing lithium-ion batteries are classified as hazardous goods. The regulations for how they should be transported differentiate, because they fall under different categories. The packaging regulations for the lithium-ion batteries are more strict, this because the batteries inside of products already have a battery management system that protects them from for example creating short circuits. Although, these packaging regulations seem to be the same for both new, consumed and fully consumed (end-of-life) batteries. So there is no difference in risk in transporting new, consumed or fully consumed batteries. But there are batteries that are classified as “damaged and defective batteries” and transportation of these means an increased safety risk. Therefore, the “damaged and defective batteries” have special regulations that need to be followed during transport. These "damaged and defective batteries" can be both new, consumed or fully consumed batteries.

4.2 GUIDELINES

This chapter presents the guidelines of the systems; *Circularity*, *Transportation*, *Manufacturing and disassembling, Collection of consumed batteries*, and *Recycling*. There are two levels of guidelines for the system areas; standards and recommendations. This, to make a distinction of which guidelines that are the most important. Standards are international ISO standards that should be followed and recommendations are good to follow. The optimum would be that all guidelines are followed, but if the guidelines need to be prioritised, the two levels explains in which order to prioritise them.

4.2.1 Circularity

These are the recommendations for creating a more circular business within reuse of consumed batteries from electric vehicles:

- Create networks where different stakeholders can spread and/or share knowledge within reuse of consumed batteries from electric vehicles. Exchanges of knowledge and experiences between different industries are a prerequisite for the development of a market for reusing consumed batteries from electric vehicles.
- Producer responsibility (Olsson et al., 2018) of lithium-ion batteries in electric vehicles applies to both the manufacturers of batteries, manufacturers/designers of electric vehicles and manufacturers/designers of second-life products. Therefore, the electric vehicles and the second-life products should go back from the users, through the retailers, to the manufacturers so that the manufacturers can make sure that the batteries are taken care of.
- Electric vehicles and second-life products should be rented by the users instead of purchased. This, to make sure that the vehicle or the product goes back into the circular system once it has been used.
- Electric vehicles and second-life products should, if possible, be maintained and/or repaired instead of scrapped. If possible, parts of the vehicle or product should be replaced/upgraded instead of replacing/upgrading the entire vehicles or products. This to both extend the life of the vehicles and products but also to save resources (Naturskyddsföreningen, 2019), (Ellen MacArthur Foundation, 2015). The maintenance, reparations, scrapping, replacements and upgrades should all take place at the manufacturers due to producer responsibility (Olsson et al., 2018).

4.2.2 Transportation

These are the standards that should be set for the transportation of consumed batteries from electric vehicles:

- Education in safety is needed for the people taking part in the transportation of consumed batteries. This, since lithium-ion batteries from electric vehicles are classified as hazardous goods and standards need to be followed in order for the transport to be safe (Myndigheten för samhällsskydd och beredskap [MSB], 2019).
- Equipment in terms of packaging, labeling and transport documents for lithium-ion batteries are required when transporting lithium-ion batteries from electric vehicles (Myndigheten för samhällsskydd och beredskap [MSB], 2019). The packagings are important since lithium-ion batteries contain hazardous materials that should not be exposed to people or nature (Wu, 2015).
- The batteries should be kept cool and dry without exposure to direct sunlight as said in the battery regulation (SFS 2008:834). This, to extend the life of the batteries but also due to safety. Lithium-ion batteries contain hazardous materials that should not be exposed to people or nature (Wu, 2015).

These are the recommendations that should be set for the transportation of consumed batteries from electric vehicles:

- The batteries, electric vehicles, second-life products and materials should be transported according to the system image (see chapter 4.1). This, to facilitate the flows of batteries, electric vehicles, second-life products and materials for the new market.

4.2.3 Manufacturing and disassembling

These are the standards that should be set for the manufacturing of batteries and disassembling of consumed batteries from electric vehicles:

- Education in safety is needed for the people taking part in the manufacturing of lithium-ion batteries. This, since lithium-ion batteries are classified as hazardous goods and standards need to be followed in order for the manufacturing process to be safe (Myndigheten för samhällsskydd och beredskap [MSB], 2019).
- Education in safety is needed for the people taking part in the disassembling of consumed lithium-ion batteries. This, since lithium-ion batteries from electric vehicles are classified as hazardous goods and standards need to be followed in order for the disassembling process to be safe (Myndigheten för samhällsskydd och beredskap [MSB], 2019).
- Safety equipment in regards of both protective gear, tools and machines is needed when manufacturing batteries for electric vehicles in order to keep the manufacturing process safe, both for the people working in the factory but also for the environment.

This, since lithium-ion batteries contain hazardous materials that should not be exposed to people or nature (Wu, 2015).

- Safety equipment in regards of both protective gear, tools and machines is needed when disassembling batteries from electric vehicles in order to keep the disassembling process safe, both for the people working in the factory but also for the environment. This, since lithium-ion batteries contain hazardous materials that should not be exposed to people or nature (Wu, 2015).

These are the recommendations for the manufacturing of batteries and disassembling of consumed batteries from electric vehicles:

- Electric vehicles should be designed to facilitate disassembling of their battery, in terms of placement and attachment principle (Naturskyddsföreningen, 2019).
- Renewable and recycled resources should be used in the manufacturing of lithium-ion batteries, electric vehicles and second-life products. The resources should be used efficiently to minimize waste (Naturskyddsföreningen, 2019).
- Modularity should be involved when manufacturing lithium-ion batteries, electric vehicles and second-life products, this to enable replacing/upgrading parts of the product instead of replacing/upgrading the entire product (Naturskyddsföreningen, 2019) (Ellen MacArthur Foundation, 2015).

4.2.4 Collection of consumed batteries

These are the standards that should be set for the collection of consumed batteries from electric vehicles:

- Education in safety is needed for the people taking part in the collection of consumed and/or end-of-life lithium-ion batteries. This, since lithium-ion batteries are classified as hazardous goods and standards need to be followed in order for the collection of consumed batteries to be safe (Myndigheten för samhällsskydd och beredskap [MSB], 2019).
- Safety equipment in regards of both protective gear, tools and machines is needed when collecting consumed batteries from electric vehicles in order for the collection of consumed batteries to be safe, both for the people working but also for the environment. This, since lithium-ion batteries contain hazardous materials that should not be exposed to people or nature (Wu, 2015).

These are the recommendations that should be set for the collection of consumed batteries from electric vehicles:

- The consumed lithium-ion batteries from electric vehicles should be collected by a new stakeholder. The battery collectors are to determine the condition and remaining capacity of the consumed batteries. If there is enough capacity left in order for the batteries to work in second-life products, the batteries are sold to actors responsible for giving the batteries a second life in other products. If there is not enough capacity left in order for the batteries to work in second-life products, the batteries are sold to actors responsible for recycling the batteries.

4.2.5 Recycling

These are the standards that should be set for the recycling of batteries from electric vehicles:

- Education in safety is needed for the people taking part in the recycling of lithium-ion batteries. This, since lithium-ion batteries are classified as hazardous goods and standards need to be followed in order for the recycling process to be safe (Myndigheten för samhällsskydd och beredskap [MSB], 2019).
- Safety equipment in regards of both protective gear, tools and machines is needed when recycling batteries for electric vehicles in order to keep the recycling process safe, both for the people working in the factory but also for the environment. This, since lithium-ion batteries contain hazardous materials that should not be exposed to people or nature (Wu, 2015).
- All lithium-ion batteries used in electric vehicles should consist of the same type of cells, physical shape and chemistry, this to facilitate during recycling (Olsson et al., 2018).
- The waste from the recycling process should be minimized (Naturskyddsföreningen, 2019).

These are the recommendations for the recycling of batteries from electric vehicles:

- All lithium-ion batteries, that do not have enough capacity to power electric vehicles or second-life products, should be recycled. This is the responsibility of the manufacturers, due to produces responsibility (Olsson et al., 2018).
- The materials used in the lithium-ion batteries should be kept in the loop for as long as possible. This to save resources and minimize waste (Naturskyddsföreningen, 2019).
- The location of the recycling centres should be in close proximity to the battery manufacturers. This to decrease both the cost and the environmental impact of transportation (Olsson et al., 2018).

AREAS FOR SECOND-LIFE

This chapter presents areas that could be potential users of second-life applications. The areas that have been investigated in this project are *At home, Public areas, Construction sites, Mines and Harbours*. Potential second-life applications have been made on four areas; *At home, Public areas, Construction sites and Mines*. Three of the areas, *Public areas, Construction sites and Mines*, have design suggestions that are still in a very early stage. The design suggestion for the area *At home* have been developed the furthest. *At home* was chosen because it was the area where the most people could benefit from the solution, since basically anyone with their own house could be the user of this product.

5.1 AT HOME

The interest of being self-supporting when it comes to electricity is increasing. Individuals are more and more conscious of the environmental issues and want to make sustainable choices that benefits the environment ecologically (Nordbergh 2018).

In the first survey that was sent out via Facebook, the first question was if there was any situation when people were in need of electricity but electricity was not available. 71% answered yes which was a positive finding since it showed that many individuals would hopefully be interested in some kind of battery solution. As a follow up question, they were asked to answer in which situation they were in need of electricity when electricity was not available. There were many different answers but a common denominator for the answers was when "one was on the go". "On the go" could be at the bus, train or tram, when running or hiking, when being out in the nature for example when being in the forest, when climbing mountains or when you are out with the boat or when being in the garden or on the balcony. This result gave inspiration to create a modular design suggestion where parts of the battery solution could be brought when "on the go", this to provide the user with electricity.

Another question was if they could find any situation where electricity was available but in a limited amount. Here the answers differed a lot, but the majority could not come up with such a situation. The result showed that when electricity is available, the capacity is often large enough and that is probably due to the fact that there is a great access to electricity here in Sweden. Thereby, a conclusion was drawn that the capacity of the second-life product did not have to be as large as it was thought from the beginning. This insight facilitated the design of the second-life product since it could be smaller and cheaper.

The last question in the survey was: "If you get access to a battery that you can use wherever you are to whatever you want, what would it be? (the battery has an unlimited capacity)". Many people answered that they would use the battery to charge various portable electronic devices such as phones, computers, cameras etcetera. Some people also mentioned that they wanted to use the battery during a blackout or when electricity is not available. This result gave an idea of how much capacity that was needed for the second-life product and in which situations the users probably would use it.

Challenges

One of the challenges with having a second-life product containing consumed batteries for *At home* is that people want to use electricity when they are "on the go", so the product needs to be easy to carry. Another challenge is that the accessibility and reliability of the electricity grid in Sweden is very good and a battery solution is therefore redundant in many situations.

Benefits

The benefits with having a second-life product containing consumed batteries are that many individuals are interested in having some kind of battery solution when they are "on the go" and that they only want the battery solution for smaller tasks. This means that the capacity of the second-life product can be rather small, and when the capacity can be small, the battery solution can be small too and will therefore be easy to carry.

5.1.1 At home design suggestion

This chapter presents the design suggestion for *At home*. This design suggestion has been developed the furthest and it is built on the findings from the research and user studies. The product is to be rented from the retailer of second-life products.

Explanation of the design suggestion

The design suggestion is an energy storage product for the home, which means that the product can provide the home with electricity. The product is connected to solar panels that can be placed on the roof of the house and these solar panels charges the battery in the product which then stores this energy. In this way, one can reduce energy peaks, lower the energy costs and become more self-sufficient. The energy storage product can be placed on the house wall as in the picture, see figure 3.

Figure 3: The energy storage product in a real context

This energy storage product is multifunctional, it has an integrated charger for electric vehicles and two integrated power banks, see figure 4.

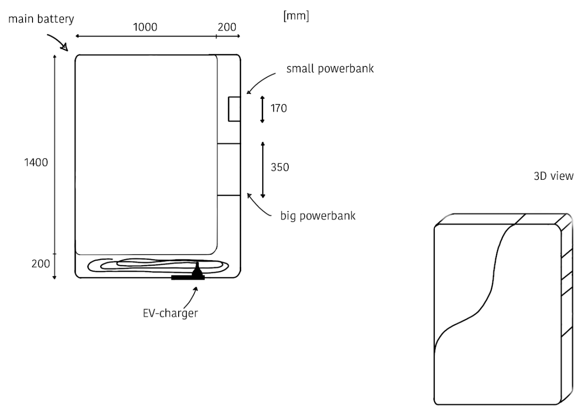


Figure 4: Product sketch

The contact and cord for the charger to electric vehicles is in the bottom of the product and can be used to charge the electric vehicle at for example blackouts when no other electricity is available. So the product is not built to be used as the everyday charger for the electric car, but rather in special times of need. The contact and the cord works as the one on a vacuum cleaner, it is drawn out and can later be drawn in again into the product, see figure 5. So the cord and contact are integrated in the product when they are not used. This feature is something that can be selected as a supplement for the product. If the user does not have an electric vehicle, it should not have to pay for this feature. If the user does purchase an electric vehicle and changes its mind about having the charger for the electric vehicle, the product can easily be upgraded with this feature. The cord will have a length of ten meters, this since it was considered as a sufficient length for most driveways.

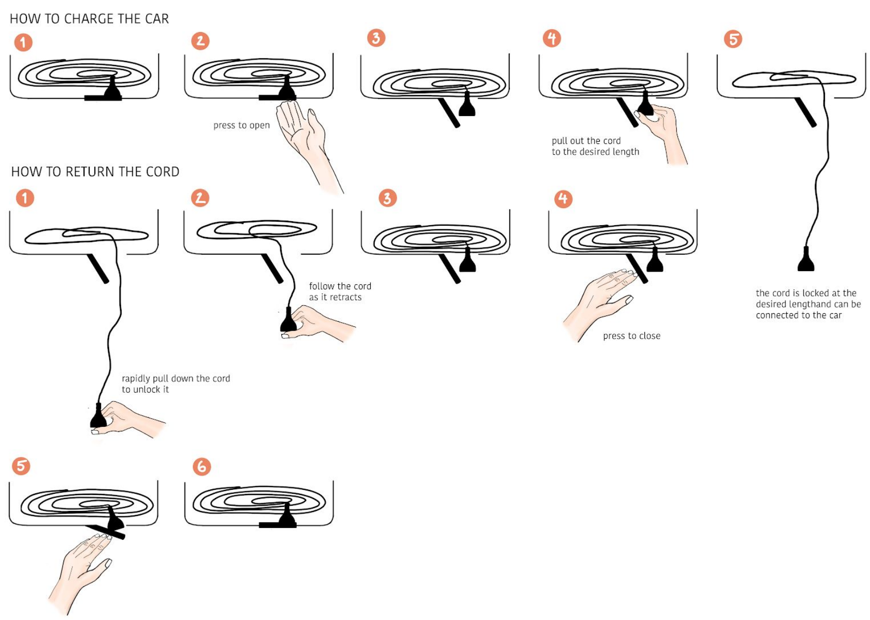


Figure 5: How to use the charger

The integrated power banks were added because it was found from the user studies that there was a need for electricity when people were "on the go". Based on the tasks that people wanted electricity for, two different sizes of power banks were created, one small and one big. The two power banks are located on the side of the product, see figure 4 and since they are integrated in the product, the batteries of the power banks are charged at the same time as the energy storage battery. The power banks are taken out by pushing the hatch, see figure 6.

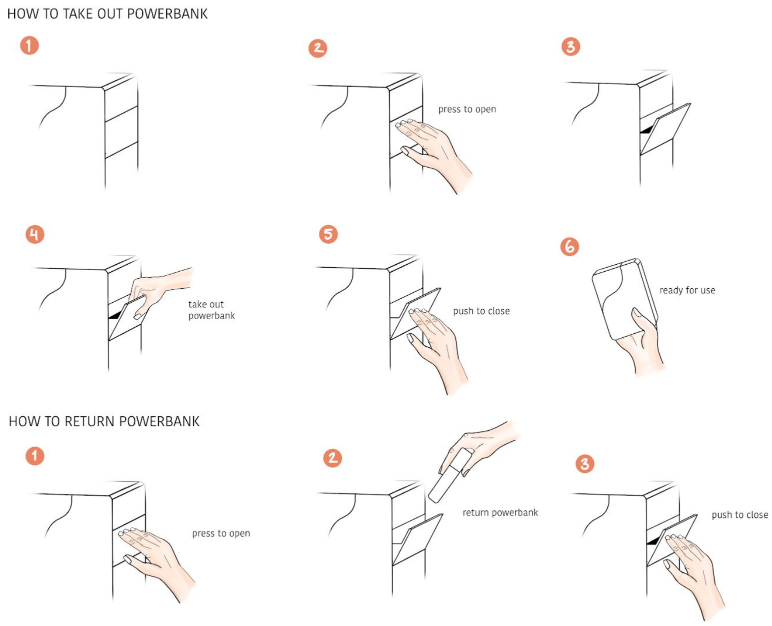


Figure 6: How to take out and return the power bank

The small power bank can be used to charge smaller electronic devices such as mobile phones when one is "on the go" and do not have access to power outlets. The bigger power bank can be used when one needs larger amounts of electricity, for example when one is going camping or if one is taking a trip on a boat. The bigger power bank should have a handle to facilitate carrying it, see figure 7.

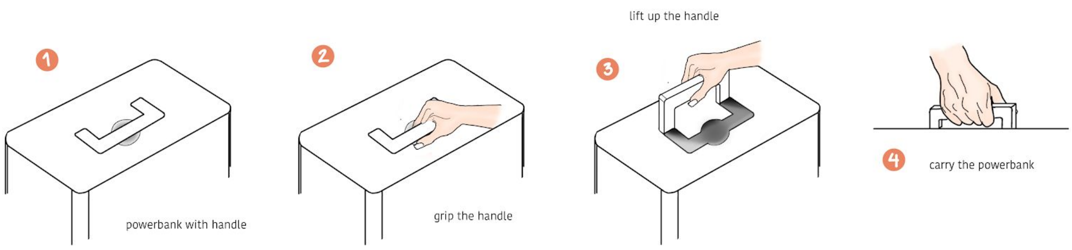


Figure 7: How to carry the big power bank

Specific features

The shape of the product is rectangular, to follow the shape of the battery and to facilitate during transportation. It comes in two versions, one made completely out of raw aluminium, see figure 8, and one made out of a combination of raw aluminium and teak wood, see figure 9. The power banks of the different versions should follow the look of the product.

Figure 8: Raw aluminium version

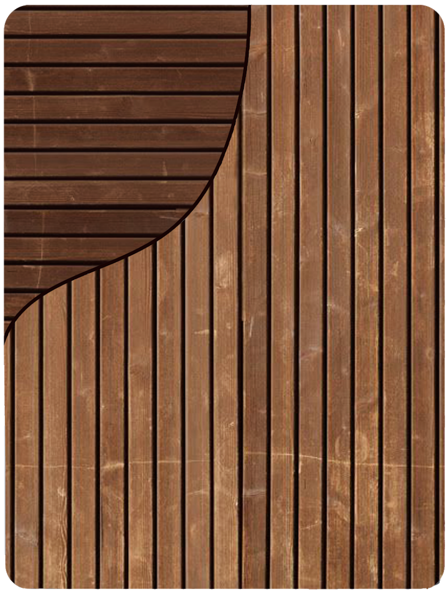


Figure 9: Teak wood version

The aluminium one is for the people that wants a product that pops and the aluminium/wooden one is for people who want the product to blend in more with their home, since they can paint the product in the same colour as their house. The look of the product is supposed to "show off", but in a discreet way. There should not be any distinct logo on the product, because the product should instead speak for itself. The people that own this product should be proud of it and therefore want to show it off, but at the same time it should look like a natural part of the home. The product should be placed somewhere on the exterior walls of the home, see example in figure 3, but the exact position of the product is up to the user. If one wants to use the charger for the car, it should be positioned somewhere close to the driveway.

To know how much capacity that is left in the product, charging statuses are placed on both the main battery and the power banks. The charging status shows how much capacity that is left in both percentage and in watt hours. This, is in order for the user to know if the capacity is enough for their purpose of use.

Technical details

The product needs to have some sort of insulating material between the batteries and the shells of the product, both the big battery and the two smaller ones in the powerbanks. All three batteries also need to have a power inverter, to alter the DC from the batteries to AC to be able to charge the electric vehicle and other products (Inverterbutiken, 2019).

Calculations

When calculating the capacity of the energy storage battery and the power banks, the battery from Nissan leaf of 40 kWh and 360 V was used (Nissan, 2019). When a battery from an electric vehicle has consumed its maximum effect, it has 80% of its capacity left (Guenther, Schott, Hennings, Waldowski & Danzer, 2013).

This means:
0,8 * 40 kWh ≈ 32 kWh

A battery in an electric vehicle has a size of approximately 2000x1400 mm. The size of the energy storage battery in this design suggestion is half of the original size, which means 1000x1400 mm.

This results in half of the capacity:
0,5 * 32 kWh = 16 kWh

A battery in an electric vehicle is built of several modules and the modules consist of several cells. In this case, it is assumed that the original electric vehicle battery has 48 modules and each module has 4 cells (Nissan, 2019). Since the energy storage battery has been decided to be half of the original electric vehicle battery, the energy storage battery has 24 modules.

This means that each module has a capacity of:
16 kWh / 24 modules ≈ 0,67 kWh/module

Each cell will then have a capacity of:
0,67 kWh / 4 cells ≈ 0,17 kWh

The power banks come in two different sizes, the small one consists of one cell and the big one consists of one module (four cells). By using the size of the original electric vehicle battery: 2000x1400x200 mm, it has been calculated that a cell has a size of 90x170x200 mm and that a module has a size of 350x170x200 mm, see figure 10.

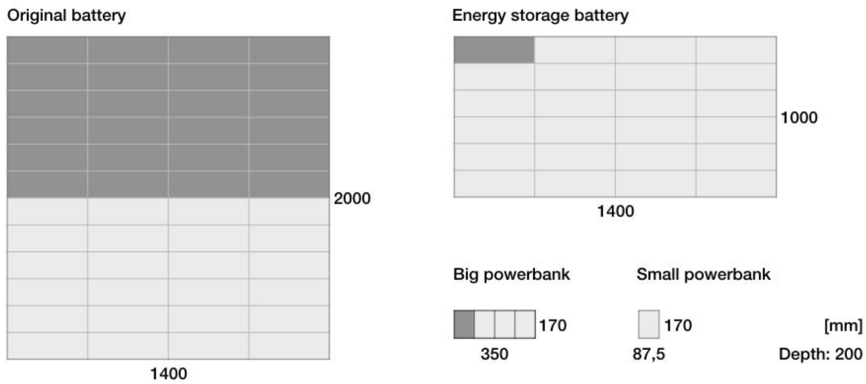


Figure 10: Measurements

The weight of the original electric vehicle battery is 272 kg (Nilsson, 2014) which means that the energy storage battery will have a weight of 136 kg. A module will have a weight of 6 kg and a cell will then have a weight of 1,5 kg, see figure 11.

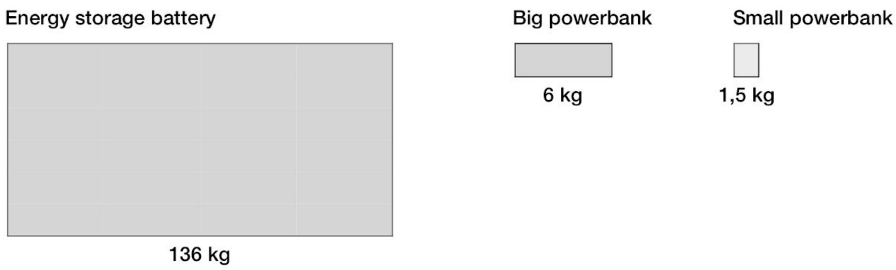


Figure 11: Weights

The same calculations have been made with an original electric vehicle battery from Nissan with a capacity of 62 kWh (Nissan, 2019). This results in a span of:

14 kWh < energy storage battery < 24,8 kWh
0,58 kWh < big powerbank < 1,03 kWh
0,15 kWh < small powerbank < 0,236kWh

Reflections regarding the calculations

The first original electric vehicle battery from Nissan leaf had a capacity of 24 kWh but that capacity is considered to be too low for this second-life product. These batteries should instead be used in bigger energy storage systems, for example residential or telecom base stations. Nowadays, the battery in a Nissan Leaf has a capacity of 40 kWh or 62 kWh and these two different values have been used in the calculations above. This, since the capacity of the future electric vehicles most likely will fall within this span. Some batteries will have a higher capacity and that will result in a higher capacity of both the energy storage and the power banks, which will only be positive.

As the electric vehicle batteries are under constant development, the capacity of the batteries will become higher and higher over the years. The future consumed batteries will have a higher capacity compared to the consumed batteries that exist on the market today, this due to a higher capacity of the original batteries. Because of this, the second-life products of the future will have a higher capacity than those that exist today.

The design of the battery differs depending on aspects such as car brand and battery capacity. Even though the batteries have more or less the same size, the number of modules and cells within the battery can vary. For example, Tesla's model S has around 7000 cells whereas the Nissan Leaf has 192 cells. However, the number of cells and modules doesn't really matter, the capacity and the size of the power banks will be the same, the only thing that will change if using another battery is the number of modules and/or cells in each power bank.

Finally, it has to be taken into consideration that all measurements and calculations are very rough and approximate. This due to the lack of available information regarding size, weight and capacity of the electric vehicles batteries.

Design suggestion in the system image

The journey of this design suggestion can be described by using the system image, see figure 12.

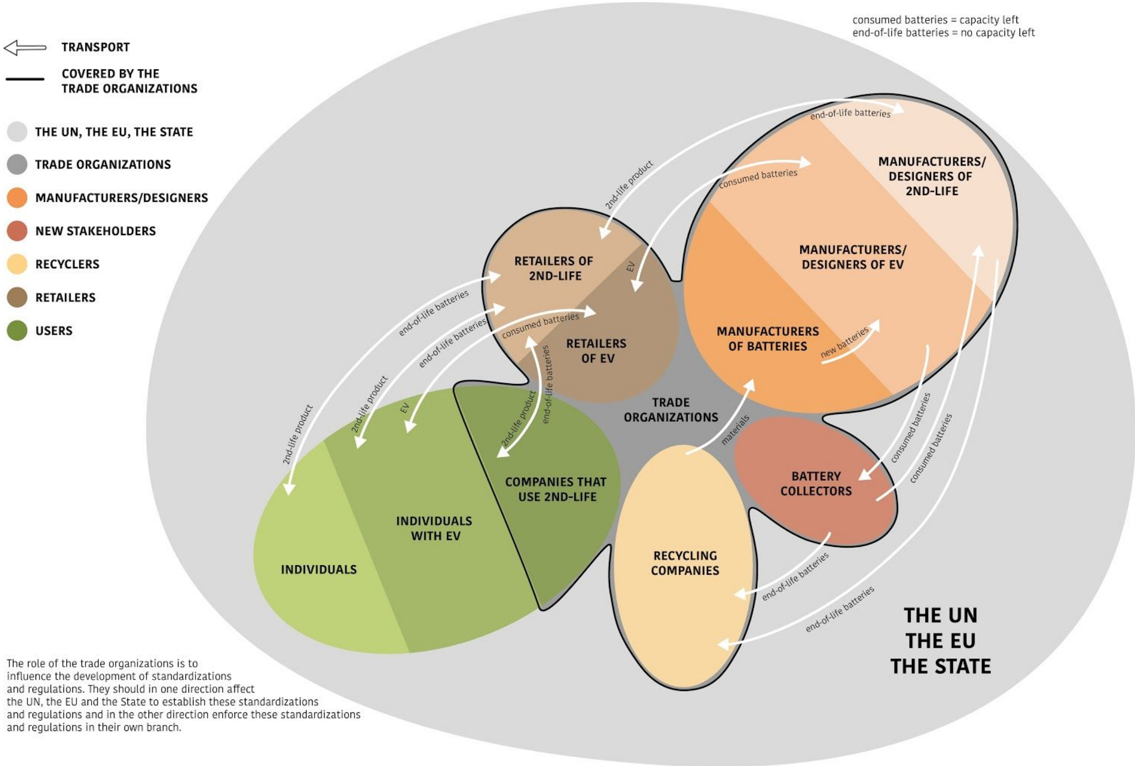


Figure 12: The system image

Firstly, the electric vehicle battery is manufactured. The battery is transported to the manufacturer of electric vehicles where it is put into a car. The car is then transported to the retailer of electric vehicles and from this, the car is either sold or rented to a homeowner in Sweden. Here, the car is used for some years until the battery has consumed its maximum effect. The car is then transported back to retailer of electric vehicles and later to the manufacturer of electric vehicles. The consumed battery in this car is then sent to the battery collector that determine the condition and remaining capacity of the consumed battery. The battery in this case still has 80% remaining capacity, so it is sent to the manufacturer of second-life products where it is reused in the *At home* design suggestion, the energy storage product. The energy storage product is then sent to the retailer of second-life products and from this, the energy storage product is rented to a homeowner in Sweden. Here, the energy storage product is used for some years until the battery has reached its end-of-life for this application. The energy storage product is then transported back to the retailer of second-life products. The homeowner wants a new battery in the energy storage product so the retailer sends the energy storage product back to the manufacturer of second-life products. There, the exchange of the battery takes place and the energy storage product is sent back to the homeowner. The end-of-life battery is sent to the recycling companies in order for the end-of-life battery to be recycled. Materials from the recycled battery can then be used when manufacturing new batteries.

Evaluation of the design suggestion

The aim of the survey was to investigate how much individuals would be prepared to pay for the suggested second-life product; solar cells with associated energy storage battery. The first question was if they could imagine themselves investing in solar cells with associated energy back-up in order to reduce their electricity costs in the long term? Almost everyone, 96,6% percent, answered yes, which was a positive finding since it showed that many individuals would hopefully be interested in investing in this kind of solution.

As a follow up question, the persons that answered yes were asked to answer for what reason they would invest in such a solution. There were two recurrent responses, the first was due to reducing the costs and the second was due to reducing the environmental impact. Both of these were positive responses since reducing costs and environmental impact are two benefits that have been considered when developing the design suggestion.

The next question was; “If you were to invest in solar cells with associated energy back-up, how much would you be willing to invest initially?” They got four different span of sums to choose between and the answers differed a lot, see figure 13. Even though the answers differed a lot, there was more people that crossed the boxes in the upper spans than in the lower ones and that gave an indication that people are willing to pay quite much for this kind of solution.

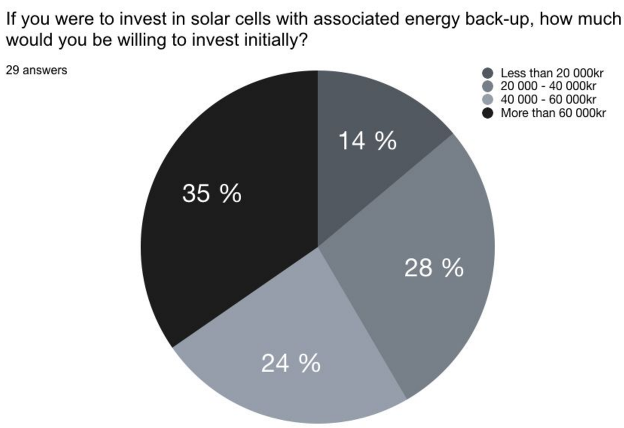


Figure 13: Answers from the question “If you were to invest in solar cells with associated energy back-up, how much would you be willing to invest initially?”

The last question in the survey was: “What is your maximum limit, in number of years, for an investment in solar cells with associated energy back-up to be profitable?”. They got three different spans of years to choose between and this time, one of the spans got the majority of the answers, see figure 14. However, it was thought that this could depend on the way the question was asked and on the different spans of years to choose between. Generally, people want to pay as little as possible for as much benefit as possible and do not want to invest too much with too long repayment, therefore it was thought that the majority chose the lowest span, less than ten years.

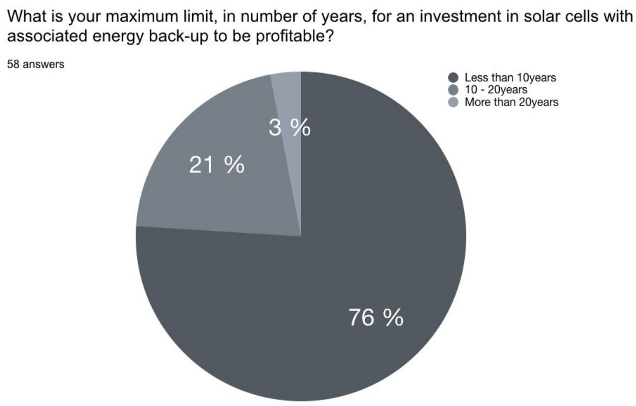


Figure 14: Answers from the question "What is your maximum limit, in number of years, for an investment in solar cells with associated energy back-up to be profitable?"

The result of the interviews regarding the charging function of the *At home* design suggestion gave some interesting inputs. People owning an electric vehicle were asked to share their experiences about charging but also to give comments on the charging function integrated in the design suggestion.

All of the interviewees charged their electric vehicles during the night. This charge was sufficient for their daily use of the electric vehicle. When they were going for longer trips they charged their electric vehicle at different charging stations along the road. A common problem seemed to be unstandardized cords, connectors and power outlets. This since the voltage of the electric vehicle battery can differ from the voltage coming from the charger.

When the interviewees were asked to respond to the charging function of the *At home* design suggestion, they came with some some interesting ideas. To start with, they mentioned that the function would be beneficial when electricity from the electricity grid is not available, for example during blackouts. Furthermore, one mentioned that a "three-phase-cord" is needed in order for the charging to be effective. However, this three-phase-cord is quite stiff and bulky which can cause problem when the cord is to be pulled in and collected to the product. This is something that has to be further investigated but it is an easy problem to solve since the space for the cord simply can be made larger.

Another of the interviewees was a little hesitant to the solution since, here in Sweden, electricity is almost always available and that the electricity network is too stable to motivate a back-up system. On the other hand, he could imagine this product placed at every ten kilometers along roads such as E45 i Sweden. He thought that this would be a very strong argument for those who have anxiety regarding how far their electric vehicle can drive on one charge.

To summarize, the charging function was hard to evaluate since the interviewees did not have the ability to interact with the product. More evaluations must to be made if the product is to be further developed.

The result of the semantic scale was compared to the wanted expression of the three different versions of the product. The result of the semantic scale can be seen in figure 15 and the wanted expression can be seen in figure 16. The perceived expression of the three versions of the product differed a lot and to get a more clear picture of the result the median values was used. This made the result easier to compare with the wanted expression.

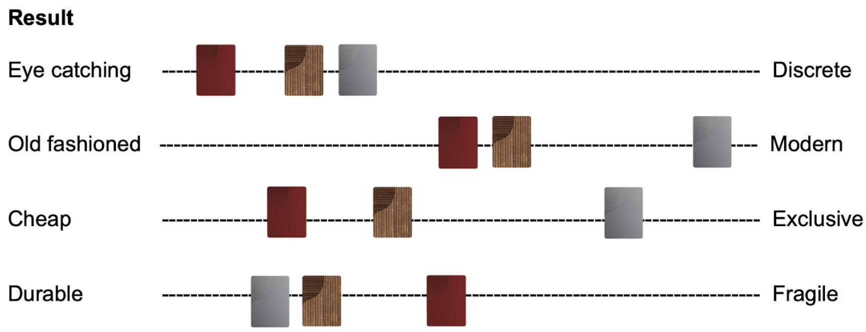


Figure 15: Result of the semantic scale

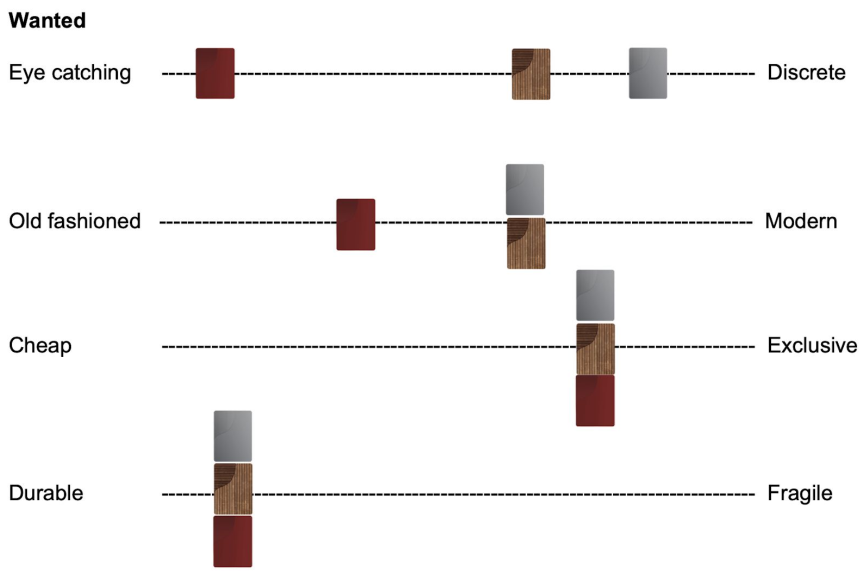


Figure 16: Wanted expression of the semantic scale

Besides the difference in perceived expressions, it also differed how the individuals evaluated the material versus the colour of the product. For some, the material was more prominent and for others, the colour was more prominent. A lot of them also thought that it was difficult to not having a reference when evaluating the different semantics of the products. This, since they thought that it would be easier to have another product to compare with when rating the semantics.

One aspect that was changed after the evaluation of the *At home* design suggestion was which colours the product should have. Going into the evaluation, it was decided to have three versions; one made out of metal, one made out of wood and one red version. However, this was changed after doing the semantic scale evaluation, since the wish to hide the product was bigger than what was thought in the beginning. The idea with three versions was that both the metal version and the wooden version should be discrete and that the red version should be more eye catching. The evaluation on the other hand showed that two of the individuals were interested in buying the wooden version and then colour it in the same colour as their houses to hide it even further. Both these two individuals live in houses with tree-panel and they did not think that any of the three existing versions of the product would fit their houses. They compared the product with distribution boxes that are on almost every house and that often are perceived as ugly, since they do not go together with the house facades very well. Therefore, the choice was made to not have the red version of the product. Instead, the wooden version of the product can be coloured in any wanted colour or be kept as it is. When purchasing the wooden version, it comes with information of how to best colour it and what type of colour to use. For the user to have this colour option, the product can be personalized to fit any house.

So instead of having one metal version, one wooden version and one red version, the decision was made to keep the metal version and the wooden version, but with the opportunity of colouring the wooden version. This, since the wish for hiding the product was big and the three initial versions did not cover all houses.

5.2 PUBLIC AREAS

The cities of the future are free from carbon dioxide emissions. Electrification of vehicles is highly topical and cities are constantly striving to be more ecologically and socially sustainable (Kanth, 2018).

The product categories that were investigated in the benchmarking were different energy storage solutions, different power banks, electric buses, electric bicycles and electric scooters.

Challenges

The biggest challenge with having a second-life product containing consumed batteries for *Public areas* is that the accessibility and reliability of the electricity grid in Sweden is very good and a battery solution is therefore redundant in many situations.

5.2.1 Public areas design suggestion

This chapter presents the design suggestion for *Public areas* and this design suggestion is still in a very early stage. The chapter explains the basic idea of the design suggestion and no details in regards of exact size, weight, shape, colour or features has been set. The design suggestion is built on the findings from the research and user studies.

Explanation of the design suggestion

In public areas, everything that is stationary is powered by the electricity grid. The areas where battery solutions could be of use are when temporary solutions are needed, for example at events, games, tournaments, concerts and festivals. Consumed batteries can therefore be reused in portable, modular pillars that can be located in different parts of the cities. The pillars should be powered mainly by the electricity grid, but they also have solar panels on top. The pillars contain several smaller batteries that can be used as power banks and brought to locations where electricity is needed. The pillars themselves can also be used as charging stations.

This design suggestion is a part of the "Styr och Ställ" system that exists in Gothenburg. It is a system where one temporary rents a bicycle to get from one part of the city to another. "Styr och Ställ" has fixed stations where the bicycles are parked, and to get a bicycle one shows its membership card to a machine, and one gets a bike. When one has arrived at the destination, one locates a nearby "Styr och Ställ" station and parks the bicycle there. The membership card is personal and it keeps track of weather one has returned the bicycle or not.

A con with the "Styr och Ställ" bicycles is that there are no electric bikes, which makes it popular to travel by bike when one is going downhill, but many people rather take the tram or bus when one needs to go uphill. So this is where the design suggestion comes in.

The design suggestion is a rectangular, modular pillar that is located at the parking stations of the “Styr och Ställ” bicycles. It contains several small batteries, that originally were cells in battery packs in electric vehicles. The pillar is powered mainly by the electricity grid, but it also has solar panels on top. These batteries have three functions, it can be used to power a “Styr och Ställ” bicycle, it can be used as a powerbank or it can be used as a power station.

To power the bicycle, the battery is fastened to the “Styr och Ställ” bicycle and this makes it an electric bicycle, which is good when one wants some extra help. One use its membership card to get the battery, the same way as ones does for the bicycle, and in the same way the membership card keeps track of weather one has returned the battery or not. When one arrives at the destination, one parks the bicycle at the nearest “Styr och Ställ” parking and then fastens the battery to that parking’s battery pillar. A pro with attaching the battery yourself is that one can choose weather or not one wants to have an electric bicycle. Some people might still want to use an ordinary bicycle and in this way one can choose if he or she wants that extra support or not.

If one wants to use the battery as a powerbank, one simply uses its membership card to take a battery. One can then carry it around for as long as one like and then one returns it at the bicycle parking of its choice.

The battery pillar also works as a power station, which means that one can charge any application at the pillar itself. This could be useful if for example a pillar is located near a bus stop and one needs to charge its phone.

At different events in the city, temporary parkings for “Styr och Ställ” including the battery pillars can be implemented. It is also possible to choose how many parking spaces and battery pillars one wants. At Way Out West for an example, a lot of people are gathered at the same place. There it could be good to implement several battery pillars in order for the people visiting the festival to charge their phones, cameras and other applications. When the festival is over, the battery pillars could easily be removed again.

The thought of this design suggestion is that the battery pillars should be owned by cities/municipalities or by private actors and be rented out for example during concerts and/or events like Way out west or in other situations where a mobile and temporary charging solution is needed.

There also need to be some sort of indication on the charging status of the batteries on the pillar. One idea is for it to work the same way as it does with the bicycles today, that when one swipes its membership card in the machine, one of the bikes lights up. This could be used for the batteries as well, and then one knows that the battery that lighting up is fully charged.

Evaluation of the design suggestion

Generally, all contacted persons were positive to the idea of having a mobile charging station with integrated power banks. They all liked the idea of reusing consumed batteries from electric vehicles and they all liked the thought of having a sustainable solution for providing electricity. They had some comments about that similar ideas have been brought up before and that a similar solution already exist in the city of Gothenburg today. The similar solution that exists today is owned by Göteborgs Energi and they have fixed charging stations located in different parts of the city where one can charge its phone. These charging stations are also used temporary as mobile charging stations at different events.

When it comes to events, it was said that for bigger events the arrangers of the event usually know where the electricity centrals are and they almost always have the possibility to connect to these. Therefore, the electricity grid is often used for the bigger events. For smaller events on the other hand, it could be a good idea to have a mobile charging station. It exists some solutions today, but these mobile charging stations are often powered by fossil fuels. Therefore, the design suggestion could be a possible solution at smaller events or at other events where there is trouble to connect to the electricity grid. The idea that the mobile charging stations should be provided by the city was viewed as positive, but since the different districts in the city have limited budgets, the leasing needs to be cheap or even for free. If the leasing is too expensive, the districts will not be able to prioritise the leasing of the mobile charging stations. It was also said that the mobile charging stations need to be practical in terms of the ability of moving them. It should be easy to move them from one location to another. If not, the usage of them will be low and the costs of creating this service will therefore not be justifiable.

Other comments from the companies who were contacted were that Gothenburg already has a well distributed electricity grid with good connection opportunities, so the overall need for such a solution is not that big in Gothenburg. Since the electricity grid is of such easy access, it puts an even higher demand on how practical the charging stations need to be.

Finally, there were comments that the solution would work for more cities than Gothenburg. They said that it can be difficult to find someone within the city of Gothenburg who wants to purchase and handle everything around the mobile charging stations and that it might be better if an outside private actor was in charge of them instead. This would also facilitate the idea of using the mobile charging stations in other cities than Gothenburg.

5.3 CONSTRUCTION SITES

Construction sites are dependent of electrical energy, this to drive tools, machines, lights, and barracks. Construction sites are also dependent of internet connection, this in order to have camera surveillance and to create APD plans and 3D drawings (Lambertsson, 2017).

It is considered as very important to create energy-efficient buildings and a lot of time, money and effort is spent on that. In contrast, the impact on the environment from the operating phase is often forgotten. Calculations indicate that the total climate impact from construction processes in Sweden amounts to approximately 10 million tonnes of carbon dioxide equivalents per year (IVA, 2014). The machines that are used on construction sites are almost always driven by fossil fuels. Material extraction and transportation, dehydration and temporary heating are other factors that affect the carbon dioxide emissions negatively.

Caterpillar, an US manufacturer of construction equipment, diesel engines, gas turbines, diesel powered power generators and mining equipment, are moving away from fossil fuels to electrify the entire range (Edgren, 2019). A great advantage with this transition, expect from the environmental benefits, is that electrified machines are quieter which enables work around the clock since the machines then not will disturb people that are sleeping.

When visiting the construction sites, it was realised that all vehicles and most of the machines used on the construction sites were driven by fossil fuels. However, all the workers were interested in changing to vehicles and machines driven by electric power. They were also positive to using batteries since it is difficult and very time consuming to draw electricity from the electricity grid. One of the workers at the visited construction site said that they often have to wait for eight months in order for the electricity to be drawn.

Even though they were positive to introducing electric vehicles, machines and tools on the construction sites, they saw some challenges with it. Firstly, they use vehicles and machines that require a very high capacity for a long time which can be problematic if batteries are to be used instead of fossil fuels. Secondly, the batteries in the tools cannot be big and bulky, this since the workers are moving around a lot on the construction site while working. Lastly, another challenge with introducing vehicles and machines driven by electric power was the lack of space. Due to the lack of space, it can be a problem with finding places on the construction sites where the vehicles and machines can be charged.

Challenges

The challenges with electrifying construction sites are that all vehicles and most of the machines used today are driven by fossil fuels and they also require a very high capacity for a long time. The lack of space on construction sites is also a huge challenge when trying to implement reused batteries solutions.

Benefits

The benefits with electrifying construction sites are that many of the workers are interested in changing to vehicles and machines driven by electric power instead of fossil fuels. Many of the workers are also positive to using batteries since it is a difficult and time consuming process to draw electricity from the electricity grid. Lastly, reusing batteries on construction sites would result in a significant decrease of carbon dioxide emissions, since the total climate impact from construction processes in Sweden amounts to approximately 10 million tonnes of carbon dioxide equivalents per year (IVA, 2014).

5.3.1 Construction sites design suggestion

This chapter presents the design suggestion for *Construction sites* and this design suggestion is still in a very early stage. The chapter explains the basic idea of the design suggestion and no details in regards of exact size, weight, shape, colour or features has been set. The design suggestion is built on the findings from the research and user study phase.

Prerequisites

The prerequisites for this design suggestion is that all vehicles, machines and tools are driven by electric power. This assumption is based on (Niléhn, 2018) that says that the construction sites of the future are free from carbon dioxide emissions. Another prerequisite is that the electric vehicles can work for eight hours on one charge. Therefore, if working in more than one shift a day, the shifts should be adapted to the charging time of the electric vehicles. This in order for the vehicle to have time to charge between the shifts.

Explanation of the design suggestion

This design suggestion is a modular solution containing consumed batteries that should be placed on the sheds and work as power supply for the vehicles, machines and tools on the construction sites. The core of the design suggestion is stationary and is fastened to the short side of the building shed. However, due to the modularity of the design suggestion, parts can be removed and transported/carried to places where electricity is needed, for example to charge tools and/or machines. The design suggestion has a square shape, to follow the shape of the batteries and the construction shed. The construction shed is powered by the electricity grid but it also has solar panels on its roof, and the power from the solar panels is stored in the design suggestion. This decreases the need for power from the electricity grid, but if necessary, the grid can be used. The reason why the design suggestion is stationed on the construction shed is because that is the only part of a construction site that does not get moved. The rest of the construction site is during constant change and if the design suggestion where to be put anywhere else, it most likely need to be moved at some point during the construction process.

The modularity of the container solution is to fit the needs of both charging big vehicles, medium sized machines and small tools. The vehicles need high capacity when charging and therefore it needs to be placed next to the construction shed and the core of the design suggestion to charge. This can be done during lunches or between shifts. The medium sized machines need less capacity to charge, and parts of the design suggestion could be transported/carried to the location of the machines. This transportation could be made either by fastening the part of the design suggestion to a vehicle and drive it to its location, or it can be carried by hand. The small tools need the least capacity to charge, and small parts of the design suggestion could be carried to the location of where the tools are used. This will most likely be done manually, because of the small size of the battery parts.

The modularity of the container solution is what contributes to its mobility, which is important on a construction site where different work tasks take place at different parts of the construction site.

Evaluation of the design suggestion

Christin Carlsson, Environmental Health & Safety Coordinator at Serneke Bygg AB, answered that she thought it sounded like a good idea, but only if the battery is capable of working enough hours before it needs to be charged and if the battery is capable of providing the power needed for the different work tasks. She passed on the questions to two other persons at Serneke that had more experience about the production process within the construction business. One of them, Åsa Tenggren agreed with Christin that it sounded like a good idea, she thought it was smart that it was possible to bring parts of the main battery to places on the construction sites where power is needed. However, she did not have enough knowledge about batteries and questioned the risk for fires and/or explosions. The risk of fires and explosions is one aspect that needs to look deeper into when further developing the design suggestion, this to ensure that such accidents will not occur. The other one, whose name was unfortunately left out, agreed with Christin as well and thought it sounded really interesting. However, he also mentioned that he thought that the storage of batteries would mean a risk for fires and/or explosions and as said, that is an aspect that needs to be further investigated. He questioned whether or not the "wireless" solution would be capable of providing enough power to the construction site and was unsure if the number of batteries in the design suggestion would be enough. However, it is thought that this question was asked because of a misinterpretation of the design suggestion description. This since the construction shed shall be powered by the electricity grid and also have solar panels on its roof, and the power from the solar panels is the energy that is being stored in the design suggestion. This solution will decrease the need for power from the electricity grid, but if necessary, the grid can be used. So the solution is not fully wireless as was first believed.

Finally, Christin ended the email with pointing out that all three of them had limited knowledge about the reuse of consumed batteries and she said that this limited knowledge is something that one probably will have to deal with if one is to sell in the idea.

5.4 MINES

The mines of the future are free from carbon dioxide emissions (Ejemalm, 2018). According to SweMin (2018), the mining industry accounts for about 8% of Sweden's carbon dioxide emissions and therefore electrification of mines is a very important topic. The machines used in mines are huge mining trucks and the trucks are very thirsty. In the Aitik mine, for example, they use the Caterpillar 795 truck and it requires 400 liters of diesel per hour on its way up from the 490 meter deep quarry. For such trucks, there is currently no energy storage with sufficient capacity, and instead there is the option of using overhead wires, like the ones for trams. The introduction of overhead wires is expected to reduce emissions by 80% on the routes where the technology is implemented (Kristensson 2018).

According to Anders Grauers who is part of the project of electrifying the mine of Aitik, mines are demarcated areas where a lot of fossil fuels are used for both trucks, machines, tools and ventilation. There are two different types of mines, quarries and underground mines. Quarries are basically giant holes where the operations takes place in the hole but above ground. Underground mines on the other hand are exactly what it sounds like, underground and the operations take place in narrow tunnels deep below ground.

Challenges

Above ground, the challenge of implementing overhead wires is that the road changes with the climate. The height of the road can differ by up to one meter between different times of the year, which of course is a challenge for how the overhead wire should be constructed (Kristensson 2018). The temperature is also a challenge in the Swedish mines, as batteries are sensitive to low temperatures (Wickström 2018).

The trucks in most mines basically operate 24 hours a day 365 days a year and system availability is of the utmost importance (Kristensson 2018). Therefore, a great challenge in building the overhead wires is to be able to carry out the installation without interfering with the ongoing mining operation (Hansson 2018). According to Anders Grauers, this is even more difficult in the mines than above ground, since the space is much more limited in the mine. Of course, the installation must also not affect the safety of the people who work in the mine and it is important that all technical systems work together, and with a high reliability (Wickström 2018).

There are also many challenges in the future, according to Sustainable Underground Mining (2018), in order for the mining industry to maintain its sustainability. All mines will have to go deeper to access the desirable minerals and metals and that demands better trucks, machines and ventilation. The mines will therefore reach a certain depth where it is no longer economically justifiable to use diesel trucks, because of the need for ventilation. That is one incentive to why electrification of mines is of importance. But in order to be able to carry out this electrification of the mines, technology needs to be developed and tested in real mining environment and this requires cooperation between large industrial companies. Today's mines, as stated, release large amounts of carbon dioxide, and with the climate issue, the mines of the future must be basically free from carbon dioxide emissions so that the mining can continue at the same rate as today (Sustainable Underground Mining, 2018).

Benefits

The advantages of switching to electricity, in addition to the ecological aspect, is that the vehicles that drive with overhead wires will, according to Anders Grauers, be able to drive at a higher speed than the diesel trucks. This means an energy saving as well as reduced cycle times and a better utilization of the trucks. Either fewer vehicles can be used for the same job or the mine can produce more (Kristensson 2018). Another big advantage is the reduced need for ventilation. Below ground, the air is not free since the required ventilation is extremely expensive (Power Circle Summit, 2018). In some cases it is, according to Anders Grauers, even more expensive to power the ventilation than the trucks. The costs also increase with the depth, so the deeper you get, the more unprofitable it will be to use diesel. At the same time, the requirements for the quality of the air is increasing as a result of increased health requirements for the people working in the mines. The diesel engines also need large amounts of air to not overheat the areas in which they operate (Power Circle Summit, 2018).

5.4.1 Electrification of mines

This chapter presents the electrification of *Mines* and this is built on the findings from the research and user studies.

Prerequisites

The prerequisites for the electrification of *Mines* is that all trucks, machines and tools are electric. This assumption is based on (Ejemalm, 2018) that says that the mines of the future are free from carbon dioxide emissions.

Explanation of the design suggestion

The design suggestion for *Mines* is primarily not based on consumed batteries from electric vehicles, it is more of a suggestion of how to implement electricity in the mines. This since it was found from the research and user study phase that there was a good, already introduced idea, which was to instead of using batteries, use overhead wires. However, electrification of *Mines* was decided to be kept in the report since using overhead wires in *Mines* is a good solution that should be spread.

In all mines, there are both fixed routes where all trucks drive but there are also unfixed routes where the trucks can drive freely. The idea of this design suggestion is that the fixed routes can have overhead wires on their whole routes and that the unfixed routes can have overhead wires on a part of their routes. These overhead wires work as both instant electricity that drives the truck but also as charging for the batteries inside the electric truck. When the trucks are going uphill, they need this instant electricity to be able to go forward but when the trucks are going downhill, they actually do not need instant electricity as the gravity is helping them drive downhill anyway. So the instant electricity is only needed for the uphill routes. If comparing with the diesel trucks that are driving uphill in the mines of today, an overhead wire using instant electricity would actually make the trucks drive faster, according to Anders Grauers. This means an economic gain for the mining company, as the efficiency increases. This leads to energy saving, reduced cycle times and better utilizations of the trucks. It also takes fewer vehicles in order to accomplish the same job. There is also a possibility of making these fixed routes autonomous, which means that the trucks do not need a driver. This would also be an economic gain for the mining company as the need for personal decreases. However, consideration should be taken to the ground of the fixed routes, as the ground level can vary with climate and precipitation.

For the unfixed routes, for example in the underground mines, all trucks that are going down in the mine drive basically the same route in the beginning, according to Anders Grauers. So the idea is to have an overhead wire at this part of the route, so that the trucks going down in the mine can charge the first part of their way down and the last part of their way up. When going downhill, on both the overhead wire part and the rest of the downhill route, no power is needed from the battery of the trucks. The gravity is helping the truck downhill so the only part of the unfixed routes where the battery needs to power the truck is when the truck is driving the first part uphill. Having electric powered trucks on these unfixed routes will enhance the air quality in the mines, especially in underground mines. For the underground mines, this will decreases the need for ventilation, which is an economic gain.

From the research and the user study phase, it has also been shown that it is common to have electricity drawn in the mines. Therefore, machines and tools that are used in the mines should be using this electricity. For the underground mines, it is also needed a lot of ventilation and lighting. The lighting is already powered by electricity but a lot of the ventilation is powered by diesel. However, if electricity is drawn in a better way in the underground mines, it should be possible for almost all ventilation to be powered by electricity too. Consumed batteries from electric vehicles was unfortunately not an option to power the ventilation, because the capacity of the consumed batteries was too low. Although, the need for ventilation will decrease when going from diesel trucks to electric powered trucks, which is both an economic gain for the mining company but it also improves the condition for the people working in the mines, as it improves the air quality. Additionally, if the need for ventilation decreases, consumed batteries may be an alternative.

Evaluation of the design suggestion

The result of the interview with Anders Grauers was that overhead wires is a good and effective way to reduce the use of fossil fuels in mines, both in quarries but mainly in underground mines. The design suggestion had many factors in common with the solution that is being tested in the mine of Aitik, and so far the project in Aitik has worked very good. The mine of Aitik is a quarry and the design suggestion is for both quarries and underground mines, but Anders was positive that the design suggestion would work well for them both. There will of course be some challenges regarding how far the trucks can drive on one charge in the underground mines, but since the batteries for trucks are under constant development, this is not seen as a problem. The installation of the overhead wires is also a challenge, especially in underground mines where the space is limited, but Anders still thinks that it will be possible.

5.5 HARBOURS

The batteries used on ships are specially adapted for each individual vessel, therefore it is difficult to create any "standard charge" for electricity in port. Most of the major ports in Sweden seem to have drawn electricity, but not the smaller ports. Electricity in ports is primarily intended to reduce emissions and noise from the ship when it is at the quay, by being able to shut off the ship's generator set that generates the electricity that the vessel needs at the quay. Although this service is provided by the ports, it is unclear how many vessels that are actually using this opportunity (Lighthouse, 2018).

What is important to keep in mind regarding the charging infrastructure is the location of the chargers and the effect of the chargers. It is not always physically possible for ships to charge electricity because they dock where it is best suited to unload their cargo, not where it is closest to a charging station. Some vessels stay longer in port and then the energy transfer can take place at a lower power, while in other cases high power is required to transfer a large amount of energy in a short time. The higher the charging effect, the shorter the time to charge, but higher charging power also means higher costs and requires higher power from the electricity grid (Lighthouse, 2018).

The charging speed also depends on the battery of the vessel. The energy capacity of the battery sets requirements on the charging speed and power in the land connection. An example where short charging times are a requirement is in ferry traffic, which is the segment that until today has implemented full battery operation. In these cases, the size of the battery is designed after the charging time. For example, if a ferry requires 100 kWh for an overpass and has to charge this power in 5 minutes, then the maximum possible charge rate limits the size of the battery. For example, a battery consisting of Lithium, nickel, magnesium and cobalt with a charging capacity of 2,4 C is used, which means the battery can run from 0% to 100% state-of-charge in 25 minutes. If the requirement is to be able to charge 100 kWh in 5 minutes, this means that the size of the battery must be at least 500 kWh in order to be able to handle the operation based on the maximum charge rate of the battery (Lighthouse, 2018).

Challenges

A risk (in other countries where the electricity grid is not stable) is that the ship risks a blackout if they connect to the grid in port. The actual connection to the charging station is also a big security risk if it is done manually (Lighthouse, 2018).

The safety of battery use is something that has been identified as a challenge, where there is limited experience from the practice in how different security systems work in dangerous situations. A functioning charging infrastructure is a necessary prerequisite and here there is a need to clarify what requirements that exists for the infrastructure, based on possible applications of maritime electrification (Lighthouse, 2018).

A problem is that it is not only Swedish ships that are in the Swedish ports, but there are ships from several different countries. On these vessels there are several different battery solutions in terms of frequencies and voltage, which complicates any type of standardization of the charge for the vessels (Lighthouse, 2018).

The connection to the cable at the quay is also different for different vessels, according to Lighthouse (2018). For example, for HH ferries, the connection is made by a robot arm which automatically connects the vessel to the electricity grid in order to optimize the time for charging, which also is a more secure solution because of the high power in the cable (up to 12 MW).

The charging method is a technical challenge and the solutions available today, according to Lighthouse (2018) are categorized as follows:

- Electrical connection principle
  - Through contact
    - Direct current (DC) power connector
    - Alternating current (AC) power connection
  - Through induction
    - Always alternating current (AC) power connection
- Connection method
  - Manual
    - Cable winch on board the ship and connection on the quay
    - Cable winch on the quay and connection on board the ship

- Automatic
  - Industrial robot arm with several degrees of freedom
  - Pantograph
  - Contacts mounted on "spears", which are pushed into a corresponding contact via telescopic arm or by the vessel entering the connector in its normal position

Which solutions that are preferable in different environments is not entirely self-evident. Moreover, it is not obvious that a theoretically good solution works well in practice. The practical conditions differ from day to day, for example by waves, water levels and wind (Lighthouse 2018).

Most actors lack economic incentives that drive the electrification in shipping. The maintenance cost of the machine systems on a battery-powered vessel is expected to be much lower and is considered a possible economic saving, but one drawback is that electricity is taxed but not diesel. It is also a great initial investment cost to convert an existing conventional vessel into electric power or to build a new one. It is clear in several examples in ferry traffic that an electrification investment is dependent on co-financing from the public sector in order to be possible to implement. However, there is a potential PR value in electrifying vessels and harbors (Lighthouse, 2018).

There is also a challenge in behaviour, according to Lighthouse (2018), that those who drive the vessels may have to change their behaviour for how they drive and stop at ports in order to be able to switch from diesel to electricity.

Benefits

Problems with different frequencies on ships and land can be solved with voltage converters, but these are unfortunately very expensive (Lighthouse 2018).

Land connection of ships has a positive effect on the noise levels in the port, as the machinery can be shut down. Reduced noise levels can also enable increased opportunities to maintain or locate new quay locations for ferries and other vessels in urban environments (Lighthouse, 2018).

There are cases where batteries are used on board vessels in the form of energy storage. The energy storage is then charged either by the machinery and allows a more efficient use of the machinery, or the energy storage is charged by connection at the quay and thereby reduces the fuel consumption on board the vessel (Lighthouse, 2018).

Many of Sweden's ports today offer the possibility of land connection as part of improving the local environment and offering the shipping companies the opportunity to reduce their climate footprint (Stockholms hamnar, 2016) (Göteborgs hamn, 2018). From a European perspective, one can see that land connection with high voltage is in every fifth port, while low voltage (which is offered to merchant vessels for example in Stockholm) is more widespread. To enable more and larger vessels to join the land stream in Swedish ports, a development of the charging infrastructure is required (Lighthouse, 2018).

5.6 FINAL COMMENTS

After analysing all the design suggestions, it was found that there were some common factors. For both *Public areas*, *Construction sites* and *Mines* it was found that the design suggestion needs to be mobile in order for it to be beneficial to use batteries. All stationary solutions get their electricity from the electricity grid, and since batteries cannot compete with the electricity grid there is no need for having stationary battery solutions. It was also found in these three areas that the design suggestion needs to be temporary in order for it to be beneficial to use batteries. Because the same as for stationary solutions, all solutions that are meant to be used during a longer period of time get their electricity from the electricity grid, simply because batteries need to be charged when they are to be used during a longer period of time. These were also the reasons why a battery solution was not chosen for the *Mines*.

When it comes to the design suggestion for *At home*, it differs a bit in regards of mobility and being a temporary solution. The design suggestion itself is stationary but there is still some mobility included through the power banks. The design suggestion itself is not temporary, on the contrary it needs to be used during a longer period of time in order for the design suggestion to be economically beneficial for the user. However, the use of the design suggestion is temporary. This, since the design suggestion is to be used during blackouts, energy peaks or when “on the go”.

Another thing that the areas *At home*, *Public areas* and *Construction sites* have in common is that the battery solution covers a changing need for electricity. When different amounts of electricity are needed during different times, it can be economically beneficial to have a battery solution as a backup that can be added when the need for electricity is peaking. This, since the electricity from the electricity grid becomes more expensive during energy peaks.

CALL-TO-ACTION

The two following chapters present the call-to-action result, which is how the result is mediated to the different stakeholders within the system. It is primarily connected to the third research question; “How to explain the complex issues with reusing batteries from electric vehicles in a clear way in order to make people aware of its extent?”. Call-to-action includes chapter 6 and 7, which consist of the short-film and the website.

SHORT-FILM

This chapter presents the short-film that should spread the message about the problematic situation with consumed batteries in a simple and understandable way.

6.1 PURPOSE

The short-film was created for two main reasons, firstly to spread the message about the issues with consumed batteries from electric vehicles in an easy and efficient way and secondly in order to get the different stakeholders to take the issues more seriously. The short-film should inform the stakeholders about the extent of the issues and inspire them to take action against them. The motto was: inform, inspire, act. The length of the short-film is approximately one minute.

inform.
inspire.
act.

6.2 AIM

The aim of the short-film is to affect the higher authorities to establish standards in order for this new market to work.

6.3 TARGET GROUP

The target group of the short-film is mainly the different trade organizations. This short-film is thought to be the basis in order for the them to put pressure on the higher authorities to implement standards for this new market to work.

6.4 WANTED REACTION

The trade organizations should, through the short-film, understand that a change is necessary and that it is them, together with the higher authorities, that have the power to create good prerequisites for a well working market within the reuse of consumed batteries from electric vehicles. They can create these prerequisites by implementing standards as well as cooperations between all different stakeholders. Except from the trade organizations and the higher authorities, individuals and smaller companies can also be a part of this new market. In the end of the short-film, there is a link to a website where all watchers can read about how they can be a part and contribute in this sustainable development of the society. This website is presented in chapter 7.

6.5 FEELING AND EXPRESSION

The feeling and expression of the short-film are straightforward, credible and raw. The female storyteller describes the issues and complementary background music is added to make the short-film more vivid.

6.6 DISTRIBUTION STRATEGY

The short-film should be published on different channels on social media, such as for example Instagram and Facebook. The short film should be distributed by a company within either the design business or the automotive business, a well known company that is credible and has knowledge within the area of reusing consumed batteries from electric vehicles. The company should provide credibility for the short-film, so that it is understood that the content of the short-film should be taken seriously. The short-film should be distributed such as other commercial-films are distributed on social media, but the company behind the short-film should make people aware that this is more than just a commercial, this describes the problematic issues. The short-film differ from commercial-films since the short-film has no product focus, the short-film has an informative approach instead.

7

WEBSITE

This chapter presents the website that should be a place where all information can be gathered.
The link to the website: https://seden4.wixsite.com/minsida

7.1 PURPOSE

It was considered beneficial to have a place where all important information regarding reuse of consumed batteries from electric vehicles could be gathered and presented. Therefore, the website was created. The website includes short information about us, the background of the project, an explanation of the system image, information about how consumed batteries can be reused in different areas and guidelines for the different systems. All this information can be updated when more knowledge and information is gained. The website should inform stakeholders about the extent of the problem and inspire them to take action against it. So again, the motto was: inform, inspire, act.

inform.
inspire.
act.

7.2 AIM

The aim of the website is to spread information about this new market, to affect the higher authorities to establish standards in order for this new market to work and to inform all stakeholders how they can play a part in this new system.

7.3 TARGET GROUP

The target group of the website is mainly the different trade organizations and the higher authorities but also individuals and smaller companies. The trade organizations should receive all information and then try to affect the higher authorities which are those who should establish the standards. The trade organizations should also mediate the information to the companies within their branch about how they can contribute to and benefit from this new market. The individuals visiting the website should primarily be enlighten about the problematic issues but they are also able to receive information about how they can contribute.

7.4 WANTED REACTION

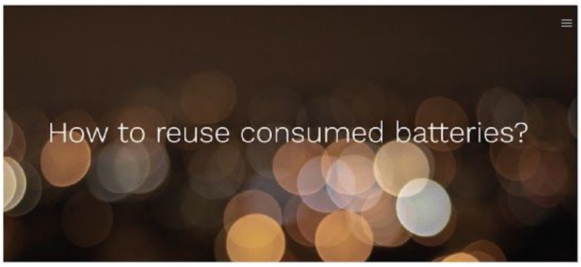
The trade organizations should be informed and inspired to act, which means inspired to put pressure on the higher authorities to implement standards and inspired to mediate how their companies can contribute to the system of reusing consumed batteries from electric vehicles. The trade organizations should also contribute with their insights about the industries involved in this new system to the higher authorities.

7.5 FEELING AND EXPRESSION

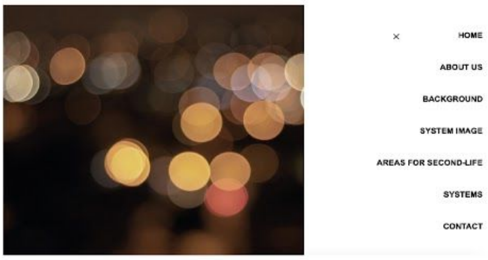
The feeling and expression of the website is informative but minimalistic. Informative in terms of delivering important and reliable information that covers the basic knowledge that is needed in order to understand the problematic issues, and minimalistic in terms of a clean and stylish expression where both the texts and the pictures are carefully chosen. A monochrome colour theme have been used and the expression of the website is also supposed to fit together with the existing website of yovinn.

7.6 WALK-THROUGH

The following screenshots presents a walk-through of the website, see figure 17-20.



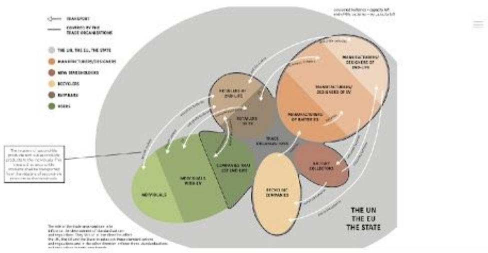
The home page



The menu

Information about us

The project background



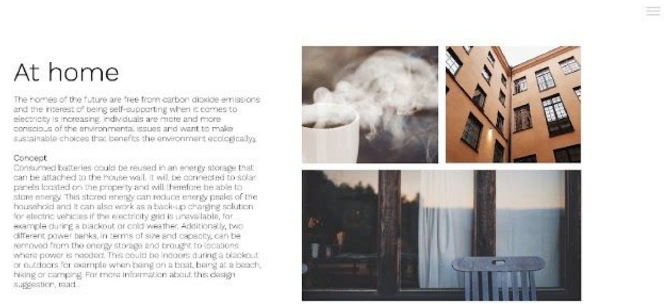
The system image. Specific feature: when clicking on a coloured area or at an arrow, a pop-up box will appear where a more detailed explanation is presented.

The first sub menu ”Areas for second-life” that includes at home, public areas, construction sites and mines.

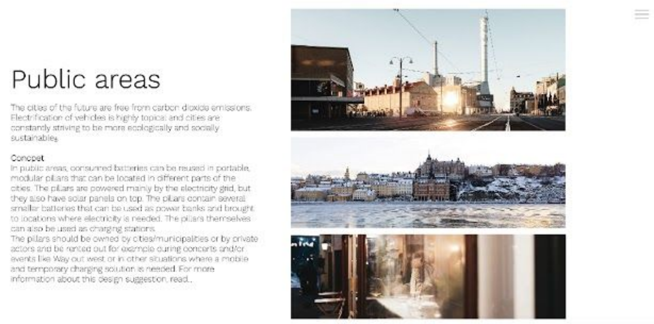
The second sub menu ”Systems” that includes circular business models, transportation, manufacturing and disassembling, collection of consumed batteries and recycling.

Contact

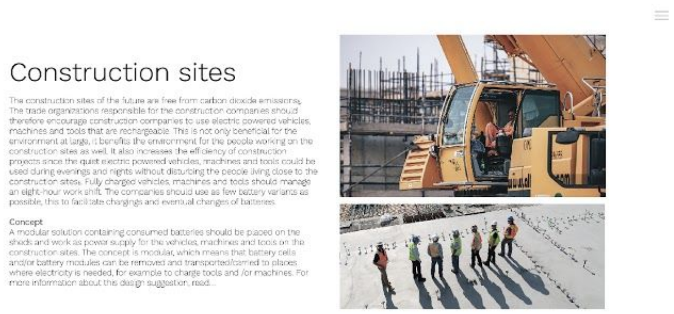
Figure 17: Walk-through of the website part 1



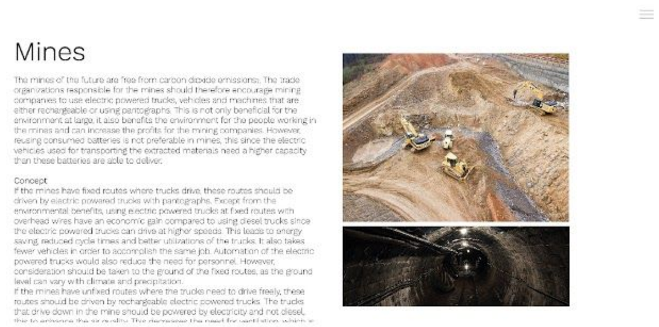
At home



Public areas

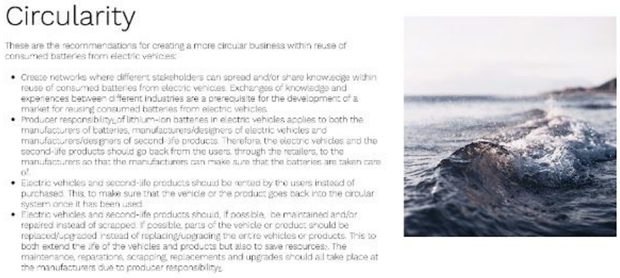


Construction sites



Mines

Figure 18: Walk-through of the website part 2



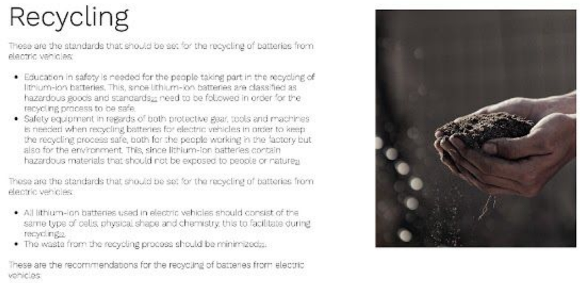
Circularity

Transportation

Manufacturing and disassembling

Figure 19: Walk-through of the website part 3

Collection of consumed batteries



Recycling

Figure 20: Walk-through of the website part 4

8 DISCUSSION

This chapter presents the discussion of the project.

In this project, suggestions for how to take care of consumed batteries from electric vehicles have been presented, this in order to create a sustainable this in order to create a sustainable use of electric vehicles and their batteries. It was learned from research that there were many aspects and parties to take into consideration within this area, for example the many involved stakeholders, such as the manufacturers/designers, the retailers, the companies and individuals, the battery collectors and the recycling companies. It was realised that all these stakeholders have their own strong wills and that all big decisions need to be taken on a very high level. In order to sort out all of this, a system image that aims to describe the different stakeholders their roles and the relationships between them was created. It describes both the new stakeholders and the stakeholders that already exist. It also describes both the new relationships that will appear between the different stakeholders within this new system and how the already existing relationships will change. This system image definitely shows the complexity of this new market and that collaboration between all stakeholders is necessary in order for it to work. In addition to the system image, guidelines have been produced in order to present additional information on how this market could work. This facilitates for all stakeholders since they can easily find information of how they can contribute to the system of reuse of consumed batteries.

Furthermore, design suggestions for how consumed batteries can be reused in second-life applications have been presented for four different areas, *At home*, *Public areas*, *Construction sites* and *Mines*. This was to create more concrete examples of how the reuse of consumed batteries could be implemented in the different areas. The design suggestions firstly show that reuse of consumed batteries in second-life applications is possible, but they also show that the different areas could benefit from using such applications. This creates an incentive to use second-life applications containing consumed batteries from electric vehicles in these areas and when there is an incentive, an interest is created.

There are some existing ideas of how to reuse batteries in second-life applications, see chapter 3.1.2, but not enough effort has been put into this stage of the battery's life cycle, which is when the battery does not have enough capacity left in order to be considered useful in an electric vehicle. Therefore, it was realised that the message, that there will be big problematic issues in the future if no change occurs, has to be spread. Based on that, the short-film was created as a wake-up call with the motto: inform, inspire, act. It explains the problematic issues in a clear way and makes people aware of their extent. The link that is presented in the end of the short-film references to the website that aims to spread the more detailed information about this new market and how all stakeholders can play a part in this new system. This, by presenting the system image, the guidelines and the design suggestions. The advantages with having this website is that all information can be updated when more knowledge and information is gained and thereby, up-to-date information will always be available to the different stakeholders to take part of. However, it requires that they visit the website regularly.

This entire project is a vision of the future where we have given proposals, based on research, of how consumed batteries from electric vehicles could be reused in second-life applications, of how the system could work and how the information about the complex issues of reusing batteries could be spread. The main target group for the last proposal, how to spread the information, is the trade organizations. They were chosen since they have a greater power to implement change than individuals and companies have, since the trade organizations are on a higher level in society. The real power to implement change is in the hands of the higher authorities, the UN, the EU and the State of Sweden, because they are the ones that can establish standards for this new market to work. However, the trade organizations have a great power of affecting these authorities towards establishing these standards and they are also closer to the different industries that will be affected by the implementation of these standards. This was also the reason why the trade organizations were chosen and not for example the general public. The general public could also have been able to affect the higher authorities to establish the standards, but the trade organizations have knowledge about the industries that will become a part of this new system that the general public does not have and therefore they were chosen. Not only are the trade organizations to affect the establishment of standards, they are also to come with important insight regarding the industries that will be affected of these standards.

So, how likely is it that the trade organisations will see the film, visit the website and act on the information? It is hard to reach the trade organizations, but based on our conditions, we have managed to create a tool in terms of a short-film that have a good possibility of reaching the trade organizations. This, since more or less all people are on social media och thereby the chance of encountering the short-film is big if it is spread on social media. If someone from the trade organizations encounters the short-film, there is a great possibility that the short-film is taken seriously since the short-film is to be distributed by a credible and well-known company within either the design business or the automotive industry that have knowledge within the area of consumed batteries from electric vehicles.

Another way of reaching the trade organizations could have been to try to get in direct contact with them, either by talking to them and mediate the insights that we have come up with, or by sending the short-film to them by email to get their attention and to get them to visit our website. Another alternative could have been to spread the short-film as commercial on television and the radio, but based on our own personal experiences, we think that the possibility of encountering the short-film on television or the radio is lower than on social media. This, since everyone is not watching television and listening to the radio to the same extent as they use social media. Another idea could have been to send the short-film or other parts of the material of this project to a news channel, for example TV4. If they were to choose to bring up the subject of reusing consumed batteries from electric vehicles and explain the associated issues, it might have gained a greater impact among the trade organizations. Unfortunately, sending the material to a news channel was outside the timeframe of this project, but it is an interesting idea.

After reviewing some alternative ways of spreading the information to the trade organizations, one aspect that favours our choice of spreading the short-film via social media is that it is supported by a credible and well-known company within either the design industry or the automotive industry, and that gives the short-film a weight that would have been difficult to achieve if we had contacted the trade organizations ourselves. Indirectly, this also gives weight to the website.

Furthermore, an aspect of this project that needs to be discussed is that this project differed a lot from a typical product development project. The scope of the project was bigger and it started from a much more open and broad perspective than a typical project. Also, since the project had a very vague brief, the focus of the project was changed a lot during the project. Lastly, the project approach was mainly system oriented, whereas a user oriented approach is usually used as the main approach in a typical product development project.

This was an innovative project within a market that is currently under development and that has brought some challenges to the project. Firstly, in some cases, there was a lack of concrete information, so therefore, assumptions have had to be made. One example of this was the exact size, weight and capacity of different batteries in electric vehicles where no exact information was found and assumptions needed to be made. Secondly, due to the lack of some concrete information and to the fact that this market is still very new, the design suggestions could not be evaluated in a traditional way. Access to enough information and material such as batteries from electric vehicles has not been available. For example, evaluating the final design suggestion in the aspect of economics was complicated. It was hard to ask people if they could imagine buying the product, since there were no information about how much the initial investment would be and within how long the investment would become profitable. The optimum would have been to get an approximate price of the product, since one of the purposes of purchasing this product is to benefit economically from it in the long term. Evaluating the charging aspect of the final design suggestion was also a bit tricky. When evaluating the charger for electric vehicles that is a part of the final design suggestion, people that own electric vehicles were interviewed. Since there was no access to any batteries from electric vehicles, a mock-up could not be built and that meant, the interviewees could not interact with the charger. Additionally, due to the fact that electric vehicles are still very new and expensive, it was hard to get in touch with people owning an electric vehicle and therefore the number of participants in the interview was low. Therefore, it can be discussed whether or not that part of the evaluation covers a sufficiently wide range of users. To summarize, more evaluations need to be done if this design suggestion is to be further developed.

This project was limited to countries with an infrastructure such as the infrastructure in Sweden since the system of reusing consumed batteries from electric vehicles is dependent of well working transportation possibilities and on a well working and stable electricity grid. However, it can be discussed whether the *At home* design suggestion will be of most use in developed countries or if the developing countries could utilise the second-life product even more. This since they do not have the same access to electricity and are probably in greater need of such a solution. On the other hand, even though the developing countries might could utilise the second-life product to a greater extent, the whole system with consumed batteries may not be possible to implement in these countries. A further development could therefore be to investigate different opportunities with developed countries helping developing countries by providing second-life products and also knowledge about this market.

The ecological impact of batteries is an aspect that needs to be considered. This is important since the automotive business is moving towards using more and more batteries. Lithium-ion batteries reach their end-of-life when still 80% of their capacity is left (Guenther, Schott, Hennings, Waldowski & Danzer, 2013) and that is a lot of unexploited capacity. This is not a sustainable solution and therefore, a suggestion for how to reuse and take better care of these batteries has been presented.

When it comes to ethics, one could question whether it is ethical of the automotive companies to have their main focus on the first stage, which is to create the coolest and best electric vehicle on the market, without considering the later stage seriously enough. Of course, it is good to move away from finite resources such as oil and gasoline, but a plan for what to do with the huge amount of consumed batteries that will follow is needed. The short-film together with the website will help inform these companies about these problematic issues and they are issues that need to be solved now, not in the future. However, no single actor or producer have the responsibility to solve these issues by itself, a working system has to be implemented and in order for this to happen, collaboration between all stakeholders is necessary.

Additionally, another ethical aspect that can be discussed is that the extraction of the materials used in lithium-ion batteries today includes very bad working conditions and in many times child labor (Walt, Vivienne and Fortune, 2018). Without taking care of the consumed batteries, more batteries have to be produced, more materials have to be extracted and more children will be exploited. By creating a system for how to take care of the consumed batteries in second-life applications, not as much new lithium-ion batteries have to be created, not as much material extraction is needed and thereby, there will be less exploitation of children.

9 CONCLUSION

This chapter presents the conclusions of the project.

One thing that has been clarified during the course of this project is that in order for the new market with reuse of batteries to work, collaboration is necessary. As stated in the background, see chapter 1.1, all stakeholders need to collaborate in order for the system to be implemented. This, since the different stakeholders are part of different stages in the life cycle of the battery and therefore they are dependent on each other in order for the system to work. No single actor or producer can implement this new system by itself and therefore, collaboration is necessary.

Since the automotive companies have a producer responsibility, see chapter 3.1.7, this could be used to get the automotive companies to take back their own batteries into their system for either reuse or recycle. This should also be presented as an opportunity for the automotive companies, because it does not only benefit the environment, it also benefits them economically by doing this. However, this only accounts for the batteries of these specific companies since they only take back their own batteries. It would be better if all automotive companies would collaborate with this collection of consumed batteries. That would make it possible to avoid for example long transportations. This since the electric vehicle containing the battery can be returned to the closest retailer instead of having to be returned to a specific company.

In the end, it is considered valuable to have a platform where all information regarding reuse of consumed batteries from electric vehicles is gathered. The website that has been created is thought to be updated constantly when new knowledge is gained and hence, up-to-date information will always be available for all stakeholders to take part of.

10

FURTHER DEVELOPMENT

This chapter presents the further development of the project.

The next step for this project would first of all be to build a model of the design suggestion and test it. This, to get a more qualitative result from the evaluation of the product, both regarding the semantics and the functions. The economics would still be hard to fully evaluate before there is better information on the prices for consumed batteries from electric vehicles available.

Furthermore, a plan for how the system should be implemented has to be developed. People in high positions within the different stakeholders, that have the power to implement change, need to come together and discuss how this can be done. They need to see the reuse of batteries as an opportunity instead of a problem and that they can benefit from being a part of this new market.

Regarding the website, the next step would be to make a complete and working presentation of the system image. It should work so that one can click on the different stakeholders and arrows and get pop-up windows with information about roles, relationships and what is being transported. To keep the information up-to-date, the website should be updated when new information arises.

An interesting aspect that could be further investigated is to use blockchain. Using blockchain could be a way to keep track of the consumed batteries. It would work as a log that stores information about for example where the batteries have been, for how long they have been used and how much capacity that is left in the batteries. Information like this would be valuable to many of the stakeholders within the system of reusing consumed batteries from electric vehicles. This, firstly since the stakeholder gets the chance to make a better decision of what to do with the battery. Secondly, information like this would probably help those stakeholders that work with the development of the batteries of how to improve the batteries. Everyone who wants access to this log can then pay a small amount of money for this information. The information is encrypted and one pays to get a key to this encrypted code. Additionally, the implementation of blockchain is considered valuable because blockchain is viewed as a very safe system.

By turning this valuable information into a trade product and by creating a trade location for the information using blockchain, economical incitements are created. This creates an alternative way of creating a market for reusing consumed batteries from electric vehicles that does not depend on the establishment of standards.

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APPENDICES

I. Survey: User study to investigate the need for electricity in everyday life
II. Interview: User study regarding *Construction sites*
III. Interview: Expert interview regarding recycling of batteries
IV. Interview: Expert interview regarding reuse of batteries
V. Interview: Expert interview regarding *Mines*
VI. Survey: Evaluation of the economics of the *At home* concept
VII. Semantic scale: Evaluation of the semantics of the *At home* concept
VIII. Interview: Evaluation of the charging function for the *At home* concept
IX. Interview: Evaluation of the *Public Areas* concept
X. Interview: Evaluation of the *Construction sites* concept

APPENDIX I

This appendix presents the battery survey that was sent out to individuals via social media.

Survey batteries
We are two students from Chalmers, Industrial Design Engineering, that are currently writing our master thesis within the area of reusing batteries from electric vehicles. It would have been a great help for us if you would like to answer the following questions about this (it takes a maximum of five minutes). The answers will be treated anonymously.
Thanks in advance! / Emelie and Rebecca
***Compulsory**

Age *
Under 25
25-40
40-60
60+

Gender *
Female
Male
Undefined

Education *
Technical/scientific
Other

Profession *

Is there any situation when you are in need of electricity but it is not available? *
Yes
No
If yes, in what situation?

Could find any situation where electricity is available but in a limited amount? *
Yes
No
If yes, in what situation?

If you get access to a battery that you can use wherever you are to whatever you want, what would it be? (the battery has an unlimited capacity) *

APPENDIX II

This appendix presents the interview guide that was used for the semi-structured interviews with the workers at the two visited construction sites.

- What do you need electricity for?
- “How much” electricity is needed? (Which capacity is needed for the different tasks?)
- How do you get electricity to support the construction site?
- If from the electricity grid, is it complicated to draw electricity from the electricity grid?
- Would a mobile electricity solution facilitate the work on construction sites?

APPENDIX III

This appendix presents the interview guide that was used for the semi-structured interview with Dr Christian Ekberg Professor Nuclear Chemistry, Chemistry and Chemical Engineering.

Hi Christian!
We are two students from Chalmers that are currently writing our master thesis within the area of reusing batteries from electric vehicles. We have read that you are developing a method for recycling lithium ion batteries so that lithium can go back into battery manufacturing and we have some questions about this.

- How does the method work?
- How far has the method been developed?
- Will it be able to use? If so, how far away are it in time?
- What are the factors that influence whether the method can be used in practice? For example, economy, logistics, demand and so on.
- What are the challenges of recycling lithium-ion batteries?
- Which materials will be able to take care of after recycling?
- What will be the residual materials that cannot be recycled? What is done with them?

Have a nice day!
/Emelie & Rebecca

APPENDIX IV

This appendix presents the two interview guides that were used for the semi-structured interview with Hans Eric Melin, founder of Circular Energy Storage Research and Consulting.

Hi Hans Eric!

We are two students from Chalmers that are currently writing our master thesis within the area of reusing batteries from electric vehicles. We have read that you are doing research within this area and we have some questions about this.

- What are the major challenges in the recycling of future car batteries?
- Is it possible to divide a lithium-ion battery from an electric car in several smaller cells and reuse the individual cells? For example, in computers, phones or other things?
- We have read that there is a possibility to reuse car batteries in energy storage, but we have also realized that it can be a problem to reuse car batteries as energy storage, as they require different characteristics of the batteries for the two different areas of use. So our question is what characteristics distinguish a car battery from an energy storage battery?

Have a nice day!
/Emelie & Rebecca

Hi again!

- We have read that the battery chemistry is different for electric car batteries and energy storage batteries, is this correct or is it just BMS that distinguishes them functionally?
- If the module has a high capacity, is there any case where you choose to disassemble it anyway? Or is it best to reuse the entire module? And where does the limit go when a module is considered to have high vs low capacity?
- What are the challenges of reusing car batteries in energy storages?
- Regarding second-life for car batteries, is there any area besides energy storage that has been established or which you think seems promising in the future? And if so, what are the challenges with that area of application?

Have a nice day!
/Emelie & Rebecca

APPENDIX V

This appendix presents the two interview guides that were used for the semi-structured interview with Anders Grauers, who is part of the project of electrifying the mine of Aitik.

First interview guide:

- How did it go to put the electrified test section into operation?
- What challenges have you faced?
- What has gone good/not good?
- Do you have electric trucks that drive freely, meaning that they do not follow the test section?

Second interview guide:

- Are there used any tools/smaller machines down in the mine that are driven by electricity or diesel? Approximately how many kWh do these machines consume per day?
- How does the ventilation work down in the mine? How is it powered? Approximately how many kWh does the ventilation consume per day?
- How does it look down in the mine? Are there any bigger open areas where the trucks drive or is it more like narrow aisles and a lack of space?
- How does the lighting work down in the mine? How is it powered? Approximately how many kWh does the lighting consume per day?
- Is it one and the same truck that drives both the electrified test section, down the mine, up the mine and at the electrified test section again? Or does some trucks only drive the test section and some trucks only in the mine?
- You wrote earlier that there would be an overhead wire in the mine at 20% of the section, where would that be?

APPENDIX VI

This appendix presents the solar cells and energy back-up survey that was sent out to individuals via social media.

Solar cells and energy back-up
We are two students from Chalmers, Industrial Design Engineering, that are currently writing our master thesis within the area of reusing batteries from electric vehicles. It would have been a great help for us if you would like to answer the following questions about this (it takes a maximum of five minutes). The answers will be treated anonymously.
Thanks in advance! / Emelie and Rebecca

***Compulsory**

Age*
Under 25
25 - 40
40 - 60
60+

Education *
Technical/scientific
Other

Profession *

Accommodation *
Villa
Terrace house (radhus)
Apartment
Other

Could imagine yourself investing in solar cells with associated energy back-up in order to reduce your electricity costs in the long term? *
Yes
No
If yes, for what reason?

If no, for what reason?

If you were to invest in solar cells with associated energy back-up, how much would you be willing to invest initially? *

Less than 20 000 kr
20 000 - 40 000 kr
40 000 - 60 000 kr
More than 60 000 kr

What is your maximum limit, in number of years, for an investment in solar cells with associated energy back-up to be profitable? *

Less than 10 years
10 - 20 years
More than 20 years

APPENDIX VII

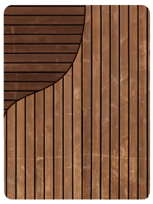
This appendix presents the semantic scales.

Metall

Eye catching -- Discrete
Old fashioned --- Modern
Cheap -- Exclusive
Durable -- Fragile

Metall/wood

Eye catching -- Discrete
Old fashioned --- Modern
Cheap -- Exclusive
Durable -- Fragile



Colour

Eye catching -- Discrete
Old fashioned --- Modern
Cheap -- Exclusive
Durable -- Fragile

APPENDIX VIII

This appendix presents the interview guide that was used for the structured interviews of the charging function for the *At home* design suggestion.

Age:
Education: technical/scientific other
Profession:

How much do you drive your electric vehicle?

How do you charge your electric vehicle today? (when? where? for how long?)

Have there been any problems regarding the charging of our electric vehicle? (too cold, too hot, blackouts etc?)

In that case, what did you do?

What are your thoughts of our design suggestion? (after explaining the design suggestion)

APPENDIX IX

This appendix presents the interview guide that was used for the semi-structured interviews with different companies and administrations within the city of Gothenburg that were held via email.

Hello!
We are two students from Chalmers that are currently writing our master thesis within the area of reusing batteries from electric vehicles. We have looked at whether there may be areas of use for this in Gothenburg city and realized that one of our design suggestions had potential. So we would like to get your comments on the idea, what advantages/disadvantages you see with the design suggestion and if you see a need for the design suggestion in the city of Gothenburg. The design suggestion is as follows:

The idea is at large to have some type of modular, mobile and temporary charging station that can be placed at events, games, festivals and other activities in the city as the need for electricity increases in a certain area over a certain period of time. The design suggestion is a pillar with charging sockets and smaller power banks, so you can either charge via your own cable directly at the charging pillar or rent power banks if you want to carry the power source with you. One or more pillars can be placed where needed, for example in/at Slottsskogen during Way Out West and they can then be removed after the festival. The pillar is powered by reused batteries from electric vehicles inside of it and therefore it does not need to be connected to the electricity grid. The idea is that the city of Gothenburg owns these pillars and that the companies that organize events in Gothenburg can rent these pillars from the city of Gothenburg.

We are very grateful for answers and feedback!

Sincerely,
Emelie and Rebecca

APPENDIX X

This appendix presents the interview guide that was used for the semi-structured interviews with the Serneke construction company that were held via email.

Hello!
We are two students from Chalmers that are currently writing our master thesis within the area of reusing batteries from electric vehicles. We have looked at whether there may be areas of use for this at construction sites and realized that one of our design suggestions had potential. So we would like to get your comments on the idea, what advantages/disadvantages you see with the design suggestion and if you see a need for the design suggestion at construction sites. The design suggestion is as follows:

The idea is at large to have some type of modular, mobile and temporary charging station that can be placed at events, games, festivals and other activities in the city as the need for electricity increases in a certain area over a certain period of time. The design suggestion is a pillar with charging sockets and smaller power banks, so you can either charge via your own cable directly at the charging pillar or rent power banks if you want to carry the power source with you. One or more pillars can be placed where needed, for example in/at Slottsskogen during Way Out West and they can then be removed after the festival. The pillar is powered by reused batteries from electric vehicles inside of it and therefore it does not need to be connected to the electricity grid. The idea is that the city of Gothenburg owns these pillars and that the companies that organize events in Gothenburg can rent these pillars from the city of Gothenburg.

The idea is at large a kind of container solution consisting of re-used electric vehicle batteries whose core is on the short side of a construction shed. The container solution is modular, which means that parts can be removed and carried to where power is needed. Electric vehicles can be loaded at the shed and the smaller, portable parts of the container solution can be carried/driven to machines and tools that need to be loaded elsewhere than at the shed. This solution means that the construction site does not have to draw electricity from the electricity grid more than to the sheds, so no cables will lie in the way of the construction site.

We are very grateful for answers and feedback!

Sincerely,
Emelie and Rebecca