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Business Finland: Assessment of Li-ion battery reuse solutions – final report

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TABLE OF CONTENTS

1 Introduction

1.1 Background

The focus of this study is the second life use of electric vehicle traction batteries (referred to as "EV batteries" in this report). Reusing EV batteries has significant potential to the EV battery and electric vehicle value chains. This is due to the fact that EV batteries can be used in less demanding applications after the end of their useful life as an EV battery, enabling EV batteries to retain some of the value of their high initial cost. The potential environmental benefits of reuse versus recycling is also an important driver for the reuse of EV batteries. A large amount of potential second life EV batteries are expected to become available in coming years, further stressing the potential of EV battery second life solutions.[1, 2]

The great majority of current EV batteries on the market are based on some variation of lithium ion battery technology. Lithium ion batteries have been on the market since early 1990's, currently being extremely common as a power source for portable devices such as laptops. However, only in recent years the price vs. capacity of lithium ion battery technology has reached a point where it is cost-effective enough to manufacture very high capacity batteries that can power electric vehicles, making the electrification of traffic possible. The falling price of EV batteries is an important factor in electric vehicles becoming more and more common. This results in EV batteries becoming a significant source of used batteries for second life applications in the future.

As an EV battery undergoes discharge/charge cycles it slowly degrades, losing its capacity and resulting in otherwise decreased performance. Usually an EV battery is considered to have reached its end-of-life as an EV battery after it has 80% of capacity left[3]. The strict performance requirements result in used EV batteries still retaining enough capacity to be potentially used in other applications, such as stationary energy storage systems, which have significantly less strict performance requirements than electric vehicles.

The battery packs on ships can be much bigger than in cars, even 30 MW and usage patterns differ significantly from that of normal electric cars: a private car is used on average only 5% of the time daily compared to a ship that has much more continuous operational hours on daily average. The batteries are normally kept in their first use until they have reached 60-70% of their original power after which they are not anymore guaranteed and most probably will

[1] McKinsey: Second-life EV batteries: The newest value pool in energy storage
[2] WEF: A Vision for a Sustainable Battery Value Chain in 2030
[3] McKinsey: Second-life EV batteries: The newest value pool in energy storage

be replaced and ready for second life. Companies might give as long as 10 years guarantee for batteries in the ocean sector.[4]

Based on the abovementioned points, EV batteries are considered to be the most potential source of lithium ion batteries for second life applications. This study focuses on EV batteries especially in the context of the automotive industry and lightly touches the ocean sector and omits other large lithium ion batteries as a source of reusable batteries.

Finally, it should be noted that second life utilization of EV batteries is not straightforward. There are many aspects that need to be taken into account – for example safety aspects, large variation of EV battery designs, complexity of refurbishing, limited amount of regulation and standards, and falling costs of new batteries and other economic aspects, which affect the business potential of reusing EV batteries. These are examined in this report.

1.2 Methods and Objectives

The objective of this study is to assess the current situation of the reuse (second life) possibilities of lithium ion based EV batteries for Business Finland, the innovation funding and international growth promoting organization under the Ministry of Economic Affairs in Finland. The study was conducted by Gaia Consulting Oy. The study focuses on the EV battery reuse situation in Finland, Sweden, Norway, Denmark, France and Germany. Legislation and legislatory development that affects battery reuse is examined on EU level. Also, current and upcoming European cooperation networks, ecosystems and EU-funded joint European projects are discussed.

More specifically, the study covers the following topics regarding the target countries:

- The most significant actors
- Common trends regarding EV battery reuse: what is currently happening and what is being developed
- The most potential applications for EV battery second life use
- Crucial safety aspects and other challenges and their impact on the development of EV battery reuse
- Business prospects

The study is based on a literature review and interviews of ten experts on battery reuse area from the target countries. Based on an analysis the general European trend regarding reuse is assessed and the current key challenges and questions regarding the topic are identified.

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[4] Corvus Energy: Powering a clean future

1.3 Overview of EV battery operational chain

An EV battery usually consists of several battery modules combined into one battery pack. A module in turn consists of several battery cells, which is the basic electrochemical unit that stores energy. The whole system is controlled by a battery management system. There are several different cell chemistries used by different automakers. Examples of these are NMC (nickel manganese cobalt), which is used by most car manufacturers, and NCA (nickel cobalt aluminum oxide), which is used by Tesla[5]. EV batteries are usually specific to each electric vehicle model and in addition to chemistry, they differ in size, form, capacity etc[6].

In the context of this study, the starting point for the EV battery operational chain examination is a new EV battery installed in a new electric vehicle. There are two main business models on the ownership of the battery: the battery can be sold as part of the car and the new car owner will also own the battery; or the battery can be leased i.e. sold as a service so that the car manufacturer or importer retains the ownership of the battery. The battery can reach the end of its life as an EV battery due to degradation caused by use or as a result of a traffic or other accident that causes damage that is not feasible to repair. A battery becoming obsolete due to disruptive technological advances of new batteries is also possible.

In EU all batteries, including EV batteries, are under producer responsibility, meaning the producer of the battery is required to take care of the waste management of an end-of-life battery at their own expense. In case of EV batteries, the producer refers to the manufacturer or the importer of the car. Either the producer arranges the waste management themselves, or they join a so-called producer coordination organization, which arranges the waste management on behalf of the producers. The role of a producer coordination organization may simply be administrative – reporting recycled amounts to authorities and managing contracts with waste management operators etc. The roles of producer coordination organizations vary between EU member states. [7]

A common practice is that when an EV battery has reached the end of its useful life, maintenance service arranged by the automaker or their representative (importer) removes the battery and sends the battery for recycling through an operator specialized in EV battery recycling, or - as discussed later in this report - sends the battery back to the manufacturer or their partner to be refurbished and repurposed for utilization in a second life application. In case a car is wrecked beyond repair, the salvage company similarly sends the battery for recycling or in case the battery is still functional, can sell it as a spare part.

There are also exceptions to the abovementioned operational model. EV batteries have a high initial cost, forming half of the value of a new electric vehicle. They potentially retain significant monetary value after the end of their service as an EV battery. This has resulted in

[5] Battery University: Lithium-ion batteries
[6] McKinsey: Second-life EV batteries: The newest value pool in energy storage
[7] European Commission: Directive 2006/66/EC on batteries

situations where the end-of-life battery does not end up in the possession of the car manufacturer or their representative, as intended, but is instead used in DIY second life applications. Another exception is the business model where an EV battery that does not perform adequately anymore is sent to the manufacturer or their representative and repaired to meet the performance requirements of EV use again. These batteries are then offered as EV batteries for a considerably lesser price than fresh batteries. However, this business model is only followed by some electric car manufacturers. Unauthorized third-party repairs of EV batteries are also possible, raising questions of safety.

Note that in this report, "reuse" refers to the utilization of used EV batteries in second life applications. In practice whole battery packs can be reused, or its modules can be repurposed into new batteries. The basic definition of battery reuse is that when reused, the battery or its components retain their original function of energy storage. If an end-of-life battery is not reused, it is either recycled or disposed. Recycling in this report refers to reprocessing a battery into new raw materials[8]. This requires recycling methods specific to lithium ion batteries and is carried out by operators and facilities specialized in this type of work. Some parts of waste batteries can also be utilized as energy. Simple disposal (i.e. landfilling) of whole EV batteries without other treatment is generally forbidden in EU.

2 Main actors in the battery reuse sector

All car manufacturers are doing something in the battery reuse context. Especially those that have electric or plug-in hybrid cars in the market have also activities related to the second life of batteries. Renault, Nissan and Daimler are most advanced in this sense. The more batteries there are in the market, the more there is urgency from the OEMs (original equipment manufacturers). That is why for example there are a lot of activities in Norway ongoing, no other country has more electric vehicles per capita than Norway[9], even if most of the batteries are still on the market in their first use.

Daimler started in 2015 using batteries from production vehicles and test fleets in stationary storage systems. The company takes a holistic view on electric mobility and product lifecycle of EV batteries. They take back and prepare the used batteries from the electric vehicle fleet for use in second life energy storage to store excess energy from renewable resources and stabilize the electricity grids. Also, first life spare parts storage batteries are used for such purposes. For the battery and electric vehicle production the company seeks to utilize self-generated, renewable energy from in-house photovoltaic systems and wind farms. Daimler produces its own batteries, partly at the production plant in Kamenz in Germany by its fully owned subsidiary company Deutsche Accumotive. Thus, they can integrate different types of

[8] These definitions are used for the sake of simplification and due to the scope of this study. The exact definitions of reuse and recycling are somewhat different in legislation than what is used in this report, and legally recycling can also refer to making functionally similar products from waste as the material's original function.
[9] Government.no: Norway is electric

batteries to second use applications. The company has a 13 MWh second life energy storage facility in Lünen, Germany, housing 1000 automotive battery modules. [10]

Renault engages in both recycling and reuse programs with industry partners and a structured process in each pathway, rooted in regional context. It announced its Advanced Storage Battery Program in September 2018. This collaboration has developed quickly and involves several partners in the energy sector. It is expected to result in a 70 megawatt/60 megawatt-hours used EV battery installation in Europe by 2020, the largest in Europe to date.[11] Also, already in 2016 Renault partnered with energy storage company Connected Energy in the UK to develop a modular storage product called E-STOR. E-STOR uses second life EV batteries to store electricity for such applications as storing energy generated from intermittent renewable resources, charging at off-peak times, enabling users to reduce energy costs, and enabling rapid EV charging without overloading the local electricity supply.[12] Renault has as a business model to lease the battery and thus the car owner does not own the battery.

Nissan and Eaton have joined forces and launched a new residential energy storage unit xStorage HOME. The product provides a sustainable second life for Nissan's electric vehicle (EV) batteries after their first life in cars is over. The unit is powered by twelve Nissan EV battery modules.[13]

BMW started a battery farm in Leipzig in autumn 2017 together with the virtual power plant operator e2m. The battery farm built at the BMW Group factory in Leipzig is a large energy storage system comprising up to 700 BMW i3 batteries, a large number of which are second life batteries. This system buffers energy, e.g. from wind power systems at the factory premises and as such optimizes local energy management, as well as provides power bidirectionally as balancing power for the public grid.[14] Also, BMW announced in autumn 2018 its partnership with Umicore and Northvolt to develop the reuse of its batteries[15], and in 2018 its collaboration with Vattenfall to provide its i3 car batteries for energy storage purposes at the Vattenfal wind farm in Wales in the UK (according to public information with first use batteries). [16] No public information is available how these activities have evolved since.

Audi is testing factory vehicles powered by used lithium-ion batteries at its main plant in Ingolstadt. Factory vehicles in Audi's production plants such as fork-lift trucks and tow tractors have so far been powered by lead-acid batteries. When using lithium-ion batteries, they can be charged directly where the vehicles are parked during normal downtimes unlike in case of lead-acid batteries. This saves space and also eliminates the high manual effort re-

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[10] Daimler
[11] McKinsey: Second-life EV batteries: The newest value pool in energy storage
[12] Charged: Renault and Connected Energy collaborate on E-STOR energy storage product
[13] Eaton: Nissan and Eaton Make Home Energy Storage Reliable and Affordable to Everyone with 'xStorage HOME
[14] E2m: En route to the optimisation of energy usage at an automobile production site
[15] For example: Energy Reports: BMW signs battery reuse deal
[16] Vattenfall: Largest co-located battery installed in the United Kingdom

quired to replace the batteries. Audi has calculated that it could save millions if it converted its entire fleet of factory vehicles to lithium-ion batteries at its 16 production sites worldwide.[17]

In some markets, Tesla batteries constitute even half of the second life battery market. However, not much is known about Tesla's activities in this sector. Tesla does some remanufacturing of used batteries. However, they do not own the batteries in their cars and also, due to the high price of Tesla batteries, it would be too expensive to buy them back for a second life use. It seems that the Tesla battery packs are not designed for an easy removal and reuse[18]. Tesla has also announced plans to invest in battery recycling facilities on the contrary to many other car makers who are looking at second life applications[19]. Thus, it is expected that Tesla is not much involved in the second life activities for batteries.

Volkswagen has recently announced plans to start producing a mobile charging station from old EV batteries. The new stations are to be equipped with batteries that have lost too much capacity and power to be used in an active Volkswagen vehicle. The new fast charging stations can store up to 360 kilowatt hours of energy. This is enough energy to charge up to four vehicles at the same time. The stations will function similarly to portable cell phone backup chargers, either by connecting them to the power supply for unlimited use, or by disconnecting them from the mains and using them until their charge is used up. The devices are small and mobile enough to be used in strategically important locations. Also, major events sometimes cause a certain area to experience a sudden surge in EVs that the existing charging infrastructure cannot handle. VW hopes that its fast-charging stations, which run on old batteries, can solve this demand problem. Production of the new charging stations will begin sometime in 2020 at the VW Salzgitter plant. The plant will initially only have a recycling capacity of around 3,000 batteries per year. However, given the goal of selling 22 million electric vehicles over the next decade, the company plans to rapidly increase that production volume. [20]

The German company The Mobility House[21] integrates second life vehicle batteries into the power grid using intelligent charging, energy and storage solutions. They connect batteries into a management pool and operate and monitor them connected to the energy market. They also take the construction perspective when necessary, including system design, and are a consulting energy storage integrator. Their goal however is to be manager and energy market participant and also be involved in development of the projects. OEMs are investors to the company which makes it easier to start building various ecosystems. They have previously partnered with Daimler and are now partnering with Renault in two separate large-

[17] Audi media center: Audi installs used lithium-ion batteries in factory vehicles
[18] Hackaday: Fail of the week: Taking apart a Tesla battery
[19] Electrek: Tesla is developing a unique battery recycling system
[20] Engineering.com: Wolkswagen plant die Wiederverwendung alter Batterien
[21] The Mobility House: The goal of The Mobility House is to create a zero-emission energy and mobility future

scale ecosystems or integrated platforms in France and Germany totaling 60 MW of energy storage capacity. Previously the company has applied already 30 MW of storage capacity.

The Finnish company Akkurate Oy is a provider of battery diagnostics software which can be also utilized for second use purposes. Akkurate software reports on in-use activities and instructs the battery user on how to use batteries with greater efficiency to gain a longer lifetime for the battery. The software also reports on statistical variation between batteries, including how the battery behaves, and also on the system level, e.g. for an electric bus, on how to most efficiently use the battery. These things are essential for reuse batteries in second life applications. [22]

The Finnish-Swedish energy company Fortum is piloting second life solutions for used batteries in India, where the company is developing a leasing system whereby auto rickshaw owners return their used batteries to Fortum for recharging and receive a full battery in return.[23]

Spiers New Technologies (SNT), a US company having an affiliation in the Netherlands, is a leading full-service provider of "4R" services (repair, remanufacturing, refurbishing and repurposing) for advanced battery packs used in hybrid and electric vehicles. SNT's 4R services allow vehicle OEM's to optimize the life cycle management of their battery pack inventory and maximize its value.[24]

In Norway, also the ocean sector is starting to be active in batteries and their reuse. For example, the Norwegian-Canadian ship system company Corvus Energy has recently opened a battery manufacturing plant in Norway[25] and is considering new business models for its operations based on second life of batteries used in their ships.

In general, the major players in the battery second use business are still very much spread out and the OEMs have challenges in creating proper ecosystems. No clear leaders have emerged yet.

3 Status and trends in battery reuse

In general, a lot is happening at the moment in the context of battery reuse, but still in a rather small scale. Much of the activities can be described as piloting, demonstration or R&D work. The used battery volumes are also still such limited that large scale activities are not yet feasible. Large volumes of used batteries are expected to come to market by year 2025. At the moment, the big energy storage providers are using first life batteries. When second life batteries appear to the market, it depends on the price and especially on the price difference between the first and second life batteries, how well the latter will be accepted to the applica-

[22] Akkurate.fi
[23] Fortum: Second life for lithium-ion batteries
[24] Spiers new technologies: The go to partner of vehicle oem's for life cycle management of advanced batteries
[25] Corvus Energy: Corvus Energy opens a new battery factory in Norway

tions. Also, the application area is determinant, most potential being the use in the context of renewable energy production.

3.1 Norway and Sweden leading the way in the Nordics

Norway has a high penetration of electric cars in use. Thus, also the number of battery packs for reuse and recycling is already several thousand annually and is growing exponentially. Since there is a lack of specific regulation on battery reuse issues, there starts to be a growing unregulated market of used batteries in Norway: who pays the highest price for the battery, gets it. More and more car wreck companies are selling online used batteries. Also, a lot of private persons are doing their own DIY projects in reusing the batteries.

At the same time new car dealers pay to the producer responsibility company Batteriretur[26] for taking care of the used batteries in recycling. Batteriretur is owned by the battery importers and originally set up for handling used lead acid batteries, but they are getting more and more lithium ion batteries as well. Thus, Batteriretur has started projects to investigate reuse possibilities for example in the off-grid cabin market. However, the car owner is owning the battery in his/her car in Norway and if returning the battery to Batteriretur, will not get any money for the battery, as opposed to the car wreck companies dealing used parts.

Whether going to recycling or reuse, the batteries mostly need at least some sorting and dismantling to modules and cells. In most cases the used battery packs are dismantled to modules and then reconstructed for the second life use anew. Robotization is being developed at R&D level in Norway for these tasks. However, at least one company, Ecohome, is using the used battery packs as such.

Overall, it seems still unsure how things evolve in Norway since especially the car companies are a kind of black box in the battery reuse issue. In electric vehicles most value is imbedded in the battery. It might thus be that the car makers want in the future to take more control of the battery lifecycle.

In Sweden much of the development around reuse is at R&D stage and there are projects ongoing that involve both companies and academic institutions. From the companies Stena is very active in the field and they have projects for example with Volkswagen and Volvo.

An example of such projects is the collaboration between Volvo Buses, Stena Property and Stena Recycling's subsidiary BatteryLoop for second use of bus batteries. BatteryLoop is a company through which Stena sells energy storage solutions, also using second life batteries. The project gives life to used bus batteries that have been converted to energy storage at a Stena Property residential area in Gothenburg, Sweden. The reused batteries will be charged from solar cells on the roofs and the stored electricity will be used for public areas such as

[26] Batteri Retur

laundry rooms and for outdoor lighting or sold into the grid. When the batteries can no longer be used, BatteryLoop's mother company, Stena Recycling, will handle the recycling of the materials.[27,28] The project uses technology from another Swedish company Ferroamp[29].

With this project, Stena has started to build a business ecosystem with the involved companies around the second use of batteries. The project merges renewable energy production, using battery driven energy storage, directly with the housing companies without having any energy utility as a partner in the system.

It is important to note that the intention of Stena is to be in control of the batteries. As such it wants to prevent that the batteries would end up to standing unused for example at summer cottages, or even worse, would be left to the nature. In the nature, the batteries, besides being hazardous waste, can also potentially be a source of e.g. forest fires in dry summers.

3.2 Automotive industry as the driving force in France and Germany

In France the main actor in the battery reuse sector is the automotive company Renault. In October 2018 it announced[30] that it is launching its new Advanced Battery Storage program that will work to build Europe's largest stationary energy storage system using a combination of used and new electric vehicle (EV) batteries by 2020. The 70 MW / 60 MWh battery is installed across several sites in France and Germany to support renewable electricity generation. The system is part of a push by the Renault Group to develop a comprehensive strategy that supports the smart electric ecosystem of the future along with the energy generation systems needed to power it.

Significant is that this project has evolved since to two projects that have been formulated as companies and that have gained private investments as projects. In April 2019 it was announced[31] that Demeter, a major European investment company for energy and ecological change, will invest in this Renault Group´s second life battery project and to another partner in the project, the German company The Mobility House. By this investment Demeter enters the growing business field of stationary storage batteries from electric vehicles and the project evolves to a project company. The investment will be made through the Fonds de Modernisation Ecologique des Transports (FMET) managed by Demeter. The first site of the project will be the Renault plant in Douai (France).

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27 Sustainable BUS: Volvo electric bus batteries used to store solar energy in apartment block
28 Battery Loop: Bus batteries as a property's energy storage
29 Ferroamp: Ett nytt sätt att tänka
30 Clean Technica: Renault's "Advanced Battery Storage" Program Explores The Potential Of Second-Life EV Batteries
31 The Mobility House: Demeter invests in Renault Group's second-life battery project and The Mobility House

In April 2019 it was also announced[32] that the Japanese company Mitsui establishes a joint project company with Groupe Renault, Demeter and The Mobility House to provide power supply optimization capabilities in Germany using an energy stationary storage system with energy sourced from Renault electric vehicle (EV) batteries. The system will have a total power output of 20 MW upon completion. The storage system will use Renault EV batteries deployed in containers that will be installed in different locations. It will provide frequency containment reserve service to the German power grid using the intelligent technology developed by The Mobility House. In the future, it will also aim at providing energy management services utilizing batteries storage capacity to industrial customers and power providers.

Renault is also partnering in a project in Belgium[33]. An industrial "second life" battery system consisting of 48 Li-Ion batteries from electric vehicles of the Renault Kangoo is put into use by ENGIE at the Umicore site in Olen in Belgium. The system forms one large storage battery of 1.2 MW or 720 kWh. The original energy content of the used batteries was 22 kWh per battery, in this second life application they still have 15-17 kWh, sufficient to contribute another 10 years to both the circular economy and the energy transition, through net balancing.

As a subsidiary of Daimler AG, Mercedes-Benz Energy, based in Kamenz, Germany, has been responsible for developing innovative energy storage solutions since 2016 based on the automotive battery technology used in electric and hybrid vehicles from Mercedes-Benz and Smart. The spectrum of large-scale storage applications by Mercedes-Benz Energy ranges from load peak compensation through black start (power system independent startup of the power plant) to uninterrupted power supply (USV). The company's focus is in particular on applications from the second life and replacement parts storage unit sector. Together with its partners, Daimler has already connected three mass storage devices with a total energy of 40 MWh from car battery systems into the German grid. Mercedes-Benz Energy has also tested together with the transmission system operator TenneT that automotive battery storage systems can take over tasks from large power stations and make a fundamental contribution towards grid stabilisation and system reconstruction following a power station outage.[34]

After piloting second use of batteries in Germany, Daimler is exporting the knowledge and technology in the area to China. Mercedes-Benz Energy GmbH and Beijing Electric Vehicle Co., Ltd. (BJEV), a subsidiary of the BAIC Group, have entered into a development partnership, intending to establish second life energy storage systems in China in the future. The partnership will see a consolidation of expertise and resources regarding the value-chain of automotive battery systems, while laying the groundwork for a sustainable renewable energy

[32] Mitsui & Co: Mitsui establishes a joint project company with Groupe Renault, Demeter and The Mobility House to provide power supply optimization capabilities in Germany using EV batteries
[33] Innovons Ensemble: Des batteries industrielles de "deuxième vie" développées par ENGIE et Umicore en Belgique
[34] Daimler: Mercedes-Benz Energy and Beijing Electric Vehicle start development partnership on 2nd-life battery storage

development. Together, Mercedes-Benz Energy and Beijing Electric Vehicle plan to set up the first second life energy storage unit in Beijing, making use of retired BJEV electric car batteries. The project aims to demonstrate how electric automotive storage units will in future also be able to support the Chinese power grid efficiently and sustainably with regard to fluctuation and power outage management.[35]

Also, in Thailand, Mercedes-Benz AG has invested more than 100 million euros together with local partners Thonburi Automotive Assembly Plant (TAAP) and Thonburi Energy Storage Systems (TESM) for local production for Mercedes-Benz plug-in hybrid-batteries in Bangkok. The battery factory in Bangkok is foreseen to meet the Mercedes-Benz's overall "Ambition2039" sustainability goals of having a carbon neutral new car fleet until 2039 by using large solar systems on the roofs of the production buildings. Excess solar power is temporarily stored in second life battery storage systems from recycled electric vehicle batteries. The plant works closely with the Mercedes-Benz Energy GmbH. The stationary storage systems, which can compensate for local energy fluctuations and contribute significantly to grid stabilization, enable economical and resource-saving reuse for disused batteries of electric and hybrid vehicles.[36]

Besides second use batteries, Daimler is also using its warranty battery spare part storage as a stationary energy storage. The idea builds partly upon the expectation that it is not known when a disruptive new battery technology will appear to the market, for example solid state battery might be such a technology, and thus the current warranty batteries are utilized as active assets. The energy storage application is considered such light use for batteries that the only minor degradation happening still enables Daimler to fulfill its warranty promise. One such live replacement parts store is located in an old coal fired power station facilities in Elverlingsen in Germany, housing 1920 automotive battery modules for a capacity of 9.8 MWh.

3.3 Major EU projects relevant for battery reuse

Most EU-level projects concerning used lithium ion batteries are currently on recycling focus and there has not been calls that would target specifically the reuse issues. Reuse has only been mainly seen as a side issue in projects where the focus in elsewhere, in materials development for example. Consequently, there are not really any major EU-level projects ongoing on the battery reuse, even if battery second use issues have been a subject area in some older projects that have ended a few years ago. In the following some most recent projects are referred in which battery reuse is considered as one part of the project.

35 Daimler: Mercedes-Benz Energy and Beijing Electric Vehicle start development partnership on 2nd-life battery storage
36 Daimler: Mercedes-Benz Cars starts local battery production in Bangkok

On EU funded project ELSA (*Energy Local Storage Advanced System*[37] , 2015-2019) finished in the beginning of the year 2019. The objective of the project was to create stationary storage solutions that comply with high safety standard requirements in a cost-effective manner. The project proposed scalable, easy-to-deploy energy storage solutions for factories, large offices, and residential buildings and districts. The aim was to develop the system based on second life EV batteries without previous dismantling of the individual battery packs. A low-cost industrialized power converter was also designed targeted specifically for use with second life batteries, as well as an Energy Management System (EMS) to work at the interface of the building EMS or the distribution grid. The partners were companies and research organizations from six different EU countries: France, Germany, United Kingdom, Italy, Spain and Ireland.

In the EU project INVADE (*Integrated electric vehicles and batteries to empower distributed and centralised storage in distribution grids*[38]*,* 2017-2019), which finished by the end of 2019, the focus was not second life use of batteries but such activities were included in one of its pilots. The project considered changes in management and distribution of the electricity system due to changes in consumption and production of electricity induced by renewable energies and electric vehicles (EVs). The project´s five pilot sites were in Norway, Germany, Spain, The Netherlands and Bulgaria.

In the EU funded project Circusol (*Circular business models for the solar power industry*[39]*,* 2018-2022) the second life batteries are one topic. The aim of the project in this particular topic is to remove the barriers for second life EV battery in stationary applications by: 1) improving technical performance with battery remanufacturing technology; 2) enhancing market confidence with labelling and certification protocols, and facilitating market adoption with performance-based PSS (product-service system) models; and 3) conducting cost and application analysis. Also, long-term business sustainability of second life batteries will be assessed. The partners include companies and research institutions from seven different EU countries: Sweden, Lithuania, Germany, Belgium, France, Switzerland and Spain.

The project LiBforSecUse (*Lithium batteries for second use*[40]*,* 2018-2021) is a project that has received funding from the EU EMPIR (European Metrology Program for Innovation and Research). The project will develop a robust measurement procedure and the supporting metrological infrastructure to measure the residual capacity of second life batteries using fast and non-destructive impedance-based methods. Feasibility to predict premature failure will also be investigated. The project includes partners from Germany, Czech Republic, France, Switzerland, UK, Sweden, Finland (Aalto University), Slovenia and Japan, as well as the European Commission Joint Research Center (JRC).

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[37] Elsa: Energy Local Storage Advanced system
[38] InVade: Horizon 2020
[39] Circusol: Circular business models for the solar power industry
[40] Lithium batteries for second use: Joint European Metrology Project LibforSecUse

4 *Most potential application areas for battery reuse*

In general, the batteries can be reused as entire battery systems, as battery modules or as battery cells. Some companies aim at reuse on battery system level for cost effectiveness. Most common is to repurpose the batteries on module level. Then only modules that are properly functioning in a battery pack are reused. Repurposing at cell level requires in most cases a lot of labor and is not effective as such. Also, many times the cells are welded together which makes it impossible or very difficult to take them apart in a module.

The reused batteries are best suited in such low maintenance applications where constant operation of the battery is not a critical necessity: it is not critical if some battery cells cease to function at some point of time. In such solutions the energy density and capacity are not critical parameters and there is no need for fast charging and recharging. Also, the second life batteries experience more degradation than first life batteries. Thus, a stronger operation and maintenance protocol is needed than for use of first life batteries, and the prerequisite is that there is no significant limitation of space to fit enough batteries to consider the risk of some of them failing.

Overall, a suitable application for second life batteries is such where battery liability is not an issue at the same time when significant cost reductions are welcome. This equation favors the use of second life batteries over first life ones at least when considering the current battery price to be high for first life battery and significantly lower for the second life battery.

The most prominent second life battery use concrete application is as energy storage in renewable energy production and especially for wind and solar energy. Especially wind as an application requires high power and low cycle and low de-charging conditions which increases second life battery suitability for the application. The EV battery-powered stationary storage system will give grid flexibility [41].

For example, in Germany and Sweden, investments are made increasingly to microgrids that provide a localized electricity grid to support renewable energy production and distribution. These microgrids can be self-supporting or alternatively they can also be connected to the main grid. The microgrids provide means to invest in grid connection enhancement in areas where there are challenges with the main grid, both in developed and developing world, and where the microgrid provides a better means for such enhancement than investments made for renewal or extension of the main grid. The microgrids are built for example to a part of a city or to a village. Energy storage solutions provide an essential part of such renewable energy base microgrids and second life batteries are well suited for such application.

[41] Energy Storage: Germany's largest EV battery-powered stationary storage system will give grid flexibility

Other potential application areas for second life batteries are telecom, and UPS systems. In general, the tendency is across all businesses to replace the lead acid batteries with lithium ion battery-based storage systems.

Some companies are commercializing residential energy storage systems based on second life batteries, such as the Nissan and Eaton joint product xStorage HOME[42]. However, due to high maintenance and large space requirements, there are also opinions that residential energy storage might not be the most useful application area for second life batteries.

As a niche application area, second life batteries are retrofitted to old, for example diesel cars for second use in a DIY manner to convert old conventional fuel cars to electric vehicles. Also, the lightweight cars or small e.g. three-wheel vehicles can be a potential niche application area for second life batteries.

In the ocean sector, the companies involved in the electrified ship business expect the end-of-life batteries continue to second life in the same sector, for example in applications that involve interconnection to the grid, even if also other alternatives can be considered. Examples could include e.g. onshore charging stations. A mixture of first and second use batteries could also be an alternative to entirely new batteries on ships, depending on the customer specific power requirements. In determining suitable second use application areas, important prerequisites are the knowledge of the sailing patterns, i.e. in what kind of usage the batteries have been during their lifetime, and that the expectation is to reuse a battery pack as a smallest entity, not the cell, i.e. there are modular plug-and-play possibilities for the battery stack. An interesting application area in ocean sector is to use second life batteries to complement the peak power needs in ships. A concrete example of such is are ferries for example sailing between Finland and Sweden that are designed by regulation to have ice breaking capacity. Due to this the engines on these ferries are oversized in operational capacity when ice breaking is not necessary, that is, for major part of the year. Using second life batteries would give a possibility to design the engine capacity more economically and sustainably by using the second life battery stacks as the needed extra power source when needed.

5 Safety issues and other challenges

5.1 Safety issues of EV battery reuse

Although lithium ion battery technology is considered relatively safe, many cases have been reported where an EV battery or some other lithium ion battery has been the source of a fire. The mechanism behind this is called thermal runaway – a situation where reactions in the battery generate heat faster than the battery is able to cool, causing a buildup of heat which

[42] Eaton: Nissan and Eaton Make Home Energy Storage Reliable and Affordable to Everyone with xStorage HOME

further accelerates the reactions, leading to a catastrophic failure. This can have the possible consequence of the battery catching fire and/or venting flammable gases or even exploding due to the pressure generated. The main enablers of a thermal runaway in a lithium ion battery are the flammable electrolytic used in them and the relatively high stored electrochemical energy vs. volume factor. The electrolytic is the main source of energy in a thermal runaway while the stored electricity can work as a detonator. Thermal runaway can occur due to an internal or external short circuit of the battery, or due to an external heat source, such as fire. During a thermal runaway the separator of the battery can melt, resulting in an increasing internal short circuit, accelerating the reaction. To prevent a thermal runaway, EV batteries in general contain many layers of safety mechanisms such as fuses, a battery management system and adequate robustness.[43]

It is estimated that a lithium ion battery manufactured under an adequate quality system has a failure rate from one in 10 million to one in 40 million.[44] However, several factors can contribute to an increased risk of thermal runaway or even cause thermal runaway outright (in addition to straight short-circuits and high temperatures)[45]:

- Physical damage caused by vibration or battering, crushing or puncturing of the battery, leading to an internal short-circuit
- High voltage or high current
- Overcharging to a voltage above specifications or recharging in freezing temperatures, which both can cause the formation of lithium dendrites and increasing a risk of internal short-circuit
- Manufacturing defects and bad quality, resulting in impurities in the electrodes or holes in the separator
- Unstable battery chemistries
- Ageing of the battery – degradation of the battery decreases its safety in addition to decreasing its performance
- Incorrect storage temperature, especially too high, accelerates the ageing of the battery
- Complete discharging of the battery

Considering the above, safety is a crucial aspect regarding the reuse of EV batteries[46]. If, for example, an EV battery has been in active use for ten years and undergone a few hundreds of thousands of kilometers of service, it has likely been subject to a considerable amount of vi-

[43] The Fire Protection Research Foundation: Lithium-Ion Batteries Hazard
[44] Science Direct: A review of international abuse testing standards and regulations for lithium ion batteries in electric and hybrid electric vehicles
[45] The Fire Protection Research Foundation: Lithium-Ion Batteries Hazard
[46] WEF: A Vision for a Sustainable Battery Value Chain in 2030

bration and usage in less-than-ideal conditions, stressing the importance of ensuring its safety before it is utilized in second life applications.

In addition to the risks caused by thermal runaway, the high voltage levels (600-700 volts) of EV batteries cause a risk of lethal electric shock. This is especially important to understand when handling end-of-life EV batteries and preparing them for reuse. This calls for adequate safety training of all the personnel involved, since removal, dismantling, refurbishing and repurposing the batteries are steps where there is a considerable risk of shock without adequate understanding of required safety measures[47]. The heavy weight of the batteries – from 100 – 700 kg or even up to 800 kg – requires its own safety measures as well in order to avoid injuries to personnel due to dropping. Also, an important challenge in the context of battery reuse is how to handle the logistics of end-of-life EV batteries. There is a need for specialized service providers that understand the special requirements for the transportation of end-of-life EV batteries (see chapter 6.2 for further information on legal requirements on transportation).

The DIY and third-party activity around the reuse of EV batteries raises questions of safety. In Norway – with a relatively high amount of electric vehicles on the road – there is already a situation where used EV batteries are sold by private people through auction sites and classified advertisements. These are then bought and reused in other electric vehicles or repurposed for example as an energy storage system at a vacation home. This can be carried out by entrepreneurs who have no link to the original producer of the battery at all – or reusing can even be carried out by private people as projects that are totally do-it-yourself. Here the risk is reusing EV batteries that are not fit for second life applications anymore due to inadequate safety performance caused by damage and degradation from prior use. Also, there is a risk that an electric shock occurs due to inadequate understanding on the required safety measures. Safe reusing of EV batteries requires adequate understanding of the functioning of the battery and its battery management system, and it is questionable whether persons carrying out DIY projects have the required knowhow. This calls for legislative work on the safety aspects of EV battery reuse and related supervision by authorities. Also, schemes that promote safe second life usage of EV batteries should be developed and general knowledge of the risks should be increased.

When repurposing the battery for a second life application after its service as an EV battery, it is crucial to ensure that it is still safe to use and not in a significantly elevated risk of a thermal runaway. Here adequate diagnostic methods of the battery are required with the BMS (battery management system) or some other monitoring electronics of the battery being an essential source of information on the State of Health (SoH) of the battery[48,49]. In general, availability of good tracking data related to the lifetime of the battery is a critical prerequisite

47 NHTSA: Lithium-ion Battery Safety Issues for Electric and Plug-in Hybrid Vehicles
48 Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art
49 European Commission: Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619- Lot 1

for a functioning second life market for batteries, while lack of such data brings uncertainty to the second life battery ecosystem. The current situation is that the tracked lifetime data of batteries is not usually openly accessible and is only meant for the manufacturer and/or authorized service personnel. This is a limiting factor for the safe reuse of EV batteries. The further the battery is used from the sphere of its original producer, the more relevant the safety issues become, stressing the importance of data on the state and on the operations of the battery during its lifetime. The key to safety here would be open access to the data or some related service business model. How current legislation and ongoing legislative work takes the safety aspects of EV battery reuse into account, including plans on the requirements of easy access of battery information and open battery lifetime data are elaborated in chapter 6 in this report.

In the ocean sector safety is always prime concern and in the use of batteries, whether in the context of first or second use, safety issues are equally important as any other safety issues. From that point of view, safety is not a barrier for second use but rather main concerns are the lifetime or performance issues: to meet the requirement to guarantee the needed power to the customer for safe operations. For example, in Norway Corvus Energy is offering second life services for their used first life battery packs provided that the customer has done an agreement with them on monitoring the health of the battery throughout its first life[50].

5.2 *Other challenges*

In addition to possible safety issues, there are other challenges to take into account regarding EV battery reuse. One of them is the diversity of EV batteries. EV batteries are usually designed for a particular electric vehicle model. Although the expected end-of-life EV battery volumes in the future are significant, the volumes are fragmented into many different battery types, meaning there are lesser amounts of a single type of EV battery available for reusing – for example, the amount of electric vehicle models by 2025 is expected to be up to 250 with batteries from more than 15 different manufacturers. Due to lack of standardization, there are variations in size, chemistry and physical form (i.e. they can be cylindrical, prismatic or pouch type). The diversity and fragmentation of volumes result in added complexity of repurposing EV batteries.[51, 52]

Predictability is very important, and it is easier to get when the battery pack is from a bigger system originally. For example, a large battery pack from one ship has all same lifetime experiences which gives good predictability for the entire system. However, if similar amount of batteries is received to the system from several individual cars that have all experienced different lifetime events, predictability is much more difficult for the system.

[50] Corvus Energy: Recycling
[51] Jätehuoltopäivät: Sähköautojen akkujen uudelleenkäyttö ja kierrätys
[52] McKinsey: Second-life EV batteries: The newest value pool in energy storage

Another challenge is the constantly falling costs of new batteries. The technological advances, increased capacities and decreased costs of new batteries in the future will decrease the cost-effectiveness of utilizing end-of-life EV batteries. When considering an end-of-life EV battery manufactured for example 10 years ago for a particular application, it will have to compete against new batteries with better technology and capacity and less cost. This decreases the cost-effectiveness of utilizing end-of-life batteries and decreases their value as reusable batteries.

The ownership of the battery could affect its cost-effectiveness as a second life battery – for example cost-effectiveness is likely determined differently for an EV battery that is owned by the car manufacturer for its entire lifetime than for an EV battery that is owned by the owner of the car.[53] The car manufacturer can design second life usage as part of the life cycle of the battery, whereas an end-of-life EV battery owned by a private person can only enter a second hand market.

In general, ownership can be a challenge for reuse - it might not always be clear who actually owns a particular EV battery and the ownership might vary during the lifetime of the car. First, during the warranty period or also otherwise during the normal use of the car, the owner of the battery can be the car manufacturer, its representative or the car leasing company. Later, after the warranty period, it might be the car owner who owns the battery. In case of e.g. Daimler and Renault, they own the battery during the entire lifetime of the car. If the car has been in an accident, it might be that the ownership of the battery changes to the insurance company.

One issue that has not been considered yet so much by the energy storage providers, such as utilities, is, that what happens to the batteries after the second life. The first immediate attention is in getting the Power Purchase Agreement (PPA) and sell energy, what happens after for the batteries is not in focus. Even if the batteries will serve for a relatively long time, maybe even 10-15 years in the energy storage application, the second life system provider has the liability to recycle the batteries afterwards. Thus, it would be necessary to consider such planning as part of the entire system and its life cycle design.

One open issue at the moment concerning the second life batteries is that who is in charge of the second life batteries? The solution aimed at is that the second life application producer will be in charge of the second life batteries. In connection to that discussion, there also remains the question of possible need for some sort of certification for the second life systems. One answer to that might be that the second life producer will provide, based on its own measurement data, self-certification similar to CE mark to the second life system, without any further certification need of a third party certification entity.

Overall, lack of standards and lack of regulation is a challenge for reuse. The current regulatory environment and its development is discussed in chapter 6. If some standardization will

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[53] Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art

be developed for the batteries, it should be battery manufacturers and/or the OEMs such as automotive industry that should lead the standardization work. The utilities do not see themselves in the positions of being part of standardization work, however, they need to stay informed of what is happening in that context.

6 Relevant regulatory environment for battery reuse within EU

6.1 Current main EU legislation on end-of-life batteries

The Waste Directive (2008/98) is relevant to end-of-life batteries in that it sets the general definitions of waste and recycling and sets other basic concepts related to waste management, such as extended producer responsibility. The ELV (end-of-life vehicles) Directive (2000/53) sets reuse, recycling and recovery targets of end-of-life vehicles and their components but does not specifically mention batteries used in vehicles. The main EU legislation on end-of-life batteries and on batteries in general is the Batteries Directive (2006/66). The directive aims to minimize the negative effects of batteries on the environment. It prohibits the use of certain hazardous substances in batteries and sets out requirements on waste management and recycling targets for batteries. The directive separates batteries into portable batteries, automotive batteries (used for starter, lighting or ignition power) and industrial batteries (batteries designed exclusively for industrial or professional use or used in an electric vehicle). EV batteries are classified as industrial batteries. As a tool to steer waste battery streams into proper waste management, the directive contains requirements on extended producer responsibility (described in section 1.3 of this report). The directive also sets out requirements on labelling of batteries and their removability from equipment. The directive also aims to improve the environmental performance of all operators in the battery life cycle.

The target of the Batteries Directive is on the separate collection of waste batteries only concerning portable batteries – there are no quantitative targets regarding the separate collection of EV batteries and other types of batteries classified in the directive as "industrial batteries". For end-of-life batteries, the directive does not contain requirements or targets concerning reusing end-of-life batteries in less demanding applications than their original application. That is, there are no requirements nor targets on reuse that would be separate from the recycling targets.

Overall the regulatory framework is not very well suited for the challenges in the ocean sector. Even if not directly relevant to reuse, for example such regulation that obligate around the emissions of ships would also positively affect the second life application of batteries.

6.2 Safety legislation on battery reuse

There is currently no EU-level legislation that would specifically deal with safety aspects of EV battery reuse. Generally, all legislation relevant to the safety of batteries and products that utilize them is also relevant for the reuse of EV batteries. These include the General Product Safety Directive (2001/95/EC), which aims to ensure that only safe products are sold on the market; the Low Voltage Directive (LVD, 2014/35/EU), which sets safety requirements for electrical equipment; and EU Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH, 1907/2006), which is relevant due to chemicals used in batteries. The Batteries Directive is not a so-called safety directive i.e. it does not contain requirements on the safety of batteries, nor does it require that batteries be supplied with a CE marking. If a battery contains a CE marking it is due to requirements from other directives than the Battery Directive. For example, a battery might contain a CE marking due to the safety requirements of the electromagnetic compatibility (EMC) Directive (2014/30).

The Directive on the inland transport of dangerous goods (2008/68/EC) and the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) are relevant to EV batteries including end-of-life batteries. They have requirements on the transportation of lithium ion batteries, including packing requirements and storage requirements in case the storage is related to logistics. The requirements vary based on various variables such as whether the battery is shipped inside a product or whether it is an end-of-life battery. The United Nations manual called "UN manual of tests and criteria" describes the so-called UN 38.3 Test which contains requirements for tests which a lithium ion battery type or model should successfully pass before it can be transported. The tests include vibration, shock, external short circuit, impact, crush and overcharge tests. In addition to the UN 38.3 Test, there are many transportation safety standards concerning lithium ion batteries, such as the IEC EN 62281: Safety of Primary and Secondary Lithium Cells and Batteries During Transport, which is used in EU. Airfreight and rail transport have their own standards and requirements as well. Interesting from the point of view of reusing EV batteries is the fact that if repurposing the battery involves replacing the BMS, the UN 38.3 tests must be redone, which is expensive[54]. This requirement is due to several of the UN 38.3 tests involving the BMS.

In addition to the transportation standards, battery safety in general is based on a relatively large amount of standards. An example is the SFS-EN 62619:2017:en: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications. There are also standards specific to the safety of EV batteries. The standards have been collected in EU's Batterystandards.info[55] web site.

The research and standards development entity UL Standards has issued the standard UL 1974: Standard for Evaluation for Repurposing Batteries, which deals with the safety aspects

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[54] European Commission: Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619- Lot 1
[55] Battery Standards.info

of reusing EV batteries in energy storage systems[56]. The standard concerns US and Canadian markets[57]. However, developing similar standard for Europe is ongoing, which will likely have similar contents as the UL 1974. The UL 1974 deals with topics such as construction (e.g. materials, wiring, connections, cells, insulation levels and coolant and other critical systems), quality control and safety of facilities for repurposing, examination of incoming samples (e.g. visual inspection, analysis of BMS data, disassembly and examination and grading of batteries for repurposing), performance testing, packing, shipment and markings.

Relevant to EV battery reuse is also the legislation concerning energy storage systems – since they are one of the most important second life applications for EV batteries. Currently there is no EU-level legislation specifically regulating the safety of energy storage systems, hence the safety of such installations is based on applying existing safety standards. Building fire safety, emergency preparedness and other general safety legislation should also be followed if installing an energy storage system in a building. Similarly, there is no EU-level safety legislation that would specifically concern the storage of end-of-life batteries unless the batteries are stored as part of the logistical chain (i.e. temporarily), in which case the abovementioned transportation legislation applies. The requirements of the Seveso Directive (2012/18/EU) - a safety legislation on storing large amounts of hazardous chemicals - could apply in case of a storage of a large amount of EV batteries that contain a large total amount of hazardous chemicals.

6.3 Ongoing legislative work on end-of-life batteries

In a recent review of the Batteries Directive by the European Commission, it is stated that "the Directive does not address the possibility of giving advanced batteries a second life, making developing re-use approaches more difficult"[58]. Further, the directive defines recycling efficiencies only for lead and cadmium, ignoring cobalt and lithium, which are valuable raw materials used in EV batteries. The review sees these current recycling requirements as inadequate in promoting a high level of recycling and recovery from waste batteries and accumulators. Also, the review sees the current extended producer responsibility obligations for industrial batteries as not well-defined, and that detailed provisions for collection, setting up national schemes and financing aspects for industrial batteries would be "increasingly relevant in future as using these batteries is considered vital for low carbon policies in the EU". If the Batteries Directive is revised so that it takes into account the findings of the review, it could lead to a more favorable legal environment for both reuse and recycling of EV batteries.

EU's Strategic Action Plan on Batteries aims to support a full competitive battery value chain in Europe, including battery reuse and recycling. The plan focuses on sustainability. Analyz-

[56] UL: UL Issues World's First Certification for Repurposed EV Batteries to 4R Energy
[57] Smart Energy International: World's first certification for repurposed EV batteries
[58] European Commission: Evaluation of the Directive 2006/66/EC on batteries

ing how to best promote the second use of advanced batteries is mentioned as a key action in the plan. In practice reuse is taken into account in the preparatory work for sustainable design requirements for industrial batteries[59]. The relevant EU legislation here is the Ecodesign Directive (2009/125/EC), which establishes a framework for the setting of ecodesign requirements for energy-related products. In the Ecodesign preparatory Study for Batteries[60], two main requirements are being planned for that would promote both reuse and recycling of batteries: 1) requirements for providing information about batteries and cells and 2) Requirements for battery management systems. Some sources refer to this kind of openly accessible information as a "battery passport"[61].

The planned requirements for providing information about batteries and cells are equivalent to a proposal that an individual battery and its modules should carry a bar code, QR code or similar that would provide access to European database with information on batteries and cells. This information would be generic to the particular battery type or model and not concern the individual battery. The provided information would include information on the battery manufacturer, battery type and chemistry, capacity, voltage and power limits, lifetime, temperature limits, among many other parameters – all of which are relevant for second life applications also.

The planned requirements for battery management systems are equivalent to requirements on data storage, and access to the data stored in the battery's Battery Management System (BMS) to facilitate the determination of the State of Health (SoH). Determining the SoH is crucial to ensure the suitability of a battery for second life applications. To determine the SoH, a large amount of data concerning the individual battery should be openly accessible through the BMS. This data includes information on the remaining capacity of each module, capacity fade, possible increase of internal resistance, cooling demand, efficiency reduction, self-discharge and its evolution, calendar age, energy throughput, temperature statistics, errors, negative events, among many other parameters[62]. Finally, batteries could also contain information about traceability of battery modules and packs via a serial number and/or information stored in the BMS. Currently the battery management systems of EV batteries collect useful data in determining the SoH, but it is meant only for the manufacturer and/or authorized service personnel, and is not openly accessible, providing a limiting factor for second-life use.

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59 Ecodesign preparatory Study for Batteries

60 European Commission: Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619- Lot 1

61 WEF: A Vision for a Sustainable Battery Value Chain in 2030

62 European Commission: Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619- Lot 1

7 Business outlook for the battery reuse sector

7.1 Business prospects

At the moment, only few used batteries are on the market and the market is rather preparing itself to the moment when used batteries become available in large quantities. The first actual end of life batteries from cars in Europe are expected to start to appear in 2029, to be reused for second life applications. However, there will be already 2022-2023 a big increase in used batteries as by that time there will be overall a lot more electric vehicles in use and thus a certain amount of used batteries will come to the second use market from for example warranty replacements and from crashed vehicles from accidents. Overall, the quantities will increase only gradually, and the volumes might be less than expected in total. This could be due to the batteries lasting longer in cars than expected. Also, not all used cars in Europe will be dismantled in Europe: significant export is seen on used electric and hybrid cars to countries like New Zealand or Ukraine. However, if there is a new exceptional battery technology coming to market, such as a solid-state battery, most companies will consider changing to new technology and suddenly there might appear a very large quantity of second life batteries on the market.

The market, applications and technologies are still so new in the battery reuse sector that it is difficult to estimate the business prospects precisely. Also, the business models are still under development. There are also issues that need to be overcome like a policy question on transport of used batteries and what kind of data is needed on the life of the battery to enable proper reuse. However, some signals are already visible that future business possibilities are seen around the reuse of batteries. For example, in the Renault led advanced battery program, the partners also include institutional investors and thus the funding is not coming purely from the OEMs. Having been able to get institutional investors onboard of such programs requires for the programs to have significant potential also from business perspective.

When considering the automotive companies, they are becoming gradually more and more battery companies for whom also the second use of batteries presents business potential. If a car company owns the battery, in which they see a lot of potential, they can change the cells whenever needed and create business of the used cells elsewhere. This might also impact the price of electric vehicles since the consumer purchasing the car will not purchase the battery anymore. Also, it appears that the tendency is more and more towards a holistic battery life business model in which the battery is not kept operational in the car until degraded but rather the battery is leased to the car for maybe five years after which it is replaced and taken for a second use application.

A new innovative business model in the context of energy use value chains is that the battery can add value in the grid and provide services to energy market at the same time when it is used in a vehicle and the subsequent earning can be applied as cost reductions to the battery owner. For example, if a bus fleet usage is commuter heavy, it means that large portion of hours the busses are standing still. Those assets can be bid to energy market to guarantee a buffer to availability and to shave peak loads.

One interesting business area in connection to the second life use of batteries is the battery management and monitoring service for the battery first life use to provide data for adequate decisions on the second life potential. This is a business area in which more and more companies are coming to the market, thus increasing the competition. Also, it might be difficult, especially for startups, to enter into partnerships with the automotive companies, which might own the batteries and be unwilling to provide means to access the needed data. However, new EU legislation on battery passport might provide a change to this.

In the ocean sector, the batteries are given even a 10-year guarantee and thus reuse is not seen as an acute matter. However, companies in the sector have started to draft plans on future business models for battery reuse and include them in their long-term business strategies. Few details of business prospects are available since the companies regard the second use as an important and strategic future main business area for them. In general, the specific business models are foreseen to be found in clusters that include customers and sector specific applications. The intention is to provide solutions that are relevant to the main customers within the ocean sector.

Second use of batteries is competing with recycling in a sense that if a company has a business model to recycle batteries, then reuse possesses of course competition to that activity and vice versa. The market will most probably decide whether the battery ends up in recycling or reuse after first use: the one who has the most efficient processes and the highest bid on the used battery will get it. Companies that buy batteries for reuse purposes can pay more for the batteries than the ones buying them for recycling. If buying for recycling, the batteries typically sell for very low prices if any price at all since even if extracting the metals, there are also costs for the extraction and recycling processes. Also, at present the recycling ecosystem is not capable to recover enough materials and is carbon intensive. There is a need to lower the carbon cost per amount of usable energy for the battery, and to reduce the lifecycle carbon intensity of the process. Thus, using second life is extremely important, especially when integrating with renewables, rather than tossing to recycling. At least some car companies are actively working on the challenge of value-enhancing use of vehicle batteries before, during and after use in electric vehicles and calculating whether the business equation for second life use of batteries makes sense: the return on the second life use must be higher than the return on recycling the battery. For both safety and also business reasons the cheap battery markets are not seen as interesting as might be expected.

7.2 *Supply and demand*

There are various estimations on the supply, demand and market of second life batteries. Bloomberg New Energy Finance estimates that by 2030, the global energy storage market would reach a capacity of more than 305 GWh[63]. According to McKinsey, the global supply for second life batteries will be approximately 15 GWh per year in 2025 and 112-227 GWh per year in 2030, while the demand for utility-scale lithium ion battery storage will be 92 GWh per year in 2025 and 183 GWh per year in 2030 (note the different unit [GWh per year] than in Bloomberg's estimation [GWh])[64]. Thus, it is possible that the supply of second life batteries will exceed the demand for lithium ion utility-scale storage by 2030. However, whether it is feasible to utilize a second life battery in a particular storage application is not straightforward, hence some of the demand of utility-scale lithium ion storage likely cannot be met by second life batteries. [65]

According to one study[66], for some applications the second life battery market in USA would be saturated in just five years after 2019. Although the results cannot be extended to global markets, the results indicate one possible outcome for a second life battery market for some applications. Thus, there are still in general a lot of uncertainties on whether the most potential second life applications will provide a sufficient market for all the end-of-life EV batteries in the future.[67] Bloomberg New Energy Finance gave an estimation that the total of 95 GWh of EV batteries will reach the end of their life by 2025, and 26 GWh could be utilized in second life applications[68]. World Economic Forum established a vision for a sustainable battery value chain with the target year of 2030, where 61% of end-of-life EV batteries would be utilized in second life applications, replacing 20 GWh of lithium ion batteries that would otherwise have been installed in energy storage systems[69]. This would represent 6% of the global demand for stationary battery storage in that year.

For EU, lithium ion energy storage capacity demand and supply of end-of-life EV and energy storage batteries were evaluated as part of the Ecodesign preparatory Study for Batteries[70]. The study forecasted the demand and supply up to year 2050 with only rough estimations concerning the years up to 2030. Based on the study, in 2030 in EU the demand for energy storage lithium ion batteries was likely considerably less than 40 GWh per year and the supply of batteries approximately 25 GWh per year. A study by Circular Energy Storage estimated that in Europe approximately 2,5 GWh of lithium ion batteries per year will become available for second life starting 2025[71].

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[63] Bloomberg NEF: Global Storage Market to Double Six Times by 2030
[64] McKinsey: Second-life EV batteries: The newest value pool in energy storage
[65] Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art
[66] Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art
[67]Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art
[68] Bloomberg NEF: Lithium-ion battery costs and market
[69] WEF: A Vision for a Sustainable Battery Value Chain in 2030
[70] Ecodesign preparatory Study for Batteries
[71] WEF: The lithium-ion battery end-of-life market – A baseline study

The results of several studies suggest that second life batteries differ from fresh batteries in their energy and power capabilities, energy density and cell-to-cell heterogeneity. These performance handicaps can be overcome if the degraded performance is taken into account in the second life applications by appropriate battery sizing and other such means. However, safety and second life battery lifetime are still aspects with significant uncertainties. These uncertainties should be addressed in order to fully understand the potential of EV battery reuse since technical and economical feasibility studies depend on the ageing performance of second life batteries.[72]

Based on the estimates above, it is clear that there will be large volumes of end-of-life EV batteries available, of which a significant portion could potentially be utilized in second life applications, although there are some uncertainties regarding the long-term performance of second life batteries. All in all, it can be concluded that the electricity storage industry cannot afford to ignore such considerable source for potentially usable batteries for their applications.

7.3 Economic viability

According to Circular Energy Storage research group, the second-life EV battery market can grow to $4.2 billion by 2025.[73] Also according to them, a supplier of reserve energy capacity with a multimegawatt energy storage system has a potential to earn approximately £50 000 (56 000€) per MW per year. Thus, for example a 100 MW energy storage plant with 7000 Nissan Leaf batteries would generate the annual revenue of 5,8 million €, translating to 830€ per battery per year. In this case each battery yields 4 200€ during their expected second life lifetime of five years. In Germany with higher prices caused by regulation, the expected yield would be nearly three times as much as in UK for a similar facility.

When considering the economic viability of reuse versus recycling, it seems that reuse is clearly more economic than recycling. [74] Recycling of an EV battery costs from 450 to 1300 €, whereas reusing the battery can generate the revenue of at least 45€/kWh. However, the falling of prices of EV batteries in general can result that in 2030 the prices have reached a point of being equal to the current value of the raw materials – such as cobalt - of the battery.[75] This could divert batteries from reuse to recycling.

Reducing the upfront costs of EV batteries is an important aspect and a driver for EV battery reuse. According E.Martinez-Laserna et al. [76], the amount of discount to upfront costs provided by EV battery reuse seems rather limited, although the authors agree that this conclusion has uncertainties as automakers or energy storage providers were barely involved in the

[72] Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art
[73] PV Magazine: Second-life EV battery market to grow to $4.2 billion by 2025
[74] Kelleher Environmental Research Study on Reuse and Recycling of Batteries
[75] Global Battery Alliance: The lithium-ion battery end-of-life market – A baseline study
[76] Ideas: Battery second life: Hype, hope or reality? A critical review of the state of the art

reviewed studies. Based on the interviews and findings described in earlier chapters of this report, it seems that apart from Tesla, automakers and related parties see considerable business potential in EV battery reuse and a lot of development on reuse and related business models is going on.

8 Conclusions and recommendations

Reusing EV batteries has significant potential to the EV battery and electric vehicle value chains: EV batteries can be used in less demanding applications after the end of their useful life as an EV battery, enabling EV batteries to retain some of the value of their high initial cost. A large amount of potential second life EV batteries are expected to become available in coming years, further stressing the potential of EV battery second life solutions.

In general, a lot is happening at the moment in the context of battery reuse, but still in a rather small scale. The used battery volumes are also still such limited that large scale activities are not yet feasible. Large volumes of used batteries are expected to come to market by year 2025, of which significant amounts would be eligible for reuse.

Almost all major car manufacturers are doing something in the battery reuse context. Especially those that have electric or plug-in hybrid cars in the market have also activities related to the second life of batteries. Renault and Daimler are among the most advanced in this sense. Daimler takes a holistic view on electric mobility and product lifecycle of EV batteries. Renault engages in both recycling and reuse programs with various industry partners. Examples of other successful companies along the second life battery value chain include The Mobility House that integrates second life vehicle batteries into the power grid using intelligent charging, energy and storage solutions. The company Akkurate Oy is a provider of battery diagnostics software, essential for reuse batteries in second life applications. The more batteries there are in the market, the more there is urgency from the OEMs. In general, the major players in the second use business are still very much spread out and no clear leaders have emerged yet.

The business models under development in the context of second use are overall disrupting the business strategies of the companies involved. When taking a holistic look on the value chain, the focus is shifting from the car to the battery and how to use it most effectively as a vehicle for the company's business. When controlling the life cycle of the battery from the business perspective, new interesting business models arise that aim at maximizing the "productivity" of the battery during its lifetime. New business models also promote new partnerships in emerging ecosystems, connecting for example energy companies, automotive companies and construction companies. Digitalization is a "lubricant" of this new business and companies providing for example data management and battery life cycle monitoring and management services and technologies are needed as integral part of these ecosystems.

Safety is a crucial aspect for second life batteries and batteries in general. Accessible information and lifetime data on batteries is the key to safety. There is currently ongoing legislative work in EU that focuses on promoting EV battery reuse by setting requirements on data accessibility. European standardization of the safety aspects of EV battery reuse is also ongoing. Hence, it can be concluded that there is legislative work going on that aims to tackle the safety and other challenges on EV battery reuse, striving to provide a more favorable legislative environment for the reuse sector in the near future.

Although scientific literature on EV battery reuse points to uncertainty regarding the economic viability of EV battery reuse, the activities of automakers and related parties described in this report indicate clear potential for positive business prospects. Realizing the business potential calls for development of new business models and strategies and establishing partnerships, all of which is already happening at least in European context. Thriving second life battery ecosystems require that the business models overcome the identified challenges. Thus, designing EV batteries and their entire life cycle with second use in mind will be an important enabler.

Based on the findings in this report, Business Finland should consider the following points when planning possible further actions in Finland concerning the battery reuse area:

- From a business perspective, some of the potentially reusable EV batteries can be "lost" to the uncoordinated do-it-yourself second life market. This is also a safety issue. Thus, it is in the interest of societies in general that lawmakers, authorities and companies involved with reuse create an environment that promotes safe and responsible reuse of EV batteries – this at the same time further improves the business case of EV battery reuse. This calls for both national initiatives and EU-wide projects that gather all the relevant stakeholders on end-of-life EV batteries.
- The perspectives are changing disruptively, for example when automakers are starting to consider business potential focused on the battery lifecycle instead of the car. Depending on the particular business models, there is room to include many different kinds of actors in an EV battery ecosystem and thus to multiply the business potential of such ecosystems. In addition to automakers and energy storage integrators, examples of actors that should be part of reuse ecosystems include technology developers, battery diagnostics providers, renewable energy producers, battery refurbishment and repurposing service providers, producer coordination organizations, research facilities and waste operators specialized in end-of-life batteries.
- The business value chains in the battery reuse are at the same time global, European and local, as the described projects are demonstrating. When facilitating the build-up of ecosystems in the sector, it will be important to consider all these three dimensions. The drivers for business might be outside Finland, but there might be potential local initiatives that need to collaborate European wide and globally in order to realize the foreseen business potentials.
- It should also be noted that it is not too late to act but rather it is the right time act. While waiting the battery second use market to start forming, the companies consider now being the right time to build relations, partnerships and strategies as a foundation for future business.

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