The impact of battery chemistries on second-life battery applications

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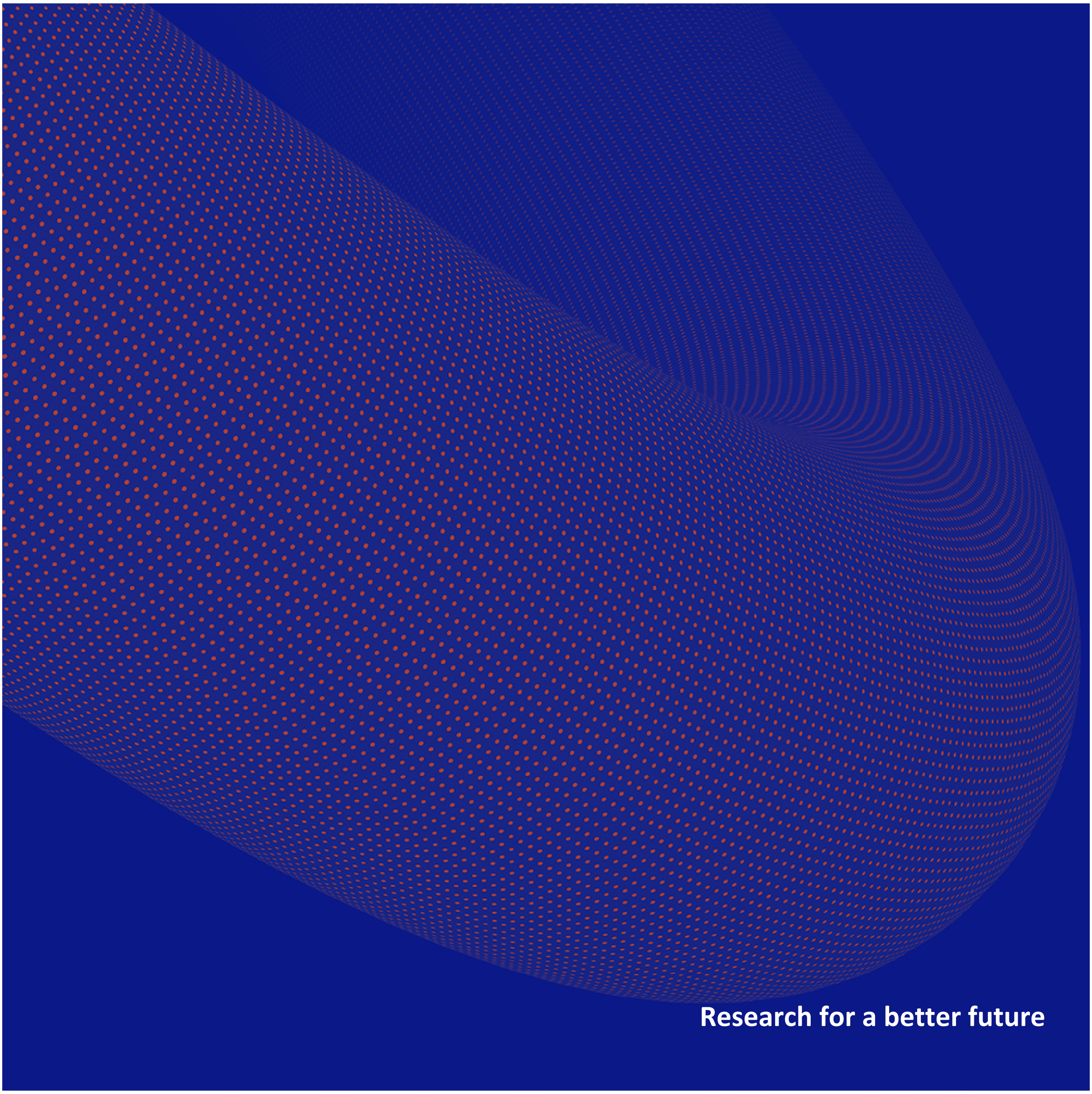

Research for a better future

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Title:
The impact of battery chemistries on second-life battery applications

Summary:
Second-life batteries are batteries that have reached their end-of-life in their original application but still have a remaining capacity to serve in another application. An electrical vehicle battery typically reaches end-of-life with around 80% of its initial capacity left, leaving a battery that still might be useful in other applications such as stationary applications. With the increasing amount of electric vehicle batteries that reaches end-of-life, the potential for second-life batteries increases. This report aims to determine which battery chemistries that have the best potential for second-life applications. In addition, the report investigates how regulations for recycling might impact the market for second-life batteries. The report addresses this by providing information from the literature based on future demands and projections for battery chemistries and the status of battery recycling. In addition, relevant industry has been interviewed to gain experiences from the industry and how they anticipate the future of second-life batteries. This report has illustrated that the growing demand for batteries and battery metals may pose challenges in the future where second-life batteries and recycling of batteries can help meet the future demand. Both the concept of second-life batteries and recycling poses some challenges; however, studies show that they can complement each other where second-life can extend the life of the battery, hence giving recycling time to mature. Based on the interview with the industry it was found out that battery chemistry has a minor impact on second-life applications. The most important factors are high volumes of homogeneous batteries of high quality.

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Contents

1 Introduction

Through the Paris Agreement, 195 countries have signed to limit their climate gas emission. The goal is to keep the global temperature increase below 2°C and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels [1]. The transport sector alone stood for 16.5% of the global climate gas emissions in 2019 [2]. Increasing electrification of the transport sector is taking place to reach climate targets. Since the first mass release of Electric Vehicles (EVs) in 2010, the global EV fleet has increased drastically [3].

The car manufacturers typically have an 8–10 year warranty period on their EV batteries. However, there are few connections between the end of the warranty and the actual end-of-life (EOL) of the battery, where many batteries seem to last longer and some towards the lifetime of the car. At EOL, EV batteries usually have about 80% of the initial capacity left [4]. Despite not fulfilling the requirements of an EV battery, the state of health of the battery is still sufficient for other stationary applications. This opens the possibility of using the batteries in a second-life, e.g., providing grid support, increasing self-consumption, and shifting demand to off-peak periods.

This report is made as a part of work package 5 “Techno-economic assessment and use case design” in the “2ND LIFE” project funded by the Research Council of Norway (project no. 320760). This report aims to determine which battery chemistries that have the best potential for second-life application. Additionally, it investigates how recycling might influence the market for second-life batteries. To gain experience from the industry, this report also comprises interviews conducted with relevant industries to include their insights and anticipations on the future of second-life batteries and battery chemistries.

The research questions addressed in this report are:

- Which battery chemistry is most suitable for second-life applications?
- How will regulations related to recycling potentially influence the second-life battery market?
- What are the experiences, opinions, and anticipations from the industry working with second-life batteries?

The rest of this report is structured as follows. In Chapter 2, some common battery chemistries used in the transport sector are introduced before the distribution of batteries and battery chemistries are presented. Chapter 3 discusses the expected battery and battery chemistry outlook for the future. In Chapter 4, the recycling and reuse of batteries are presented. Here, regulations related to recycling and the potential competition with second-life batteries are discussed. The experiences from the interviews with the industry are presented in Chapter 5. Lastly, a conclusion is presented in Chapter 6.

2 Battery Chemistry

There exist multiple different batteries for various applications. In this chapter, we aim to introduce the different types of battery chemistries used in electric transportation such as EVs, buses, and maritime vessels. This chapter will first describe the most common battery chemistries used in electric transportation. At the end of this chapter, the distribution of the battery chemistries and the respective materials used are discussed.

2.1 Battery chemistries used in the transport sector

Battery chemistries refer to the materials used in a battery to store electricity. Different battery chemistries have different characteristics, such as energy density, cost, and performance, which make them suitable for different applications. The most common battery chemistry used in the transport sector is different variations of lithium-ion batteries [5]. These are preferred due to high energy density, long life span, low weight, and relatively low self-discharge. However, some of the battery chemistries can be expensive and can be sensitive to extreme temperatures, making them unstable [5].

In this section, the most common battery chemistries used in EVs are described. This includes the battery chemistries LMO, NMC, NCA, and LFP, which are all different types of cathode materials. In Table 1, an overview of the most common features of the different battery chemistries is displayed. Moreover, cobalt-free batteries and lithium-free batteries are described.

Table 1 Overview of the features of the different battery chemistries, from [6, 7].
*This might differ slightly based on the different NMC battery technologies.

Cathode	**LMO**	**NMC**	**NCA**	**LFP**
Voltage [V]	3.7 (3-4.2 V/cell)	3.6 (3-4.2 V/cell)	3.6 (3-4.2 V/cell)	3.2 (2.5-3.65 V/cell)
Specific energy [Wh/kg]	100-150	150-220*	200-260	90-120
Cycle life	300-700	1000-2000	500	>2000
Thermal runaway [°C]	350	210	150	270

2.1.1 Lithium-ion manganese oxide (LMO)

Lithium manganese oxide (LMO) is a type of lithium-ion battery chemistry that uses lithium manganese oxide as the cathode material. The LMO battery is cobalt-free [8]. This is advantageous since cobalt is regarded as a critical raw material, being a rare element and mostly mined in the Democratic Republic of Congo where there are known challenges with ethical mining [5]. One of the main advantages of LMO batteries is their high stability and safety of the battery. This makes the battery less prone to thermal runaway. LMO batteries are characterized by high specific power but relatively low energy density. This makes the battery able to charge/recharge fast, but the capacity of the battery is low which limits the suitability of the battery for use in Battery Electric Vehicles (BEVs) [8]. On the other hand, LMO batteries have a relatively low cost compared to other battery types and have been used mostly in electric bikes and some BEVs mixed with NMC, such as in the first generation of Nissan Leaf [6, 9].

2.1.2 Lithium Nickel Manganese Cobalt Oxide (NMC)

Lithium nickel manganese cobalt oxide (NMC) is another type of lithium-ion battery, in which nickel is used to increase the energy density of the battery. This makes it suitable for both BEVs and Plug-in Hybrid Electric Vehicles (PHEVs), being able to store more energy per unit of weight [8]. In addition, NMC has a relatively low cost compared to some of the other battery chemistries, while also featuring a long life cycle. There is a development within NMC cathodes, to reduce the cobalt content whilst increasing nickel. One of the disadvantages of having a high nickel share is that the battery becomes more thermal unstable [6].

2.1.3 Lithium Iron Phosphate (LFP)

Lithium iron phosphate (LFP) is another commonly used chemistry in the transport segment. One of the main advantages of LFP batteries is that they are cobalt-free and free of critical materials that are required to be recycled. Additionally, LFP batteries have good thermal stability, resulting in safer batteries. The battery is also superior on life cycle and cost [8]. However, due to the low energy density, these batteries are currently less used in EVs. Nevertheless, LFP batteries are favorable for applications where the size and weight of the battery are less crucial, such as heavy-duty vehicle applications (trucks and e-buses) and stationary energy storage [8, 6].

2.1.4 Lithium Nickel Cobalt Aluminum Oxide (NCA)

Lithium nickel cobalt aluminum oxide (NCA) batteries have the highest specific energy density of all the described battery chemistries [6, 8]. This makes NCA especially adequate for use in EVs. NCA is widely used by Tesla as the preferable battery chemistry [10]. Due to the high energy density of the battery, it has great potential to serve also as a backup source for the power system and for load-shifting applications [8]. Additionally, NCA batteries have long storage calendar life and are considered light weighted due to their high energy density. However, NCA batteries are more expensive and have lower thermal stability compared to the other chemistries [6].

2.1.5 Lithium-free batteries

Lithium is currently not considered a critical raw material. However, to reach the climate goals, the supply from existing mines and projects in construction is only estimated to meet half of the projected lithium demand by 2030 [8]. In addition, most of the reserves for lithium are located outside of Europe, making the EU largely dependent on imports [5, 6]. Lithium-free batteries offer a solution to deal with these challenges. Instead of using lithium, these batteries rely on materials such as zinc, nickel, or sodium-ion. However, a challenge of lithium-free batteries is to reach comparable high energy density.

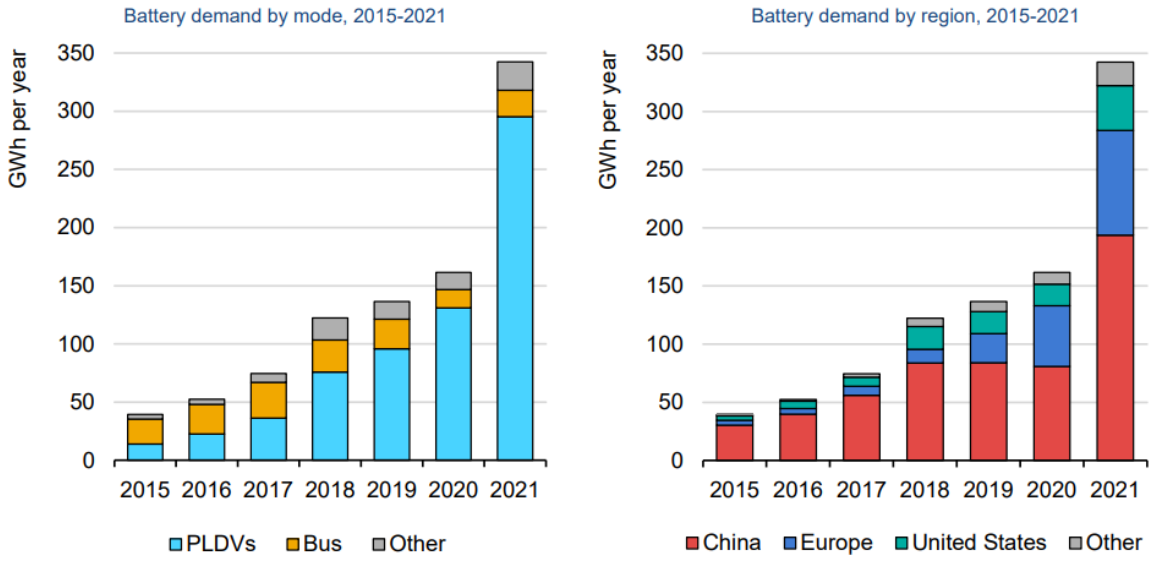
Nickel-cadmium (NiCd), Nickel-Metal Hydride (NIMH), and zinc-air battery batteries could be optional battery chemistries for lithium-ion batteries. However, they are not preferable to use in EVs due to their high weight, low life cycle, and efficiency problems related to charging/discharging [11, 12, 13, 14]. Sodium-ion batteries could potentially be the lower cost option of lithium-ion batteries for use in EVs [15]. A sodium-ion battery is more environmentally friendly than lithium-ion batteries with an abundance of mineral raw materials. However, the complexity increases with sodium-ion batteries, mostly due to the electrochemical behavior of Na, and, in addition, the size and weight of the battery are larger compared to a lithium-ion battery [15, 16]. This makes them more applicable for stationary storage and EVs where the range is less important.

2.1.6 Cobalt-free batteries

As discussed, cobalt is considered a rare element and is on the critical raw material list. In addition, cobalt is mined only in a few places of the world, such as the Democratic Republic of the Congo, which is politically unstable, making the cobalt value chain more vulnerable. Cobalt is an attractive cathode material in batteries due to its high capacity for storing lithium ions [5]. This allows the battery to store a high amount of energy. Additionally, cobalt is a stable material and resistant to degradation. The limitations related to cobalt are the high prices, environmental impact, and the mining and production of cobalt. The demand for cobalt is expected to increase up to 350% by 2050 [17]. Therefore, researchers are working on reducing the cobalt amount in the NMC-cathode, and developing cobalt-free battery chemistries that can provide similar performance as the batteries including cobalt such as NCA and NMC.

2.2 Distribution of battery chemistry and materials

With the transition to a zero-emission transport sector, the global battery demand has increased rapidly over the last couple of years. The global demand doubled in 2021 [18], as can be seen in Figure 1. The sector that experienced the highest increase was EVs (passenger light duty vehicles), however, the battery demand for buses and other transport sectors increases rapidly in line with the transition to become climate neutral. Figure 1 also discloses that China and Europe were responsible for the largest increase in demand for batteries in 2021.



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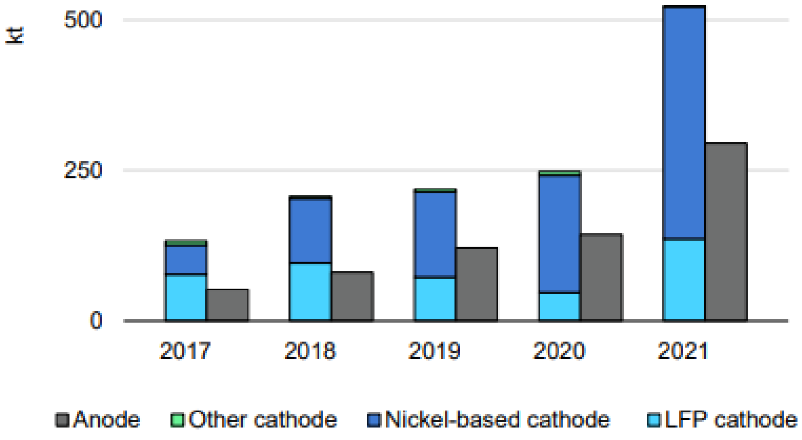
Notes: GWh = gigawatt-hours; PLDVs = passenger light-duty vehicles; other includes medium- and heavy-duty trucks and two/three-wheelers. This analysis does not include conventional hybrid vehicles.
Sources: IEA analysis based on EV Volumes.

Figure 1 Global battery demand from 2015-2021 [18].

In accordance with the increase in global battery demand, the demand for battery materials has increased as well. In Figure 2, the increase in demand for the different cathode materials from 2017-2021 is illustrated [18]. It is mostly LFP batteries and different versions of NMC and NCA batteries that have historically been in demand. The increase in LFP batteries has mostly been related to the increase of EVs in China [3]. Figure 3 illustrates the distribution of different battery chemistries for EU-27, Switzerland, and Norway [19]. The NMC has experienced a significant surge over the last years and was by 2021 the most used battery chemistry. The use of LCO has been constant over the years, being mostly used for consumer electronics such as smartphones, laptops, tablets, and cameras [20]. Compared to the global battery material demand, the increase of LFP in Europe has been minor, however, its lower price, better safety and absence of critical raw materials could be a driver for LFP in the future [18].

The demand for battery metals, especially lithium and cobalt has experienced an increase as seen in Figure 4. For lithium, the highest demand can be seen in the EV sector. There is a similar trend for cobalt, however, there is a large part of cobalt that is used in other battery applications such as stationary storage as well [18].



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Notes: kt = kilotonnes; LFP = lithium iron phosphate. Nickel-based cathode includes: lithium nickel manganese cobalt oxide NMC333, NMC532, NMC622, NMC721, NMC811; lithium nickel cobalt aluminium oxide (NCA) and lithium nickel manganese cobalt aluminium oxide (NMCA).
Sources: IEA analysis based on EV Volumes.

Figure 2 Battery cathode and anode material demand [18].

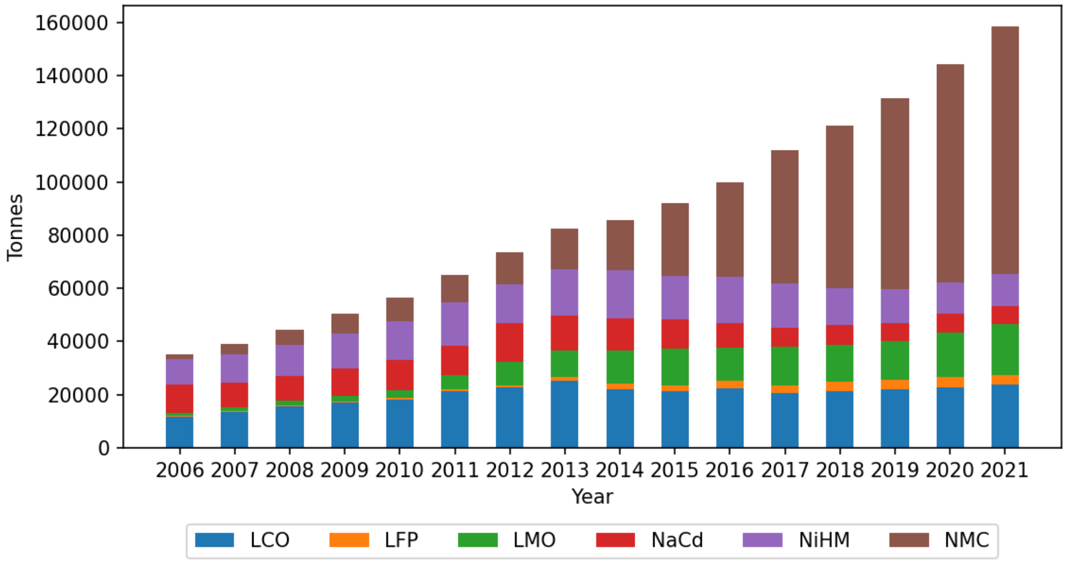
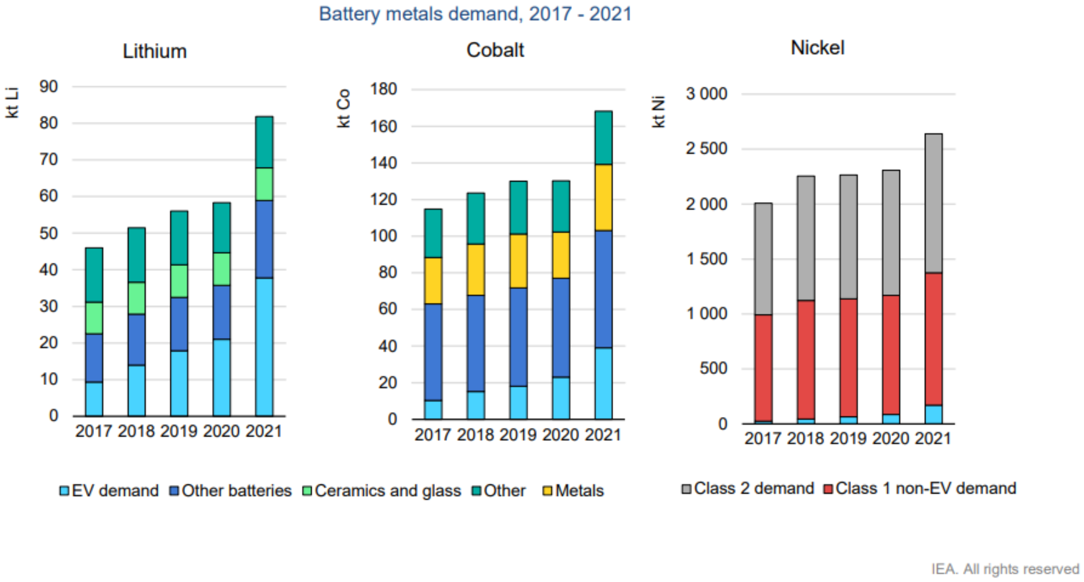


Figure 3 The total weight of batteries placed on the market for each battery chemistry in the EU-27, Switzerland, and Norway from 2006-2021 based on [19].



Notes: Class 1 nickel (>99.8%) is suitable for use in batteries and Class 2 nickel (<99.8%) is not applicable for use in batteries without significant further processing. Other batteries includes: batteries for stationary storage and consumer electronics.
Sources: IEA analysis based on EV Volumes and S&P Global.

Figure 4 Battery metals demand from 2017-2021 [18]. The figure shows the demand for lithium, cobalt, and nickel.

In Figure 5, the main supplying countries to the EU of critical raw materials are shown. The figure illustrates that the main critical raw materials are imported from China to Europe, in which graphite takes the largest share in terms of battery materials [5]. Regarding cobalt, Russia stands for a large share of the supply to the EU (96% from 2015) [5]. The figure illustrates that Europe is highly dependent on the import of battery materials from countries outside of Europe. The European countries stand for less than 30% of the material supply to the EU [21]. Regarding battery materials, Norway is a large supplier of both graphite and silicon materials [5]. EU's dependence on countries outside of the EU, especially Russia and China, could potentially lead to challenges with meeting the growing demand for batteries in the future if, for example, political disagreements occur An example of this is the increase in lithium prices after the Russian invasion of Ukraine. The lithium price increased with close to 300% from September 2021 until November 2022 [22]. Related to the production and reserves of battery materials, most of the lithium production occurs in Australia and Chile, Indonesia stands for a large share of the nickel production, the Democratic Republic of the Congo is the main producer of cobalt, while China is the main producer of graphite [21]

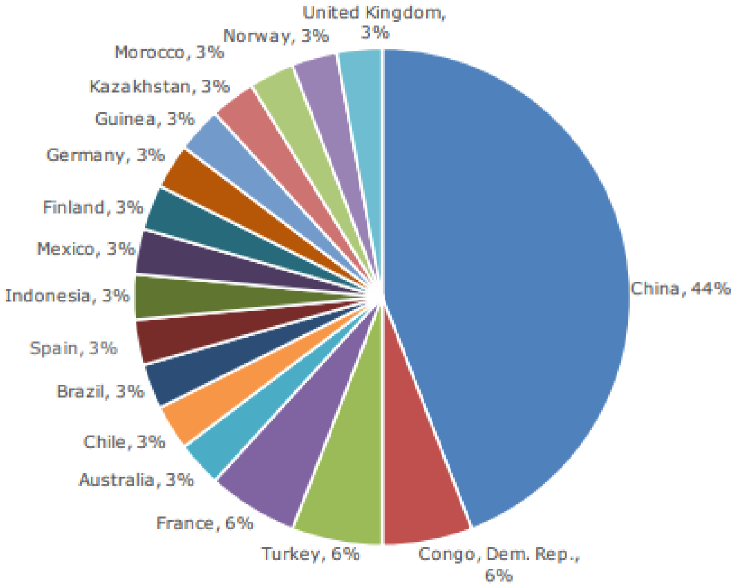


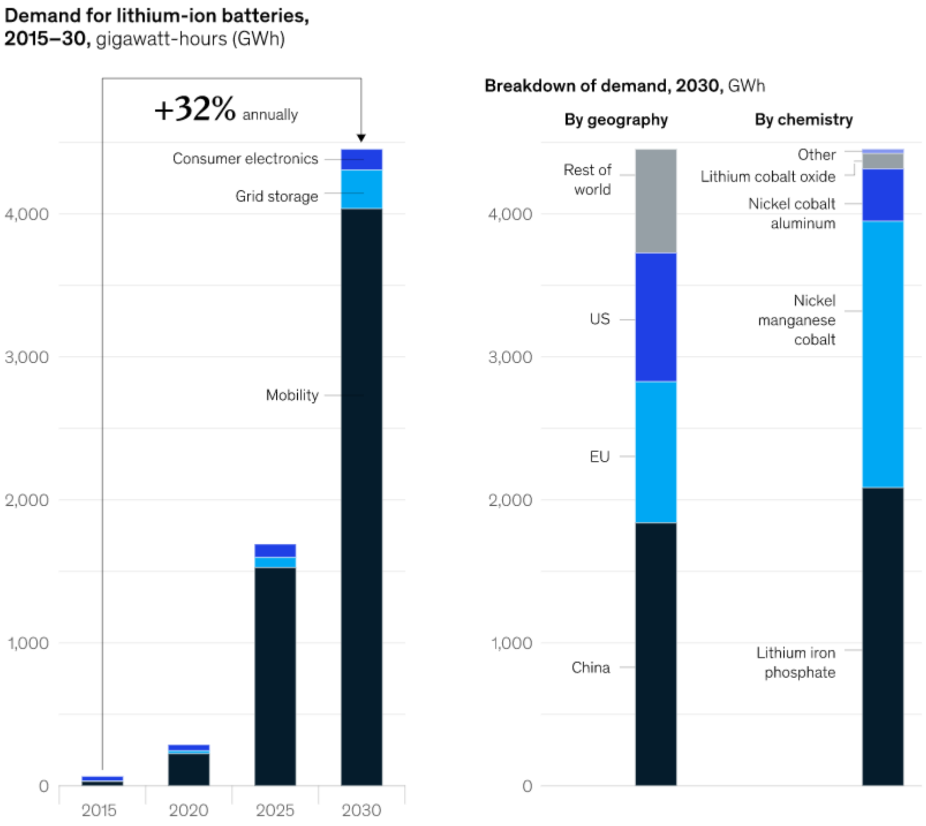
Figure 5 The main suppliers to EU of critical raw materials based on an average from 2012-2016 [23].

3 Battery and battery chemistry outlook

This chapter aims to present the future battery and battery chemistry outlook. The chapter includes an outlook for batteries used in different transportation sectors such as EVs, electrical buses, and the maritime sector. Additionally, the prediction of future battery material needs is presented to illustrate how this might unfold in the future.

3.1 Battery demand outlook

In line with the experienced increase in battery demand, the global battery demand for the future is expected to grow rapidly. In an outlook study conducted by McKinsey, the battery demand is expected to grow by approximately 30% annually towards 2030 [24]. The expected growth in battery demand divided based on application is highlighted in Figure 6. Mobility is the sector with the highest demand for batteries. Figure 6 also discloses the expected battery distribution based on geographical region. From the study, China, Europe, and the US are expected to be the regions with the highest demand for batteries in 2030, which is in line with the battery demand we see today [24].



Source: McKinsey Battery Demand Model

Figure 6 The left figure illustrates the global battery demand distributed based on applications towards 2030. The right figure illustrates the battery demand distributed based on geographical region and by chemistry for 2030 [24].

As seen in the prediction conducted by McKinsey, most of the battery demand is coming from the transport sector. Similarly, the IEA has conducted an outlook for electromobility based on different pathways to electrify road transport towards 2030 [18]. The results show a large increase in EVs, electric trucks, and electric buses, with an average annual growth of over 30%. An outlook on the potential for new energy storage solutions for Norwegian electric vehicles and maritime batteries is conducted in [25]. In the future, the total battery capacity for the passenger vehicle fleet in Norway is estimated to approximately 81 GWh in 2030 and 200-370 GWh in 2050 [25]. Additionally, by including other battery volumes this could exceed 600 GWh in 2050. This gives a total share of BEVs in 2030 of 69-95% based on different scenarios [25, 26, 27]. Related to the electrification of the maritime sector, more than 400 ships with batteries are currently in operation globally and another 135 are under construction and will be finished towards 2027. Here, 46% are hybrid applications and 24% are pure electric [28].

3.2 Battery chemistry and material outlook

As the demand for batteries increase, the distribution of chemistries becomes even more important. IEA has developed two battery chemistry projections for light-duty EVs by 2030[1], as presented in Figure 7. In line with other predictions, such as McKinsey [24], LFP batteries are expected to take a large share of the EV battery market. In the base case, where higher prices for commodities are not considered, the share between NMC and LFP is almost equal.

Moreover, other chemistries with critical raw materials also remain at a high share compared to the constrained case [18].

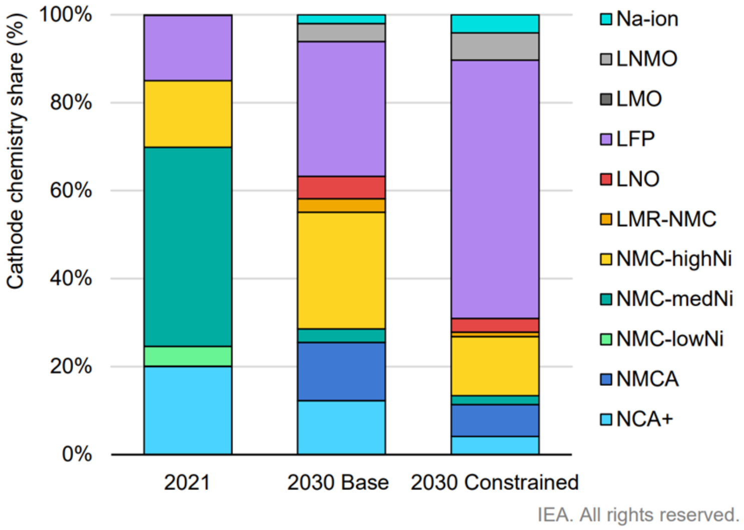


Figure 7 Battery chemistry projections towards 2030 for light-duty vehicles for two different cases[1] [18].

In another study conducted by McKinsey, the projection of material demand is compared to the expected material availability in 2030 [29]. The "2030 base scenario" is based on existing material capacity and new sources under development that will be available soon. In Figure 8, the material supply in 2021, the expected material demand for 2030, and the availability of materials in 2030 following the 2030 base scenario are illustrated for lithium, nickel, cobalt, and manganese. The result illustrates that the expected demand for lithium is 55% higher than the availability of lithium in 2030 following the 2030 base scenario. Additionally, the study shows that lithium demand will increase rapidly in the following years with an annual growth of 25-26% [30]. To meet the lithium demand, new projects for mining and focus on smart and efficient technology choices for the batteries of the future are required [29].

For the other materials, the demand and availability are more manageable, and for cobalt, the availability is higher than the demand. This is mainly due to cobalt-based batteries being substituted by LFP batteries [29]. The demand for manganese is expected to stay relatively constant, but there are some uncertainties.

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[1] Base Case, optimal allocation of chemistries to appropriate use-cases and recent price movements are considered. Constrained Chemistry Case, high commodity price in relation to strong reactions to the prices by the car manufactures are considered [18].

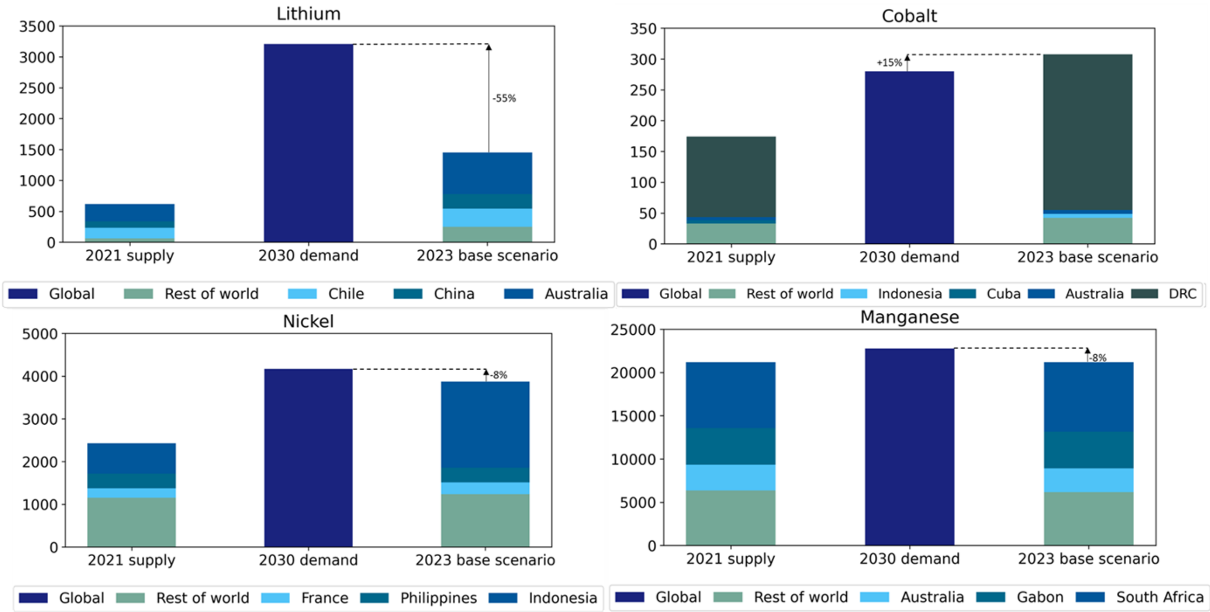

Figure 8 The global lithium carbonate, cobalt, nickel, and manganese demand for 2030, 2021 supply, and expected raw material availability in 2030 for different countries in ktonnes based on [29].

4 Recycling and second-life of batteries

When a battery reaches its EOL as an EV battery, manufacturers have several options related to the battery, 1) the battery can be disposed of, 2) valuable metals in the battery can be recycled, or 3) the battery can be reused in another application where the battery is given a second-life. This chapter aims to discuss the recycling and reuse of batteries in a second-life application. First, the concept of circular economy is introduced. Second, the recycling of batteries and regulations implemented by the EU related to the recycling of critical raw materials are presented. Third, the concept of second-life is described. Here, applications for second-life batteries are presented and the safety aspect related to the reuse of batteries is introduced.

4.1 Circular economy

In a circular economy, the aim is to increase the lifespan of products by repairing, upgrading, and reuse of the product, and in the end the product is recycled. In Figure 9, the circular battery value chain of BEVs is displayed. The figure illustrates the five stages of the value chain: 1) design and manufacturing of the battery, 2) the use of the battery in first life, 3) diagnostics and refurbishment of the battery where the health of the battery and remaining capacity are investigated to see if the battery can be reused or not 4) reuse of the battery if the health of the battery is good, including second-life, and 5) recycling of the battery [31].

This chapter focuses on the two last steps of the circular battery value chain, second-life, and recycling.

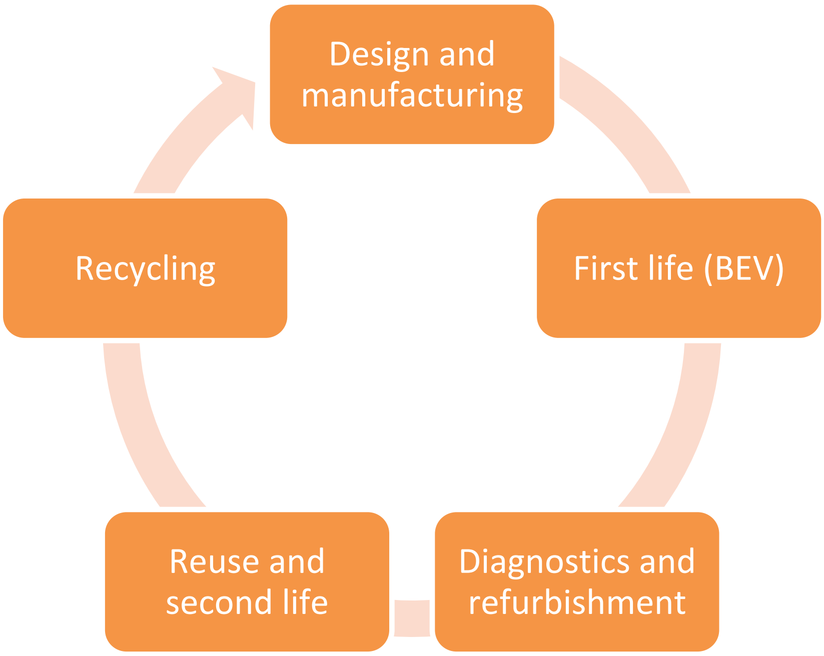

Figure 9 Circular battery value chain of BEVS [31].

4.2 Recycling of batteries

Based on the circular battery value chain, recycling is the end-of-life process where the aim should be to recycle as much material as possible that can be used in new applications. One great encouragement for recycling battery metals is to meet the future demand and by that decrease the demand and supply matching problem that is expected to occur for some of the battery metals [32]. In addition, by increasing the recycling rate of cobalt, the dependency on the few mining places of cobalt can be decreased. This section aims to present the current and future state of battery and battery metal recycling.

4.2.1 EU regulation for more sustainable batteries

Through the European Green Deal, the EU strives to make strategies to solve climate and environmental challenges across policy areas [33]. One of the ambitions is to have a climate-neutral EU by 2050. In 2022, the EU agreed on a new law for more sustainable and circular batteries [34]. Through this law, the EU aims to assure the sustainability of the batteries through their entire lifecycle, including laws for the production, recycling, and repurposing of batteries. The law highlights some important regulatory frameworks for recycling batteries that will apply from 2025 [34]. The regulations include; portable batteries recycling targets of 63% in 2027 and 73% in 2030, recycling of batteries from transport of 51% in 2028 and 61% in 2031, and minimum levels of recovered battery minerals from manufacturing and consumer waste of 16% for cobalt, 85% for lead, 6% for lithium, and 6% for nickel that must be used in new batteries [34, 35]. Additionally, all collected batteries must be recycled and collected free of charge for end-users. This law is initiated because of the expected growth of batteries towards 2030.

EU proposes new regulation for all batteries with a capacity over 2 kWh to have a "battery passport" [35]. The battery passport should include information about the materials used in the battery, energy and emission associated with the production, performance characteristics of the battery, and instructions for a safer and more environmentally friendly disposal if the battery [36]. Through the battery passport program, a global reporting framework of the battery value chain, a digital ID for batteries containing data and description of the batteries, a digital platform for collecting and exchanging data, and a quality seal for batteries, will come in place [36]. This will among others increase the transparency, create standardized frameworks, and give more information about the battery value chain.

Related to the reuse of batteries, there are no clear regulations. However, the EU encourages reuse of batteries, and that this should be arranged for.

4.2.2 Battery materials at End-of-Life and recycling rate of batteries

Table 2 shows estimates of the EOL recycling rates and the recycled content rates for common battery metals today. The recycling rate applies for all applications that uses these metals, not only batteries. The EOL recycling rate is the percentage of the metal that is recycled by EOL, while the recycled content rate gives the percentage of new content of the specific metal that comes from recycled materials. By investigating lithium, both the EOL recycle rate and the recycled content rate are very low. The reason for is the technical difficulty and cost of recovering material suitable for recycling [13]. For cobalt, the recycled content rate is not higher due to the metal's wide use in EVs where pure cobalt is needed, meaning that currently recycled cobalt is not used in EVs [13].

Table 2 Illustrates the EOL recycling rates and the recycled content rates for different metals, based on numbers from 2011-2021 [13, 37] (this is not only from batteries).

Mineral	End-of-life recycling rates	Recycled content rates
Cobalt	68%	32%
Copper	43%-53%	20%-37%
Lithium	<1%	<1%
Nickel	57%-63%	29%-41%

In [13], a study has been conducted to investigate the impacts on the recycling of different metals. The result from the study is illustrated in Figure 10 where the impact of recycling on the demand for cobalt and lithium for 2050 following the 2-degree scenario by IEA[2] is highlighted. By assuming that 100% of cobalt is recovered at EOL, the recycling content of cobalt will reach 47% by 2050. This reduces the cumulative demand for primary cobalt by 15% [13]. However, as addressed, there are technical difficulties with using recycled cobalt in battery technology. Regarding lithium, if 60% of lithium is recovered at EOL, this increases the recycling rate of lithium to 39% by 2050 and will result in a decrease in cumulative primary demand for lithium by 26% [13].

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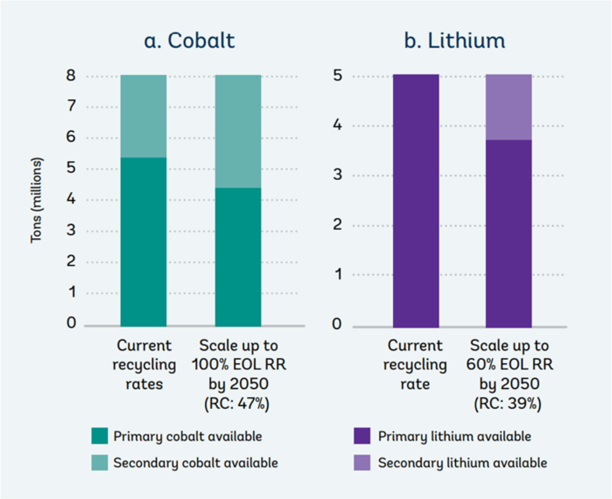
[2] The 2-degree scenario by IEA aims to follow a rapid decarbonization pathway following the international policy goals with at least a 50% chance of limiting the average global temperature increase to 2°C by 2100 [38].



Note: 2DS = 2-degree scenario.

Figure 10 Impact of recycling on cumulative demand for cobalt and lithium for 2050 based on [13] under a 2-degree scenario (2DS) by IEA[2] [38]. RR: recovery rate, RC: recycling rate.

In [39], a study on the battery value chain towards 2030 is conducted. As a part of the study, the value of recycling batteries is included. In 2030, the study expects 54% of end-of-life batteries to be recycled. With this EOL recycling rate, 7% of the battery metal demand can be met with recycled metals. However, this means that the recycling capacity must be increased by a factor of 25 in 2030 compared to today. China is expected to contribute with the largest share of battery metal recycling in 2030 [39, 40]. In addition, large shares of EOL batteries are exported to China. Today there exist more than 50 companies, most located in China, South Korea, the EU, Japan, Canada, and the US, that recycle lithium-ion batteries on some scale [40].

4.2.3 Recycling of batteries and battery metals

The largest economic value of recycling lithium-ion batteries lies in recovering the metals in the cathode which stands for 90% of the total value [41]. Today, cobalt, steel, nickel, aluminum, and cobber are recycled whereas magnesium and lithium are rarely recycled, lowering the benefits of recycling [39]. The recycling processes performed today are not flexible enough to deal with the variability of input chemistries, impurities in the battery, differences in battery composition and cell format, and new market developments [41]. One of the main problems with the recycling of lithium-ion batteries is the potential hazard which can be split into electrical hazards, fire and explosion hazards, and chemical hazards [42, 43]. There is an electrical hazard connected to the stored electric energy and high voltage of the battery. The fire hazard is especially connected to the recycling process of large lithium-ion batteries and the reaction products from the battery [39]. Toxic gases from decomposition create chemical hazards [42]. These hazards create obstacles to economic recycling practices. [39] In addition, there are challenges connected to scalability, standardization, and simplification of treatment steps in the recycling process [41].

Recycling processes are currently costly and carbon-intensive and in need of improved recycling technologies where more materials can be recovered at higher quality [39, 44]. In regions where a necessary recycling market structure is absent, disposal of the battery packs is frequent if the packs are damaged [45]. However, in most regions, preventive regulations are in place for mass disposal. Additional challenges related to the recycling of batteries are the process quality and inefficient processes, shifts in market supply, operational challenges including access to battery materials, and immature technologies which results in low yield [29]. Regulatory incentives and sustainability goals could push the recycling companies to improve their recycling processes, and, in the future, the battery manufacturers may find some new opportunities in recycling as the market matures [29]. The viability of recycling relies mainly on the cost and handling of the battery. In particular, more efficient processes are needed to improve the economic and environmental viability of recycling [46]. This will be especially important for the extraction of cobalt to enable usage in new electric vehicle batteries.

4.3 Second-life of batteries

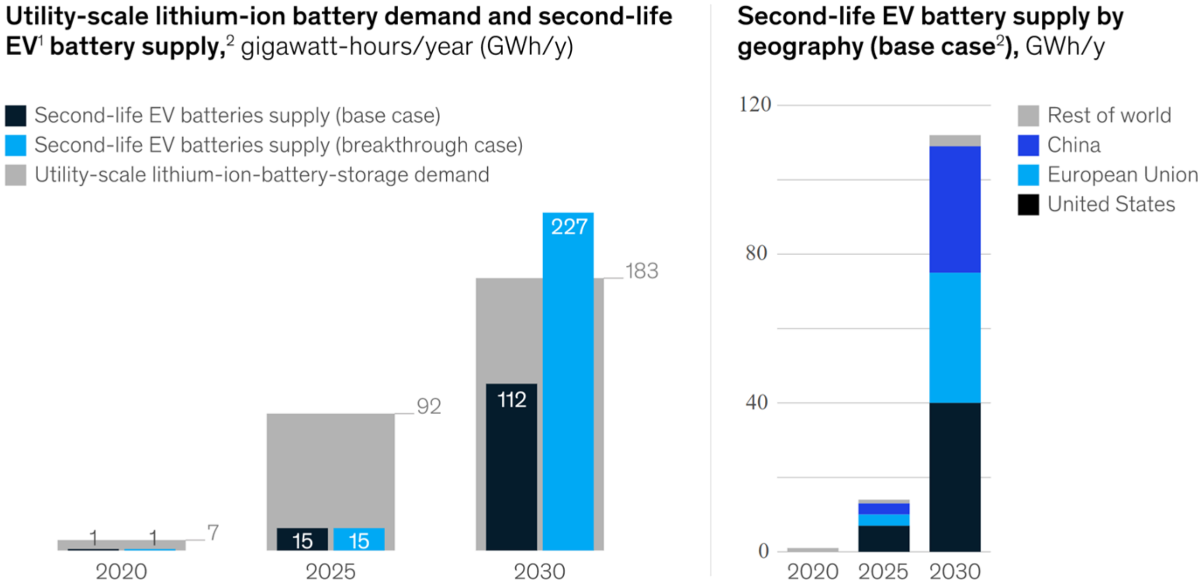
Second-life batteries are used batteries that have been repurposed for a new application after their initial use. The EOL of a first-life battery varies based on which application the battery provides for. For batteries used in the transport sector, there are high requirements for battery performance which means that the state of health of the battery can still be adequate for second-life purposes. An EV battery is assumed to reach EOL as a first life battery when there is approximately 80% capacity left in the battery, assumed to be after around 10 years [4, 45]. However, this might change based on multiple factors such as driving style, charging style, usage patterns, climate, and technical specifications of the battery [31, 4]. For the Nordic countries, studies have seen that the EVs are in operation for a longer period [47]. Depending on the remaining capacity of the battery when reaching end of first life, the battery can either be reused in another EV with a lower range, be reused in a stationary application as a second-life or be recycled.

When considering a battery for second-life, the performance, condition, and remaining capacity of the battery are important factors. These factors help to decide if the battery is suitable for a second-life, including both performance, safety and reliability, and for which applications [39, 44]. Reusing batteries in a second-life improves the economic value of the battery by extending its lifetime [39, 48]. In addition, second-life batteries can help to reduce the need for new batteries.

4.3.1 Availability of batteries at EOL for second-life and recycling

In a study conducted by McKinsey it is predicted that with the rapid increase of EVs and the expected large growth of EVs in the upcoming years, the potential for second-life batteries from the EV sector could exceed 200 GWh by 2030 [45]. This is also in line with other predictions where the potential battery capacity from second-life batteries is estimated to be in the span of 112-1000 GWh by 2030 [44]. By comparing this to the expected battery demand for grid storage in 2030 which is approximately 250-300 GWh [24] (Figure 6), the second-life batteries could potentially contribute to meet this demand significantly.

The expected growth of second-life batteries from the predictions conducted by McKinsey is illustrated in Figure 11 [45]. The results show that by following their most optimistic case, the breakthrough case, the volume of second-life batteries from EVs will exceed the demand for utility-scale stationary storage applications in 2030. However, following the base case, only 60% of the demand is reached. To reach a similar situation as illustrated in the breakthrough case, multiple challenges in repurposing EV batteries must be overcome. This is, for example, the lack of standardization in the EV battery industry and falling cost of new batteries [45]. In Figure 11, the second-life battery supply per region is also illustrated towards 2030. The result illustrates a large increase in supply in 2030 compared to 2025, with almost equal supply between China, the EU, and the US.


Utility-scale lithium-ion battery demand and second-life EV[1] battery supply,[2] gigawatt-hours/year (GWh/y)

Second-life EV battery supply by geography (base case[2]), GWh/y

[1] Electric vehicle.
[2] Only for batteries from passenger cars.

Figure 11 The left figure illustrates the potential second-life batteries towards 2030. The right figure shows the second-life battery supply by region for the base case [45].

According to a projection conducted in [18], only a small amount of the battery metals will be reused in second-life batteries in 2030. The degree of secondary production from recycled metals is greater. Nevertheless, the share of recycled metals in total demand is minimal, with less than 1% for both lithium and nickel. Based on this study, the demand for cobalt and lithium for batteries is not expected to be met in any of the cases.

The Nordic countries, especially Norway, are far along with the sales of EVs and a large increase in EVs is expected in the upcoming years [47]. A study conducted by the Nordic Council of Ministers presented a projection[3] of how EVs in operation before 2018 might enter the second-life and recycling markets [49]. The result is illustrated in Figure 12. According to this result, a notable rise in battery recycling and second-life is expected to occur in 2026. Recycling is expected to experience the highest growth, while the curve for batteries to second-life is flatter. Moreover, batteries entering the second-life market is expected to be recycled from 2032, indicating a 5-year expansion of lifetime. Consequently, the potential lifetime of an initial EV battery could exceed 20 years.

For the Norwegian market, a projection on the capacity of EOL batteries distributed based on battery chemistry has been conducted by the Institute of Transport Economics (TØI) [50]. In 2030 the available capacity for second-life in Norway could reach 2 GWh. Related to battery

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[3] The projection is based on an expected tonnage of batteries and information from experts in the industry [49].

chemistry, in 2030 most of the available battery capacity for second-life is expected to be NMC batteries. In [25], the potential for second-life in Norway is described in more detail.

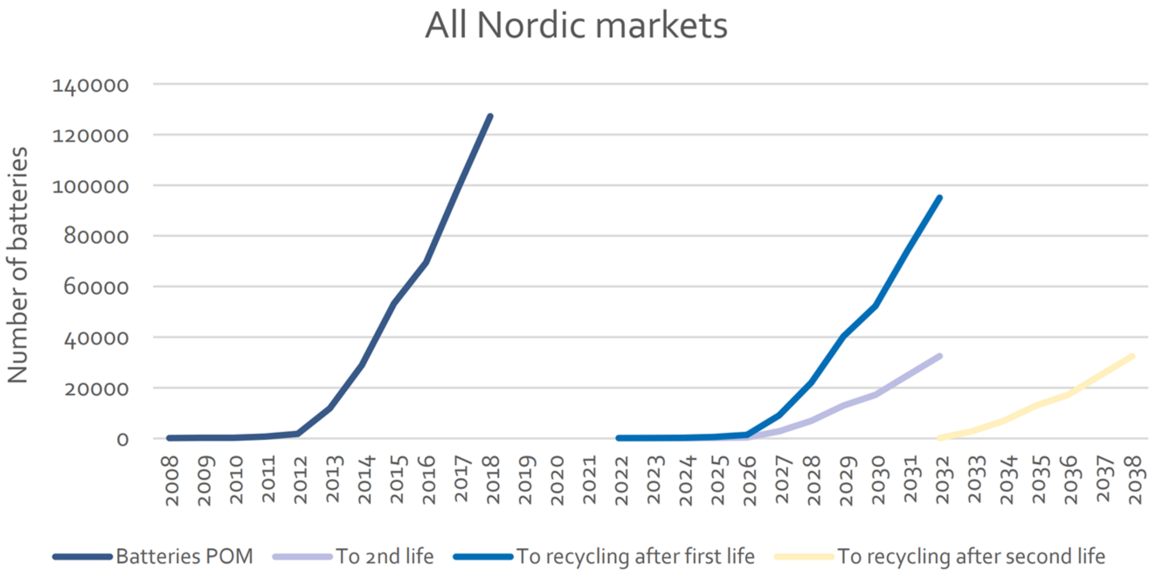

Figure 12 The figure illustrates how the batteries placed on market (POM) up until 2018 might enter the second-life and recycling market in the Nordic countries [49].

4.3.2 Challenges and safety concerns of second-life batteries

Several challenges exist related to the reuse of batteries in a second-life. The first challenge is related to the dimensioning of the battery. A given EV battery is designed to best fit a given car, which might give the battery an unsuitable design for other applications. Car manufacturers each have their own design for the EV batteries, giving a lack of standardization [45]. This makes it both costly and labor intensive to test the batteries at EOL for reuse [44]. In addition, it is challenging to receive homogenous battery packages of high standard that can be used in second-life applications.

Additional challenges with second-life batteries are related to high transaction costs, lack of information about remaining battery health, and uncertainties related to the safety and performance of the second-life batteries compared to new batteries [39]. The hazard associated with second-life batteries is similar to the hazards for first-life batteries such as thermal stability, toxic gases, and self-heating as discussed in Section 4.2.3. However, an additional safety concern related to second-life batteries is the effect of aging on thermal stability. This is difficult to predict and will require more testing of the battery cells [44].

Lastly, the competitiveness of second-life to new batteries is essential. The expected falling cost of new batteries creates an uncertainty related to the viability of second-life batteries. For second-life batteries to be profitable, it is important that they can compete both in price and give sufficient warranties for battery performance [45].

The second-life market is expected to increase sharply in the upcoming years [40]. However, it is difficult to predict how the market will unfold due to lack of regulation, information, and data about the market and few available batteries since most of the batteries applicable for second-life are still in their first-life [44, 45]. There are already initiated target actions to overcome the challenges associated with second-life batteries [45], such as designing the battery to be suitable for second-life, having a system for collecting batteries at EOL, and working on standards for second-life batteries. A variety of global agencies are currently investigating industry-wide second-life battery safety standards which might help classify storage applications based on their performance needs [45].

4.3.3 How can recycling influence the second-life market?

In this report, we have discussed and presented both the recycling and reuse of batteries. Since both methods are performed after first EOL, it is expected that some competition can occur between the two options in the future. The EU regulation related to the recycling of battery metals could put a strong lead on where many of the batteries end up after first-life. However, as discussed, the collection and recycling of batteries are costly, and the recycling rate of the critical raw materials currently used in new EV batteries is low. Moreover, the recycling industry in Europe is limited compared to China, South Korea, and Japan [44]. In addition, the current low recycling rates combined with reduced amount of cobalt used in new batteries will result in a lower value of recovered materials [46]. The viability of the recycling industry is therefore dependent on high shares of critical minerals in the batteries, as well as more efficient processes to achieve economies of scale [45]. Additionally, with the increase of other battery chemistries without critical raw materials, such as LFP batteries, the process of increasing the recycling for recovered lithium will be important to meet the future battery demand.

With the predicted increase in batteries reaching first EOL in the near future, a boost in the second-life market could occur in European countries if the recycling industry is not mature enough to meet the demand. However, lack of regulations in the second-life market could lead to differences between countries on whether recycling or second-life is the preferable choice for the batteries at EOL [45]. Moreover, not all EV batteries will be suitable for re-use when reaching first EOL, e.g., due to low residual capacities or damages to the battery [50].

An obstacle for car manufacturers to invest in the second-life market is the poor system of controlling where the battery ends up after its first-life [40]. After the battery is sold in an EV, the owner of the EV is not required to send the battery back to the car manufacturer unless there is an agreement in place. This means that the owner can sell the battery to the highest bidder. To better enable a second-life industry, battery companies could create a closed-loop system, including collection, repair of the batteries, reuse, and recycling [29]. The lack of standardization is an additional obstacle for the second-life industry [45].

While second-life batteries offer a great solution for stationary battery applications, they are not able to reduce the demand related to battery electric vehicles. Following the battery outlook, the global demand is mainly driven by the transport sector. This could potentially increase the need to recycle EOL batteries, to free more materials for use in the transport sector.

Figure 13 displays a projection on the number of batteries placed on the market up to 2018 that could be available for recycling based on different scenarios[4] [49]. The result illustrates that fewer second-life batteries result in an increase of batteries available for recycling, which

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[4] High reno scenario assume the BEVs to last longer than average, the high 2nd life scenario expects a quick increase of second-life batteries with starting levels of second-life at 70% for EVs and 80% for electrical buses. And the low 2nd life scenario assumes a slower adaption of second-life [49].

could be expected. In the high second-life scenario, the number of batteries recycled reach about the same level, but with a 6-years delay. This could be beneficial as it allows the recycling industry to mature as well as prolongs the lifetime of the batteries as recycling is predicted to contribute significantly to supply in the long term [18]. Based on this, second-life will both prolong the lifetime of the battery and give a great number of batteries for recycling.

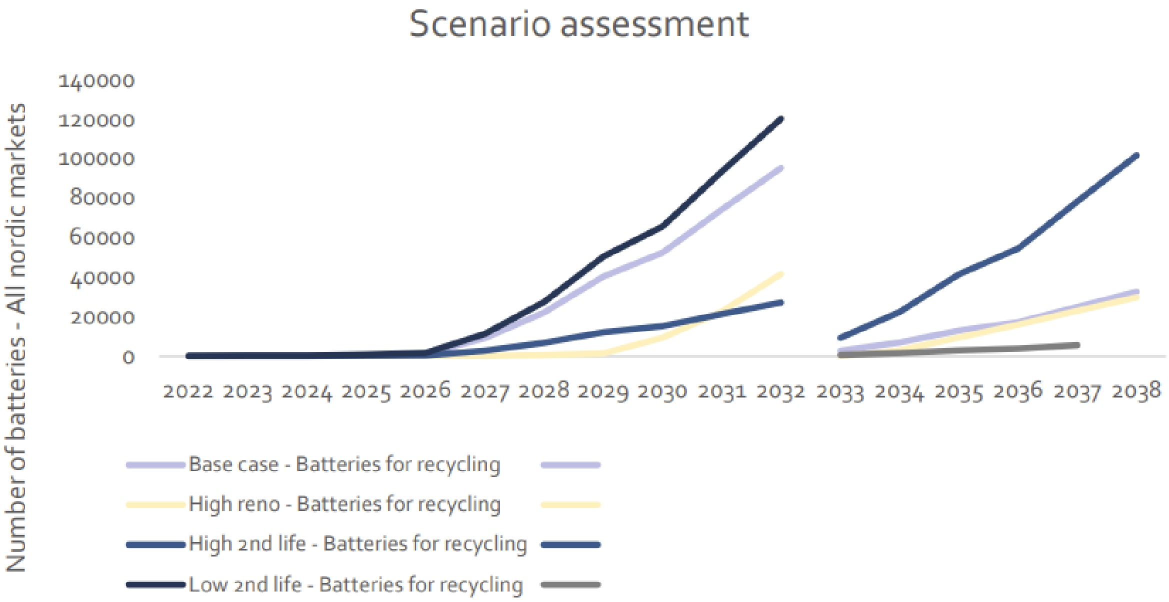

Figure 13 Illustrates how batteries placed on the market up to 2018 will become available for recycling based on different scenarios [49].

Currently, it is expensive to recycle batteries, especially in Europe [49]. There is a short-term trade-off with battery recycling, however, analysis shows that life extension of the battery through reuse and second-life would be more environmentally beneficial and could be preferable over immediate recycling [39]. By prolonging the lifetime of the battery, the maximum economic value of the battery could be extracted. In addition, technological advances, improved methods for monitoring and testing of the second-life batteries will enable individual characterization of the batteries which makes it easier to find the most suitable application of the battery in a second-life [46]. This could lead to a longer lifetime, safer second-life batteries, and increase the market value before the battery is recycled in the end. When discussing if the batteries will end up in recycling or second-life applications, the cost seems to be a dominant factor. If the owner of the battery and the industry can see a current future value in holding on to the battery or reusing it, it is not that probable that the battery is recycled at once [49]. On the other hand, strong regulations related to recycling could force batteries to be recycled after their first-life.

5 Experiences from the industry

In this report, we have interviewed four relevant companies working with batteries, battery management systems, and second-life batteries and applications. The interviewed companies are ECO STOR with Mathias Winther Thorsen, Hagal with Fredrik Ringnes and Une Tjøm, Evyon with Jørgen Erdal, and Corvus with Rambabu Kandepu and Kristian Thorbjørnsen. At the interview, the different companies were asked questions related to the list:

- Do you see any differences between various battery chemistries?
- Do you find any battery chemistries more suitable for second-life applications than others?
- Do you experience any challenges related to batteries and battery chemistries?
- How do you see combination systems and mixing combinations of different battery chemistries?
- How are you testing the batteries?
- Are you developing BMS and if so, how does it function?
- How do you get hold of the batteries?
- What are the differences in batteries coming from EVs, electric buses, and boats?
- How do you predict recycling of batteries might influence the second-life market?
- How do you see the future of second-life batteries, business models, costs, and the market?

The questions varied slightly based on the answers from the companies and their competence. In this section, we will summarize the gained experiences from the interviews with the different represented companies before a general discussion follows in the end. It is important to emphasize that the interviews portray the experiences, opinions, anticipations, and beliefs of the interviewed companies. The depictions presented in this chapter are, therefore, based on the information obtained from the company, which is subject to uncertainties.

5.1 Interview with ECO STOR

ECO STOR was established in 2018 and develops technology for energy storage solutions using second-life batteries from electric vehicles. The company has an agreement with Nissan where they receive batteries that have reached their EOL as an electric vehicle battery or for some reason do not meet the requirements to be used as a battery in a vehicle. Due to the agreement with Nissan, ECO STOR is mostly receiving LMO and NMC batteries. Despite focusing on EV batteries, ECO STOR also emphasizes the high potential for marine and bus/truck batteries for second-life applications. The batteries used in buses and ships are usually larger and more compact, increasing the opportunity of receiving a greater volume of homogenous batteries for second-life applications. Lastly, there are higher requirements for batteries that are to be used in buses and ships, and hence the batteries are likely taken out at a higher SOH compared to EV batteries.

The batteries received by ECO STOR are not opened and rebuilt but are kept as they are and assembled with other batteries into a larger battery system consisting of multiple batteries. The batteries are tested before being assembled into battery systems. This is either done by the manufacturer or by ECO STOR themself. The battery is tested to evaluate the health of the battery and the remaining life. A challenge is often to receive information about the battery from the supplier, especially if the vehicle has been used for leasing or comes from recycling stations or scrapyard. ECO STOR address that the size of the EV battery pack is not necessarily ideal for being placed in a second-life battery system. The old Nissan Leaf batteries are large and shaped to fit into a car, not being stacked with other batteries to fit a limited space. However, since the batteries ECO STOR is working with are old, the design of newer batteries might be more suitable for stacking.

ECO STOR develops battery chemistry-neutral technology. They have not experienced any significant difference between the various battery chemistries in relation to their technical capabilities for second-life applications. Often, the second-life batteries are operated with low power, where the temperature of the battery is within 20-25 degrees and well within any voltage limits. ECO STOR emphasizes that the battery chemistry can be of higher relevance when the application draws a lot of power and operate outside of the ideal temperature range. This could be the case when the batteries are used in the frequency marked since the batteries should deliver a high amount of energy in a short period of time, resulting in the heating of the batteries. However, usually, the batteries have time to cool in between operations in the frequency marked. Using a powerful cooling system is also an alternative solution to prevent heating.

5.2 Interview with Hagal

Hagal was established in 2018 and they develop smart battery solutions and battery management systems. Hagal creates full-stack battery energy solutions from modular storage systems to smart energy management software. The company has mostly been working with Korean batteries, such as batteries from the car manufacturers Honda and Kia with battery cells developed by LG and SK, and the car models Opel Ampera, and Chevrolet Bolt. These are mainly NMC batteries. They also expect an increase in NMC batteries from Korea that later can be used for second-life. Hagal also receives batteries from the factory that do not meet the requirements of the car industry. Like ECO STOR, they can also receive batteries from scrap dealers and recycling stations. Hagal has not considered hybrid electric vehicles (HEVs) or researched batteries from heavy-duty vehicles, buses, or boats. However, they emphasize that these batteries will likely be available for second-life at a more frequent rate than EV batteries, as they experience more cycles per time unit in their first-life application. Additionally, there is a potential for using batteries from electric bicycles, but the market is still rather small. At this point, Hagal has not needed large volumes of batteries since they are focusing on developing their BMS.

Different from ECO STOR, Hagal breaks down the battery package into single modules. The battery modules are then tested to evaluate the health of the battery cells in each module. After the battery modules are tested, the battery pack is assembled with the battery modules that meet the requirements. As of now, Hagal develops and sells the control system of the battery packages that can provide single-cell control. This means that the BMS can control how much energy can be taken out of a single cell in a battery, and even turn off a specific cell. From Hagal's perspective, the format of the battery is more relevant than the battery chemistry. Since they open the battery and take out the modules, small batteries with many cells like Tesla batteries are more complicated than larger batteries such as the many brands using larger prismatic battery cells.

Hagal considers all EV batteries, no matter the chemistry, to be beneficial to use in second-life applications. Like ECO STOR, Hagal also emphasizes that battery chemistries can make a difference if the battery is operated closer to the battery limits where the thermal boundaries and voltage values are exceeded. In the end, the most important factor is the energy output and temperature, and they are, therefore, more or less indifferent to the battery chemistry. For the future, Hagal anticipates an expected growth in LFP batteries until potentially new chemistries are developed since LFP batteries are free of critical raw materials.

5.3 Interview with Evyon

Eyon was established in the fall of 2020 as a response to the quickly growing volumes of discarded EV batteries. Evyon repurposes second-life EV batteries where they develop technologies for reassembly and operations to convert usable second-life batteries into modular plug-and-play battery storage systems. Evyon has an agreement with Mercedes Benz Energy, from which they receive NMC battery modules.

The battery modules received by Evyon are approved for second-life by Mercedes Benz Energy. Some of the batteries they receive come from EVs and some from batteries that do not meet the requirements of the car industry due to e.g., faults in production, or batteries that have been stored too long and have expired as an EV battery. Evyon only receives modules, and hence they do not open the batteries themselves. When assembling the battery modules in battery racks, Evyon uses batteries with the same chemistry. Additionally, Evyon delivers a BMS to the battery rack systems with algorithms for smart control which can be used in multiple different applications.

Evyon is working with NMC batteries, which are mostly chosen due to large volumes. However, they want to expand to other chemistries where LFP is considered a great option as these are expected to increase in volume. Additionally, LFP batteries are suitable for stationary applications as they are cheap, safe, and have long cycle life. For mobile applications, NMC batteries are more suitable since they have higher energy density compared to LFP and are therefore physically smaller. An advantage seen by Evyon is that NMC and LFP batteries are similar in operation and can use the same power electronics, making it easier to design a system. They believe that second-life batteries in commercial buildings and industry have greater potential than in private households. There are several reasons for this, for example, it is difficult to match the second-life EV batteries against household applications due to the voltage level, it is a challenge to get access to this market since large volumes need to be delivered, and there is a higher awareness of safety aspects related to second-life batteries for private households. Evyon is less interested in hybrid batteries because of their low energy density and second-life applications usually do not require high power output. However, they are interested in expanding to bus and boat batteries if they get a great volume of homogenous batteries. Higher requirements for batteries in boats pave the way for high second-life potential. Evyon does not plan to work with all types of batteries but rather focuses on a specific battery type and size, taking a part of the market that match their expertise and volume.

5.4 Interview with Corvus

Corvus was founded in 2009 and develops maritime energy storage systems and hydrogen fuel cell systems. They buy the battery cells from suppliers, where they build battery modules from the battery cells and create the associated BMS. Corvus mostly works with different types of NMC batteries. However, they have recently started to use LFP batteries for BlueWhale products. Additionally, they are investigating non-lithium batteries for the maritime sector. For second-life purposes, Corvus emphasizes that second-life batteries will be more application-dependent than chemistry dependent. The first use of the battery and the EOL lay the basis for which application the battery can be used for in a second-life. Additionally, they emphasize that basic safety requirements need to be in place for both first-life and second-life batteries and safer batteries might be more applicable for second-life such as LFP batteries.

The use of batteries in the maritime sector is still in an early stage, where most batteries started their first life in 2015-2017. With an expected lifetime of about 10 years, most of the batteries are still in their first life. Corvus has therefore not experienced any systems that have completed their lifetime loop as maritime batteries yet. They anticipate that this situation will change in a few years. Currently, Corvus is not selling and working directly with second-life batteries, as they do not receive enough battery cells to create second-life batteries. However, they take part in second-life projects to initiate work on second-life batteries and to get new knowledge on the topic. Additionally, they are working on characterizing the SOH of used batteries to compare them to new batteries to gain experience with the battery characteristics.

Maritime batteries have an advantage in terms of safety compared to EV batteries. If there is one cell in the battery that causes problems, the module with the cell can be taken out of the battery pack and replaced compared to the whole battery pack in an EV. Consequently, the battery system is designed such that if one cell experiences a thermal runaway situation, it will not be propagated to the neighboring cells, which may not be the case for EV systems. Additionally, the battery system in maritime vessels is installed using multiple modules making it easier to take out, transport, and put together into new battery packs Moreover, using similar battery modules results in a high volume of homogeneous batteries that have the same current and cycling after EOL, making it easier to create stationary storage solutions in a second-life application. This could especially be applicable for larger battery packs such as stationary batteries used for grid support. The applications in the maritime sector are diverse where some batteries are used for high-power applications that typically have an EOL at 90% initial capacity and other applications that require high energy where EOL is at 70-60% of the initial capacity. This gives different timelines for the batteries and could also give indications as to which second-life applications the batteries are suitable for. Corvus emphasizes that it will be important to map the different applications for second-life to find the most suitable purpose for the different maritime batteries.

5.5 Discussion

The interviewed industries all work with different approaches towards batteries and second-life batteries where they develop different system solutions and focus on different levels in the batteries. Some work at the cell level such as Corvus and Hagal, others at the module level such as Evyon, and some work with the whole battery package such as ECO STOR. All the companies work with developing a BMS system for the battery solution they sell where they aim to control the battery at the cell level to use the battery more efficiently and give a more homogenous behavior of the cells in the battery packages. The most consistent battery chemistry used by the companies is NMC. However, ECO STOR is currently mostly selling second-life batteries of LMO. This might change in the future when newer vehicles with other chemistries reach their EOL, where all companies believe that LFP will be a common battery chemistry in the future.

From the interview with the industry, it seems that the choice of battery chemistry has minor influence on most second-life battery applications. The battery chemistry might have a larger impact if the batteries are operated close to thermal limits and voltage boundaries. However, the industry emphasized that cooling could act as an alternative solution to enable such operational conditions, rather than limiting the battery chemistry based on this. The companies agree that the most important factor is to receive a great volume of homogeneous batteries. This is especially important for Hagal, Evyon, and Corvus which work on modules and cell level of the batteries where they need similar battery modules or cells to assemble a battery pack. Hence, the companies agree that batteries from boats and heavy-duty vehicles are interesting and could be beneficial to receive multiple homogenous batteries which are good for stationary large batteries.

Second-life is still an early-stage concept. The industry is uncertain about how the future will develop for second-life batteries, but there is a common consensus that they will be an important part of the battery value chain. There exist different practices between the companies related to warranties on second-life batteries with a typical span of 2-10 years. However, they emphasize that the lifetime, performance, and security of the battery are the most important factors and also a challenge to define when considering second-life batteries. Regulation for certification and responsibility of second-life batteries should come in place to make second-life batteries more competitive against new batteries. Additionally, second-life batteries need to be competitive against new batteries both in price, lifetime, performance, and safety.

The competition for used batteries will likely be high, and they believe that the batteries will be sold to the highest bidder. Currently, there exists no regulated market for the selling of used batteries, which might result in the export of used EVs, including the battery, over country borders.

The companies emphasize that some incentives should be in place for second-life batteries to become more profitable., they underline that using batteries in a second-life extends the lifetime, resulting in the battery metals being used longer before recycling and for recycling to become more mature during the second-life of the batteries. Related to the competition between second-life batteries and recycling, the strict regulation in EU for recycling could lead to more batteries going to recycling after EOL. However, the high demand for batteries might increase the demand for second-life batteries. The companies believe that more LFP batteries could potentially boost the second-life market since the chemistry does not include any critical raw materials. Additionally, requirements for sustainability and carbon footprint can be a driver for the second-life batteries.

6 Concluding remarks

This report has investigated which battery chemistries that have the best potential for second-life applications and how recycling might influence the market for second-life batteries. The report has systematically described the battery chemistries most commonly used in electric transportation, presented the distribution, and predicted the future outlook for battery chemistries and metals. Currently, NMC batteries are the most used battery chemistry. However, in the future, LFP batteries are expected to be one of the dominant battery chemistries, mostly caused by China’s frequent use of LFP batteries in electric buses and EVs. The demand for batteries is expected to grow rapidly towards 2030 and 2050. In line, the demand for battery metals is also growing. Lithium is one of the battery metals that most likely will experience a high demand in the future that could be challenging to meet. Recycling of batteries at EOL could be a solution to meet the future battery metal demand, however, the methods are expensive, complex, and technically difficult resulting in low recycling rates, especially for lithium.

To enable the second-life market it will be important to create regulations, standardization, and a good system of control to reduce uncertainties in the market. Additionally, second-life batteries need to compete against new batteries in price, performance, and stability. This is potentially something the battery passport regulation could help to solve. This will increase transparency and available data, which will make it easier for the second-life industry to find suitable batteries and to make adequate battery systems for different applications.
Recycling could potentially influence the second-life market in some manners; 1) the owner of the battery gets a financial gain when selling the battery to recycling, 2) regulations and laws for recycling could push the batteries directly to recycling, 3) the challenges in the second-life market related to standardization and safety could lead to batteries suitable for second-life ends up in recycling, and 4) second-life batteries due mostly only contribute to meet the battery demand for stationary battery applications where recycling might be needed to meet the total battery demand. However, recycling and second-life can potentially fit together. When batteries are used in a second-life, it prolongs the lifetime of the battery, while giving time for the recycling processes to mature. Additionally, not all batteries are suitable for second-life, then these batteries could go directly to recycling while the suitable could be used in a second-life application. This would contribute to the circular economy.

Based on interviews with relevant industries, the battery chemistry is anticipated to have minor influence on most of the second-life battery applications. The batteries coming from the transport sector is usually batteries of high standard, that fit well for second-life applications. However, they emphasize that it is important for them to receive large volumes of batteries, as well as homogenous batteries. Furthermore, they emphasize the importance of being able to ensure the lifetime, performance, security, and good prices of their second-life batteries to compete against new batteries. Additionally, policies, incentives, and regulations, especially related to certification of the second-life batteries, should come in place to boost the second-life market.

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