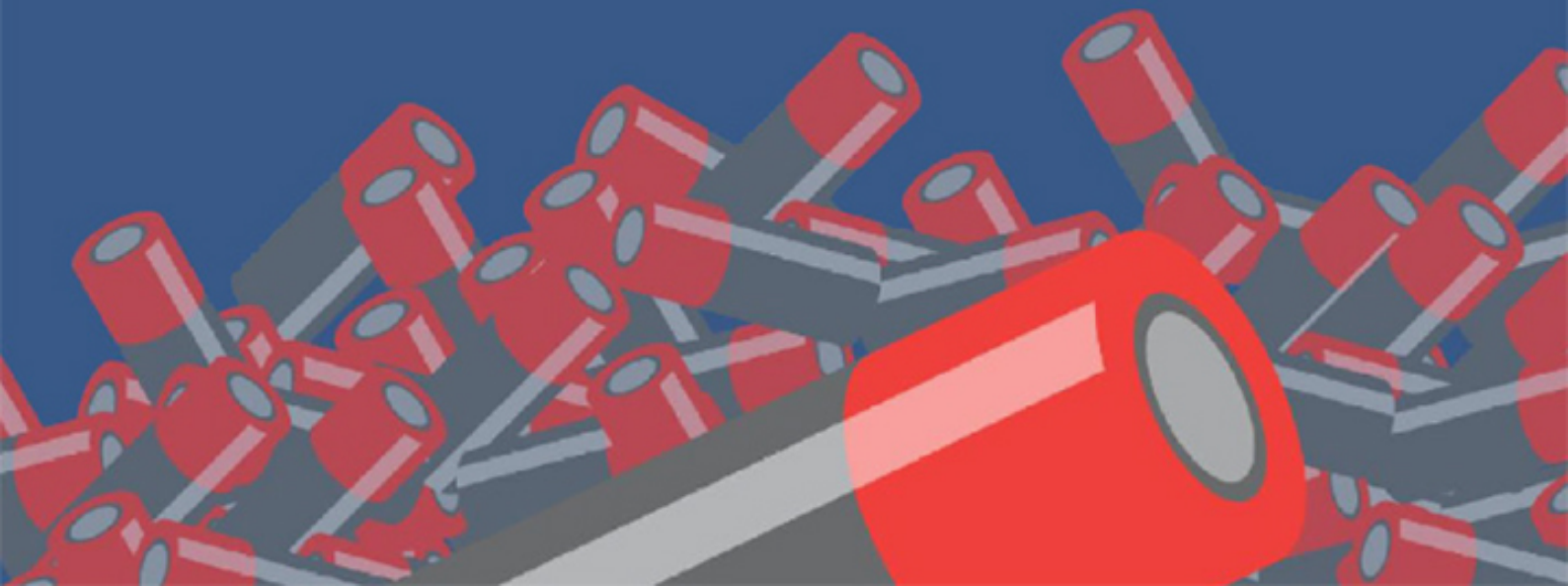


Batteries in the Nordics – Changing for Circularity



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This publication is also available online in a web-accessible version at <https://pub.norden.org/temanord2022-523>.

Executive summary – English

Introduction

The overall aim of this project is to promote the Nordic countries as a forerunner region in demanding and using sustainable design of consumer electronics, and to identify key opportunities, barriers and challenges in the transition towards a more sustainable use of battery technologies, including the transport sector. The aesthetics of the design should meet with the overall sustainability: high quality, durability and smart assembly for refurbishing.

The project is funded by the Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers. The project has been carried out by Viegand Maagøe A/S (Denmark) and IVL Swedish Environmental Research Institute (Sweden) in the period 20 October 2020 to 31 December 2021.

A reference group with representatives from the Nordics has been established, who provided valuable input to the study.

Legal framework and relevant initiatives

EU legislation and initiatives have a direct or indirect influence in the Nordics on batteries and the products containing batteries.

The **proposed new battery regulation** to replace the Battery Directive is expected to become an important driver for the circularity of batteries and for minimising the negative environmental impact of batteries. The current Battery Directive applies to all batteries placed on the market within the European Union and establishes objectives and targets (e.g. on collection and recycling); specifies measures (such as phasing out mercury or establishing national schemes for collection) and enables actions (e.g. reporting or labelling) to achieve them.

The directive has been the EU's best tool in ensuring recycling and beneficial environmental handling of batteries on the European market and have therefore also impacted the Nordic Member States' handling of batteries. Still, the directive does not ensure that all batteries are properly collected and recycled at the end of their life, increasing the risk of releasing hazardous substances and wasting valuable and critical resources. Also, the existing directive does not fully grasp the intentions of the circular economy. Therefore, a new battery regulation was proposed repealing the existing directive to better reflect circularity, improve sustainability, and keep pace with technological developments.

The proposed Battery Regulation (published on 10 December 2020) includes:

- introduction of a new category of electric vehicle batteries, alongside the existing portable, automotive and industrial battery classes;
- progressive requirements to minimise the carbon footprint of EV batteries and rechargeable industrial batteries: a carbon footprint declaration requirement,

applying as of 1 July 2024, complemented by classification in a carbon footprint performance category and related labelling (as of 1 January 2026); and a requirement to comply with maximum lifecycle carbon footprint thresholds (as of 1 July 2027);

- a recycled content declaration requirement, which would apply from 1 January 2027 to industrial batteries, EV batteries and automotive batteries containing cobalt, lead, lithium or nickel in active materials. Mandatory minimum levels of recycled content would be set for 2030 and 2035 (i.e. 12% cobalt; 85% lead, 4% lithium and 4% nickel as of 1 January 2030, increasing to 20% cobalt, 10% lithium and 12% nickel from 1 January 2035, the share for lead being unchanged);
- minimum electrochemical performance and durability requirements for portable batteries of general use (applying from 1 January 2027), as well as for rechargeable industrial batteries (from 1 January 2026). The Commission would assess the feasibility of phasing out non-rechargeable portable batteries of general use by the end of 2030;
- a new obligation of battery replaceability for portable batteries; safety requirements for stationary battery energy storage systems;
- supply chain due diligence obligations for economic operators that place rechargeable industrial batteries and EV batteries on the market. For this requirement on responsible raw material sourcing (as well as for those related to the carbon footprint and the recycled content levels), the Commission proposal envisages mandatory third-party verification through notified bodies;
- increased collection rate targets for waste portable batteries, excluding waste batteries from light means of transport (65% by the end of 2025, rising to 70% by the end of 2030);
- as regards recycling efficiencies, increased targets for lead-acid batteries (recycling of 75% by average weight of the lead-acid batteries by 2025, rising to 80% by 2030) and new targets for lithium-based batteries (65% by 2025, 70% by 2030). The proposed regulation also envisages specific material recovery targets, namely 90% for cobalt, copper, lead and nickel, and 35% for lithium, to be achieved by the end of 2025. By 2030, the recovery levels should reach 95% for cobalt, copper, lead and nickel, and 70% for lithium;
- requirements relating to the operations of repurposing and remanufacturing for a second life of industrial and EV batteries;
- labelling and information requirements. From 1 January 2027, batteries should be marked with a label with information necessary for the identification of batteries and of their main characteristics. Various labels on the battery or the battery packaging would also provide information on lifetime, charging capacity, separate collection requirements, the presence of hazardous substances and safety risks. Rechargeable industrial batteries and EV batteries should contain a

battery management system storing the information and data needed to determine the state of health and expected lifetime of batteries. This system should be accessible to battery owners and independent operators acting on their behalf (e.g. to facilitate the reuse, repurposing or remanufacturing of the battery);

- the setting up, by 1 January 2026, of an electronic exchange system for battery information, with the creation of a battery passport (i.e. electronic record) for each industrial battery and EV battery placed on the market or put into service;
- envisaging of the development of minimum mandatory green public procurement criteria or targets.

The **Ecodesign Directive** establishes a framework for setting ecodesign requirements on energy-related products such as household appliances, consumer electronics and information and communication technologies. In recent years, a set of resource efficiency requirements have been implemented in the Ecodesign product regulations including requirements on disassembly for repair and reuse and for products' built-in batteries. These include the regulations on computers and on enterprise and data centre servers and storage products and proposed requirements in the working documents for smartphones and tablets. These requirements can be highly relevant for circularity of the batteries themselves and also for extending the lifetime of the products using built-in batteries due to longer battery lifetime and possibility for easy replacement of the batteries.

Green Public Procurement (GPP) criteria for computers, monitors, tablets and smartphones include requirements for built-in batteries related to product lifetime extension, energy consumption, hazardous substances, end-of-life management and refurbished/remanufactured products. Setting such requirements to batteries should create an economic incentive to produce and sell batteries with a longer lifetime. GPP also provides incentives to produce batteries with a high endurance and quality by making sure they are tested according to international standard i.e. EN 61960-3:2017.

Other relevant legislations include:

- The Waste Electrical and Electronic Equipment (WEEE) Directive
- EU List of Waste
- The Regulation on shipments of waste
- The Regulation on CE marking
- The Restriction of Hazardous Substances (RoHS) Directive
- The Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
- The EU Conflict Minerals Regulation

Additional to the legislative initiatives, important other initiatives include the 2021 Industrial Strategy Update, where one strategic area is lithium-ion batteries (LIBs); and the Strategic Action Plan to develop a European battery value chain embracing raw materials extraction, sourcing and processing, battery materials, cell production, battery systems, as well as re-use and recycling. Furthermore, the European Commission supported the establishment of the The European Battery Alliance (EBA).

Finally, EU has funding schemes for research, pilots, demonstrators, scale-up and roll-out in batteries, such as Horizon 2020, Horizon Europe, the Innovation Fund and Important Projects of Common European Interest (IPCEI).

Today's practice regarding lithium-ion batteries

Production

LIB production is very complex and involves several steps, from mining to battery pack production. Extraction of metals occurs in different parts of the world; however, China is currently dominating cell production including cathode and anode production. Some raw materials are critical (high supply risks and very economic important) for EU including cobalt, graphite and lithium.

Metals are mined for the cathode and they are refined to sulphates or in the case of lithium, sometimes used as hydroxide. After mining and refining, the active cathode material is produced. The extraction of metals is highly impacting the environment and people working and living near the extraction sites. The battery cell is constructed with the anode, cathode, electrolyte, separator, plastics, steel, copper and aluminium. The cathodes are made of different chemistries depending on the application and the anode is usually based on graphite with the exception of LTO chemistry.

The trends for coming years for the battery chemistries in products is not only relevant for the raw material required at the production, but also for the volumes of batteries entering recycling. This is because the chemistries determine the amount of specific raw materials (e.g., cobalt and nickel), which can be recovered.

There is much research going on for new chemistries, and the main drivers are energy density increase to increase the range for cars, to reduce costs and to reduce the need for critical raw materials such as cobalt.

The key market sectors in the EU for LIBs are automotive and to a smaller extent portable device. The growth for markets sold in each market in the coming 10–15 years will probably mainly be on the automotive side. Sales for pure electric (BEV) passenger cars are dominating the growth. Other important products - which are growing considerably up to 2030 - are passenger car PHEVs, busses, and LCV (light commercial vehicles). Also batteries in power tools and tablet and smartphones have been sold more and will continue to increase until 2030.

Use

The main use is for automotive application and the second largest use is for portable devices, assuming that the pattern seen in Europe also applies for the Nordics.

For some usages, for example for power tools, high power and thus high C-rate (high current) is needed from the battery, but the energy storing capacity may be lower. Since it varies how much time people use the tool per use, the battery is often one-dimensional for private use.

For portable batteries for portable electronics such as smartphones, laptops,

tablets, loudspeakers, the batteries are built-in and laymen often may not be able to replace them; especially for waterproof products.

Especially for replaced automotive batteries, typically, the batteries still have energy capacity left, which give opportunities for refurbishment or remanufacturing and achieving a second life in vehicles or in other application e.g. for energy storage in buildings or as electric grid support. As long as there is a market and a value of these second life batteries, a larger part of the technical lifetime of the batteries are likely to be achieved before scrapped.

For EV batteries, it is common to send for a second life for industrial or commercial energy storage. In Sweden for example, many used EV batteries are sent to the real estate market and used in the rooftops of buildings to store energy produced by solar panels. For electronic devices, the main approach currently is to fully replace the batteries with new ones rather than to repair old batteries.

End of life

After the user is no longer using the product and wants to scrap it, the ownership of the battery becomes of high importance. The Extended Producer Responsibility (EPR) for batteries means that the company placing the batteries on the market is responsible for their collection when they are scrapped by the consumer.

There are no legal requirements for the owner of a battery to send it for recycling when it is no longer used by the consumer, which is why many end-of-life batteries for consumer electronics may stay in with the original owner for many years instead of getting recycled. For EV batteries, like LFP batteries, batteries may be disassembled from buses and left in storage indefinitely until a purpose for them is found.

Many small batteries are not collected for battery recycling because they are integrated into the device and cannot be disassembled. They may therefore end up in electronic (WEEE) recycling instead where there is only little chance for the battery metals to be recycled.

EV batteries are supposed to be removed during the pre-treatment process to comply with the ELV Directive (Directive on end-of-life vehicle), and the percent of batteries for which it takes place should be high as it directly correlates with the stock available for the recycling industry.

Recycling

There is a lot of variation when it comes to recycling between what types of recycling is performed and what actors are involved. Even within the bigger recycling categories, such as hydrometallurgy or pyrometallurgy, there can be major differences in how companies perform the recycling. Differences that different actors in the recycling chain choose may include: what metals and other materials are recovered, what percentage of cobalt/nickel/lithium/manganese are recovered, what type of solvents are used in hydrometallurgical recycling and what type of pretreatment is done.

The main categories of recycling today are hydrometallurgical or pyrometallurgical with subsequent hydrometallurgy. Both have different pros and cons with regard to costs, recovery efficiency, flexibility/adaptability to different battery chemistries, the need for a disassembly step, and energy use.

Pyrometallurgy means heating of batteries to smelt the metals while hydrometallurgy uses acids or bases for dissolving them. But first dismantling of parts and other pre-treatments need to be done. For hydrometallurgical recycling knowledge about the cathode chemistry is important why it is recommended to clearly mark the battery with this information, perhaps with electronic tags to facilitate sorting.

In battery recycling, the chemistry of the electrodes matters, especially the cathode. Most of the value is found in the cathode, which is where valuable metals such as cobalt, nickel, and lithium are found. Mobile phones, tablets and computers use Li-ion batteries with high-quality Co content (>12%), and this high Co concentration means that it is profitable both for the producers of these products and the recyclers to try to recycle the metals in these batteries. On the other hand, tool batteries usually contain around 6%, which is why it is not as profitable to handle (recyclers typically do not pay for these batteries but charge a fee for recycling them).

Currently, the volumes of batteries are not sufficient for hydrometallurgy of black mass in the Nordics. There are also other challenges that have to be overcome for a functioning LIB recycling.

The current battery directive does not place specific limitations on the recycled content of lithium-ion batteries, meaning that recyclers would usually recycle the easiest-to-recycle or most valuable materials. The proposal for the new regulation will likely require recyclers to introduce different methods of recycling in order to adjust the percentage of metals which are recovered.

One problem when reducing cobalt in the batteries is that the value for the recycler is reduced. LFP is therefore not recycled at all in Europe at the moment. This obstacle may be mitigated by the proposed battery regulation with its proposed recovery rates of cobalt, lithium and nickel as well as the proposed recycled contents in the production of new batteries. The proposed directive will also force the companies in the battery supply chain to be more transparent regarding ensuring recyclability (enabling disassembly).

Sustainability of batteries

Some may consider sustainability as another wording for environmental development, while others also consider the economic and social impacts. However, regarding batteries, it is important to consider all aspects of sustainability, as battery technology is a key cornerstone in the green transition towards a fossil-free society by replacing products, appliances, and transport means that requires fossil fuels.

It is important to consider all aspects of sustainability, which is in line with the Sustainable Development Goals (SDGs) that aims to: "ensure all human beings can enjoy prosperous and fulfilling lives and that economic, social, and technological

progress occurs in harmony with nature." Sustainability and sustainable development are often referred to as the three Ps (People, Planet, and Prosperity).

People: There are significant social and environmental consequences in connection with the extraction of several of the raw materials in lithium-ion batteries, particularly regarding conflict minerals. Minerals are considered conflict minerals if they are sourced from politically unstable areas and where the minerals trade can be used to finance armed groups, fuel forced labour and other human rights abuses, and support corruption and money laundering. There are several primary raw materials used to manufacture lithium-ion batteries, which can have adverse impacts on its entire value chain. Cobalt is the most problematic raw material of all listed raw materials, as it is mined mainly in countries with poor regulation and disorganized small-pits i.e. mining by hand using rudimentary and basic tools, often without adequate protective equipment. Over 50 percent of the world's cobalt is mined in the DRC (Democratic Republic of the Congo).

Planet: Batteries impact the environment both positively and negatively and environmental impact affects people. Both the pros and cons need to be considered in connection with the increased demand for different types of batteries to avoid rebound effects. The greenhouse gas emissions of producing a battery is about the same as the rest of the car itself, and thus the greenhouse gas emissions from production of an electric car are about twice as much as they are for a car that runs on only an internal combustion engine. In other impacts categories, it is clear that an electric car also produces significantly higher emissions of other types during the production.

Prosperity: Many of the Sustainable Development Goals aim to improve various areas related to the environment, people, and economic opportunities. Economic opportunities aim to provide decent work such as safe working conditions, living wages, compassionate leadership, and economic growth for those in specific communities. From a more strictly company perspective, the economic part is, of course, important. If a company has a deficit, it cannot continue to operate unless it somehow makes a turnaround. A company can focus on social and environmental impacts, but if they do not make any money, they cannot continue their liveable work (social and environment).

To ensure sustainability, the solution must be economically viable. Previously, companies were focused on profits obtained through a linear business model where higher sales equalled higher profits. The high-speed automatic assembly favours linear business models. Sustainability is a business approach to creating long-term value by considering how a given organization operates within the three Ps (People, Planet and Prosperity).

Sustainability is built on the assumption that developing such strategies foster company longevity. Without a focus on sustainability, it can be questioned how long the company can continue to operate as the expectations on corporate responsibility increases. Transparency becomes more prevalent, and more companies recognise the need to act on sustainability. Professional communications and good intentions are no longer enough as green claims are investigated, and greenwashing will hurt the reputation of the company.

Without a broad focus on sustainability, it may become increasingly difficult for companies to compete in the market. These considerations may increase the focus

on the Nordics as a suitable place for production, as the green energy supply can help companies fulfil their sustainability goals and increase their market value.

Key barriers towards increased circularity today

Though there are numerous possibilities and advantages to the circular economy, still several barriers limit the increase in circularity. Key barriers include:

- **Company culture**, which often can be a major obstacle regarding shifting from a well-established linear economy to circular economy, changing the mindset of consumers, involving full-life-cycle collaboration, and changing mindsets within companies.
- Lack of **circular design** opportunities especially within the electronics and batteries due to the complexity of small components and compact products, which makes dismantling tricky for the recyclers or refurbishers and because batteries have varying dimensions, forms, and compositions of chemicals and metals, making it challenging to establish an efficient standardised system for battery recycling.
- Lack of **legislation**, which can inhibit CE, however the Nordics and EU are still ahead due to national regulation and coming EU legislation on batteries.
- Lack of **consumer interest and awareness** because some consumers simply like new items before their old ones are worn out, which is particular for trend-based, hi-tech and fast-paced products, such as mobile phones, which discourages manufacturers from making robust and more expensive products, as there is less market demand for such product for some product segments.
- **Low raw material prices** because the fluctuating price of raw materials, like plastics or metals, hinders the economic incentive for purchasing recycled materials, when there are low raw material prices. This further discourages investments in improving the current recycling systems which could help reducing the prices of regenerated resources. Furthermore, some primary raw materials are subject to subsidies making the market price of recycled materials even more unfavourable.
- **Black battery market and illegal exports**, because between 30 and 40 percent of the EVs are exported before the end of their lives but the degree of illegal export is unknown because data on illegal export of WEEE is minimal. This leads to circularity challenges that include the batteries ending up for recycling in other parts of the world resulting in increased emissions for transportation, less efficient recycling facilities thus lower output quality, and lastly a reduced amount of recycled materials for the Nordic battery production industry.

Best practice and design for increased circularity

In this section, content is provided for separate handbooks for businesses and for consumers on best practice and design for increased circularity. For businesses, inspiration from concrete case examples is provided, while for consumers, advices on what they can do when purchasing and using the products.

For businesses

Many businesses are currently exploring the countless possibilities of working with circularity of batteries and battery-driven products through new business models and improved ways of using the batteries more efficiently. To unlock these innovative business potentials, new practices are needed in procurement, design and production departments. The handbook contains inspiration for businesses for establishing these new practices. The basis for the inspiration topics is an evolution of the Ellen MacArthur Foundation's model, where the focus on business models is stronger.

Five business model types have been explored and case examples have been provided of companies that have adopted these approaches and initiatives that consumers can apply to support the circular economy of batteries. The models cover:

- **Circular supplies** that describe how to support sustainability and circular economy looking upstream in the value chain and demanding sustainable materials.
- **Resource recovery** that describes actions that can ensure reuse and recycling by applying actions downstream in the value chain.
- **Product life extension** that includes all the actions consumers and manufacturers can apply to increase the lifespan of products and components during the use phase.
- **Sharing platforms** that help to decrease the need for products by effectively sharing fewer amenities among more users.
- **Products as a service** where product ownership is never transferred to the consumer thus supporting maintenance, product life extension, and resource recovery.

For consumers

Consumers can support the development towards circularity of batteries and battery-driven products through new business models and improved ways of using the batteries more efficiently via their purchases and at the same time achieve economic benefits for themselves and help protecting the environment.

The handbook describes the principles behind circular design to better understand the following best practice recommendations and suggest what consumers can do via their action at the purchase situation and during use of the purchased products.

Circular ways to buying, using and disposing batteries are presented together with case examples of companies that have adopted circular initiatives within the five business model types described above. The models cover:

- **Circular supplies** that describe circularity in the materials that go into the products.
- **Resource recovery** that describes actions that can ensure reuse and recycling of batteries.
- **Product life extension** that includes all the actions that can increase the lifespan of battery products and components during the use phase.
- **Sharing platforms** that help to decrease the need for products by effectively sharing fewer amenities among more users.
- **Products as a service** where product ownership is never transferred to the consumer thus supporting maintenance, product life extension, and resource recovery.

Policy recommendations

Based on the analyses recommended policy options for the Nordics have been provided on two categories of options:

- Policy recommendations for the Nordic countries to improve circularity of batteries and equipment
- Policy recommendations for the Nordic countries to contribute to creating the needed framework conditions

The policy recommendations for the Nordic countries to improve circularity of batteries and equipment focuses on existing and known technologies, including batteries, through these activities:

- **Adopt the measures from the working documents for smartphones regarding relevant measures for batteries across all product groups containing batteries that fall under the Ecodesign Directive.** One of the most comprehensive sets of measures relevant for products containing batteries is found in the working documents for smartphones, where both ecodesign requirements and energy label are proposed. Adoption of these measures can be a good example to be used when setting or reviewing requirements for other product groups.
- **Create a new metric regarding battery performance, allowing manufacturers a higher degree of freedom to develop the best-suited batteries for the specific application.** Instead of setting requirements on cycles, it could be relevant to develop a metric that calculates the lifetime of the battery, which needs to fit the expected life of the product.
- **Ensure interoperable batteries across product groups with batteries that have many similarities** in order that detachable rechargeable batteries can be used across a range of different products.
- **Support the battery proposal.** The proposed Battery Regulation is quite comprehensive and covering many relevant areas. In the current policy process, the Nordics may discuss internally and with other Member States if common

positions can be reached how it can be supported.

- **Use Green Public Procurement to increase the demand for sustainable batteries**, where the Nordics can suggest the European Commission and the GPP Advisory Group to include batteries in a technical study aiming at setting GPP criteria for batteries.
- **Support a far-reaching review of the Ecodesign directive and push for inclusion of the transport sector**, where the Nordics should push to remove the exemption for means of transport from the Ecodesign Directive - or at least that the exemption should not apply to batteries for means of transport. This can be fed into the current process of Sustainable Products Initiative amending or replacing the current Ecodesign Directive.

Policy recommendations for the Nordic countries to contribute to creating the needed framework conditions focuses on recommendations on what the Nordic countries can do to contribute to creating the right framework conditions for the Nordic countries to be centrally placed in an innovative, sustainable and competitive battery ecosystem in Europe through these activities:

- **Positioning the Nordic countries to benefit from sustainability requirements in the new EU Regulatory Framework for Batteries** proposed by the Commission and expected to be adopted during 2022. The Nordic countries should position themselves to support and subsequently benefit from the expected (i) rules on recycled content; (ii) measures to improve the collection and recycling rates of all batteries; (iii) progressively phasing out non-rechargeable batteries; and (iv) sustainability and transparency requirements for batteries (carbon footprint, ethical sourcing of raw materials, security of supply, and facilitating reuse, repurposing and recycling).
- **Preparing Nordic project developers for participation in the available financial support for European projects demonstrating and scaling up innovative sustainable battery technologies and business models**, which will include making public funding or financing for battery cells manufacturing projects available in order to incentivise, leverage and 'de-risk' private sector investment through Horizon Europe, Invest EU, LIFE and the Innovation Fund in support of innovative battery-related deployment projects.
- **Facilitating Nordic research project participation in the improved European research and innovation funding opportunities for battery technology**, which will include making available, research and innovation funds (Horizon Europe) for battery-related innovation projects and - in the longer term - the launch of a large-scale Future Emerging Technologies Flagship research initiative, which could support long-term research in advanced battery technologies for the 2025+ timeframe.
- **Working with TSOs (Transmission System Operator) and national energy market regulators to ensure that the necessary regulatory framework and pricing mechanisms allow for sustainable battery technology demonstration**

and scaleup for battery technology for decentral storage of intermittent renewable energy. This is on one side essential for the electrification of large parts of the Nordic economies and meeting climate goals by 2030 and 2050 and on the other side provides a range of services which is not currently priced in the market (frequency response, reactive power, provision of system inertia).

Executive summary – Danish

Introduktion

Det overordnede formål med dette projekt er at fremme de nordiske lande som en foregangsregion ift. at efterspørge og bruge bæredygtigt design af forbrugerelektronik, og at identificere nøglemuligheder, barrierer og udfordringer i overgangen til en mere bæredygtig brug af batteriteknologier, herunder transportsektoren. Æstetikken i designet skal gå hånd i hånd med den overordnede bæredygtighed: høj kvalitet, holdbarhed og smart montering for let renovering og reparation.

Projektet er bestilt og betalt af Nordisk Arbejdsgruppe for Cirkulær Økonomi (NCE) under Nordisk Ministerråd. Projektet er udført af Viegand Maagøe A/S (Danmark) og IVL Swedish Environmental Research Institute (Sverige) i perioden 20. oktober 2020 til 31. december 2021.

Der er nedsat en referencegruppe med repræsentanter fra Norden, som har givet værdifulde input til undersøgelsen.

Lovmæssige rammer og relevante initiativer

EU-lovgivning og -initiativer har direkte eller indirekte indflydelse i Norden på batterier og de produkter, der indeholder batterier.

Den **foreslåede nye batteriforordning**, der skal erstatte batteridirektivet, forventes at blive en vigtig drivkraft for batteriernes cirkulære karakter og for at minimere batteriernes negative miljøpåvirkning. Det nuværende batteridirektiv gælder for alle batterier, der markedsføres i Den Europæiske Union og fastlægger formål og mål (f.eks. om indsamling og genbrug); specificerer foranstaltninger (såsom udfasning af kviksløv eller etablering af nationale indsamlingsordninger) og muliggør foranstaltninger (f.eks. rapportering eller mærkning) for at opnå dem.

Direktivet har været EU's bedste værktøj til at sikre genanvendelse og gavnlig miljøhåndtering af batterier på det europæiske marked og har derfor også påvirket de nordiske medlemslandes håndtering af batterier. Alligevel sikrer direktivet ikke, at alle batterier indsamles og genbruges korrekt ved slutningen af deres levetid, hvilket øger risikoen for at frigive farlige stoffer og spilde værdifulde og kritiske ressourcer. Det eksisterende direktiv dækker heller ikke fuldt ud hensigterne med den cirkulære økonomi. Derfor er der foreslået en ny batteriforordning, der ophæver det eksisterende direktiv, for bedre at afspejle cirkulariteten, forbedre bæredygtigheden og holde trit med den teknologiske udvikling.

Den foreslåede batteriforordning (offentliggjort den 10. december 2020) omfatter:

- introduktion af en ny kategori af batterier til elektriske køretøjer sideløbende med de eksisterende for mobilt udstyr, biler og til industrielt formål;
- gradvist forøget krav for at minimere CO₂-fodaftrykket for elbilsbatterier og genopladelige industribatterier: et krav om deklaration af CO₂-fodaftryk, der gælder fra 1. juli 2024, suppleret med klassificering i en

CO2-foraftryksydelseskategori og tilhørende mærkning (pr. 1. januar 2026); og et krav om at overholde maksimale tærskelværdier for CO2-fodaftryk i livscyklussen (fra 1. juli 2027);

- et krav om deklaration af genanvendt indhold, som fra 1. januar 2027 vil gælde for industribatterier, elbilsbatterier og bilbatterier, der indeholder kobolt, bly, lithium eller nikkel i aktive materialer. Obligatoriske minimumsniveauer for genanvendt indhold vil blive fastsat for 2030 og 2035 (dvs. 12% kobolt; 85% bly, 4% lithium og 4% nikkel pr. 1. januar 2030, stigende til 20% kobolt, 10% lithium og 12% nikkel fra 1. januar 2035, idet andelen for bly er uændret);
- minimumskrav til elektrokemisk ydeevne og holdbarhed for bærbare batterier til almindelig brug (gælder fra 1. januar 2027), samt for genopladelige industribatterier (fra 1. januar 2026). Kommissionen vil vurdere gennemførligheden af at udfase ikke-genopladelige bærbare batterier til almindelig brug inden udgangen af 2030;
- en ny forpligtelse til batteriudskiftning for bærbare batterier; sikkerhedskrav til stationære batterienergilagringssystemer;
- forsyningskædens due diligence-forpligtelser for økonomiske aktører, der bringer genopladelige industribatterier og elbiler på markedet. For dette krav om ansvarlig råvareindkøb (såvel som for dem, der er relateret til CO2-fodaftrykket og niveauerne for genbrugsindhold) forudser Kommissionens forslag obligatorisk tredjepartsverifikation gennem bemyndigede organer;
- øgede mål for indsamlingsprocenten for udtjente bærbare batterier, undtaget udtjente batterier fra letvægtstransportmidler (65% ved udgangen af 2025, stigende til 70% ved udgangen af 2030);
- med hensyn til genanvendelseseffektivitet, øgede mål for blybatterier (genanvendelse af 75% af gennemsnitsvægten af blybatterier i 2025, stigende til 80% i 2030) og nye mål for lithium-baserede batterier (65% i 2025, 70% i 2030). Den foreslåede forordning forudser også specifikke materialelegenvindingsmål, nemlig 90% for kobolt, kobber, bly og nikkel, og 35% for lithium, som skal nås inden udgangen af 2025. Inden 2030 bør genvindingsniveauerne nå 95% for kobolt, kobber, bly og nikkel og 70% for lithium;
- krav i forbindelse med genanvendelse og genfremstilling for en anden levetid for industri- og elbilsbatterier;
- mærknings- og informationskrav. Fra 1. januar 2027 skal batterier være mærket med en etiket med oplysninger, der er nødvendige for identifikation af batterier og deres vigtigste egenskaber. Forskellige etiketter på batteriet eller batteriemballagen vil også give oplysninger om levetid, ladekapacitet, krav til separat indsamling, tilstedeværelsen af farlige stoffer og sikkerhedsrisici. Genopladelige industribatterier og EV-batterier bør indeholde et batteristyringssystem, der gemmer de oplysninger og data, der er

nødvendige for at bestemme batteriernes helbredstilstand og forventet levetid. Dette system bør være tilgængeligt for batteriejere og uafhængige operatører, der handler på deres vegne (f.eks. for at lette genbrug, genbrug til andet formål eller genfremstilling af batteriet);

- oprettelse senest den 1. januar 2026 af et elektronisk udvekslingssystem for batteriinformation med oprettelse af et batteripas (dvs. elektronisk registrering) for hvert industribatteri og EV-batteri, der markedsføres eller tages i brug;
- overvejer udviklingen af obligatoriske minimumskriterier eller mål for grønne offentlige indkøb.

Direktivet om miljøvenligt design fastsætter en ramme for fastlæggelse af krav for energirelaterede produkter såsom husholdningsapparater, forbrugerelektronik og informations- og kommunikationsteknologi. I de senere år er der implementeret ressourceeffektivitetskrav i ecodesign-forordningerne, herunder krav om adskillelse til reparation og genbrug og for produkternes indbyggede batterier. Disse omfatter kravene til computere og til virksomheds- og datacenterservere og datalagringsprodukter og foreslåede krav i arbejdsdokumenterne for smartphones og tablets. Disse krav kan være yderst relevante for cirkulariteten af selve batterierne og også for at forlænge levetiden af produkterne ved brug af indbyggede batterier på grund af længere batterilevetid og mulighed for nem udskiftning af batterierne.

Grønne offentlige indkøbskriterier (GPP) for computere, skærme, tablets og smartphones omfatter krav til indbyggede batterier relateret til forlængelse af produktets levetid, energiforbrug, farlige stoffer, efterbrugs-management og renoverede/genfremstillede produkter. At stille sådanne krav til batterier bør skabe et økonomisk incitament til at producere og sælge batterier med længere levetid. GPP giver også incitamenter til at producere batterier med høj holdbarhed og kvalitet ved at sikre, at de er testet i henhold til international standard, dvs. EN 61960-3:2017.

Andre relevante love omfatter:

- Direktivet om affald af elektrisk og elektronisk udstyr (WEEE).
- EU-liste over affald
- Forordningen om forsendelse af affald
- Forordningen om CE-mærkning
- Direktivet om begrænsning af farlige stoffer (RoHS).
- Forordningen om registrering, vurdering, godkendelse og begrænsning af kemikalier (REACH)
- EU's konfliktmineralforordning

Ud over de lovgivningsmæssige initiativer omfatter andre vigtige initiativer herunder 2021 Industrial Strategy Update, hvor et strategisk område er lithium-ion-batterier (LIB'er); og den strategiske handlingsplan for at udvikle en europæisk batteriværdikæde, der omfatter råvareudvinding, indkøb og forarbejdning, batterimaterialer, celleproduktion, batterisystemer og genbrug og genanvendelse. Desuden støttede Europa-Kommissionen oprettelsen af The European Battery Alliance (EBA).

Endelig har EU finansieringsordninger for forskning, pilotprojekter, demonstratorer, opskalering og udrulning i batterier, såsom Horizon 2020, Horizon Europe, Innovationsfonden og Important Projects of Common European Interest (IPCEI).

Nuværende praksis vedrørende lithium-ion batterier

Produktion

LIB-produktion er meget kompleks og involverer mange trin fra minedrift til batteripakkeproduktion. Udvinning af metaller forekommer i forskellige dele af verden. Kina dominerer dog i øjeblikket med hensyn til celleproduktion, herunder katode- og anodeproduktion. Nogle råmaterialer er kritiske (høje forsyningsrisici og økonomisk meget vigtige) for EU, herunder kobolt, grafit og lithium.

Metaller udvindes til katoden, og de raffineres til sulfater eller i tilfælde af lithium, nogle gange brugt som hydroxid. Efter minedrift og raffinering fremstilles det aktive katodemateriale. Udvinning af metaller har stor indvirkning på miljøet og mennesker, der arbejder og bor i nærheden af udvindingsstederne. Battericellen er konstrueret med anode, katode, elektrolyt, separator, plast, stål, kobber og aluminium. Katoderne er lavet af forskellige kemier afhængigt af anvendelsen, og anoden er normalt baseret på grafit med undtagelse af LTO-kemi.

De kommende års tendenser for batterikemi i produkterne er ikke kun relevante for de råvarer, der kræves ved produktionen, men også for mængden af batterier, der skal genanvendes. Dette skyldes, at kemien bestemmer mængden af specifikke råmaterialer (f.eks. kobolt og nikkel), som kan genvindes.

Der foregår meget forskning i nye kemier, og de vigtigste drivkræfter er øget energitæthed for at øge rækkevidden for biler, reducere omkostningerne og reducere behovet for kritiske råmaterialer såsom kobolt.

De vigtigste markedssektorer i EU for LIB'er er bilindustrien og i mindre grad bærbare enheder. Væksten for solgte markeder på hvert marked i de kommende 10–15 år vil formentlig hovedsageligt ligge på bilsiden. Salget af rene elektriske (BEV) personbiler dominerer væksten. Andre vigtige produkter - som vokser betydeligt frem til 2030 - er PHEV'er for personbiler, busser og LCV (lette erhvervskøretøjer). Også batterier i elværktøj og tablet og smartphones er blevet solgt mere og vil fortsætte med at stige frem til 2030.

Brug

Den primære anvendelse er til bilindustrien, og den næststørste anvendelse er til bærbare enheder, forudsat at det mønster, der ses i Europa, også gælder for Norden.

Til nogle anvendelser, for eksempel til elværktøj, kræves høj effekt og dermed høj C-rate (høj strøm) fra batteriet, men energilagringsskapaciteten kan være lavere. Da det varierer, hvor meget tid man bruger værktøjet pr. brug, er batteriet ofte overdimensioneret til privat brug.

For bærbare batterier til bærbar elektronik såsom smartphones, bærbare computere, tablets, højttalere, er batterierne indbyggede, og lægfolk er ofte ikke i

stand til at erstatte dem; især til vandtætte produkter.

Især for udskiftede bilbatterier har batterierne typisk stadig energikapacitet tilbage, hvilket giver muligheder for renovering eller omfabrikation og opnåelse af et nyt liv i køretøjer eller i anden anvendelse, f.eks. til energilagring i bygninger eller som el-netunderstøttelse. Så længe der er et marked og en værdi af disse second life-batterier, vil en større del af batteriernes tekniske levetid sandsynligvis blive opnået, før de kasseres.

For EV-batterier er det almindeligt at give dem et nyt liv til industriel eller kommerciel energilagring. I Sverige bliver mange brugte elbatterier brugt i ejendomme og fx brugt på hustage til at opbevare energi produceret af solpaneler. For elektroniske produkter er tilgangen i øjeblikket helt at udskifte batterierne med nye i stedet for at reparere gamle batterier.

Efterbrug

Efter at brugeren ikke længere bruger produktet og ønsker at skrotte det, bliver ejerskabet af batteriet af stor betydning. Det udvidede producentansvar (Extended Producer Responsibility (EPR)) for batterier betyder, at den virksomhed, der bringer batterierne på markedet, er ansvarlig for deres indsamling, når de kasseres af forbrugeren.

Der er ingen lovkrav til, at ejeren af et batteri skal sende det til genbrug, når det ikke længere bruges af forbrugeren, hvorfor mange udtjente batterier til forbrugerelektronik bliver hos den oprindelige ejer i mange år i stedet for at blive genbrugt. For EV-batterier, som LFP-batterier, kan batterier adskilles fra busser og opbevares på ubestemt tid, indtil et formål med dem er fundet.

Mange små batterier bliver ikke indsamlet til batterigenbrug, fordi de er integreret i enheden og ikke kan skilles ad. De kan derfor ende i elektronisk (WEEE) genanvendelse i stedet, hvor der kun er ringe chance for, at batterimetallerne kan genanvendes.

EV-batterier formodes at blive fjernet under forbehandlingsprocessen for at overholde ELV-direktivet (direktivet om udtjente køretøjer), og procentdelen af batterier, som det finder sted for, bør være høj, da den direkte korrelerer med lageret til rådighed for genbrugsindustrien.

Genbrug

Der er stor variation, når det kommer til genanvendelse mellem hvilke former for genbrug, der udføres, og hvilke aktører, der er involveret. Selv inden for de større genbrugskategorier, såsom hydrometallurgi eller pyrometallurgi, kan der være store forskelle på, hvordan virksomheder udfører genanvendelsen. Forskelle, som forskellige aktører i genbrugskæden vælger, kan omfatte: hvilke metaller og andre materialer, der genvindes, hvor stor en procentdel af kobolt/nikkel/lithium/mangan, der genvindes, hvilken type opløsningsmidler der bruges i hydrometallurgisk genanvendelse, og hvilken type forbehandling der udføres.

Hovedkategorierne for genanvendelse i dag er hydrometallurgisk eller

pyrometallurgisk med efterfølgende hydrometallurgi. Begge har forskellige fordele og ulemper med hensyn til omkostninger, genvindingseffektivitet, fleksibilitet/tilpasning til forskellige batterikemier, behovet for et demonteringstrin og energiforbrug.

Pyrometallurgi betyder opvarmning af batterier for at smelte metallerne, mens hydrometallurgi bruger syrer eller baser til at opløse dem. Men først skal demontering af dele og andre forbehandling foretages. For hydrometallurgisk genbrug er viden om katodekemien vigtig, hvorfor det anbefales at markere batteriet tydeligt med denne information, måske med elektroniske tags for at lette sorteringen.

Ved batterigenbrug har elektrodernes kemi betydning, især katoden. Det meste af værdien findes i katoden, hvor værdifulde metaller såsom kobolt, nikkel og lithium findes. Mobiltelefoner, tablets og computere bruger Li-ion-batterier med højkvalitets Co-indhold (>12%), og denne høje Co-koncentration betyder, at det er rentabelt både for producenterne af disse produkter og genbrugerne at forsøge at genanvende metallerne i disse batterier. Til gengæld indeholder værktøjsbatterier normalt omkring 6%, hvorfor det ikke er lige så rentabelt at håndtere (genbrugere betaler typisk ikke for disse batterier, men tager et gebyr for at genbruge dem).

I øjeblikket er batterivolumen ikke tilstrækkelig til hydrometallurgi af sort masse i Norden. Der er også andre udfordringer, der skal overvindes for et fungerende LIB-genbrug.

Det nuværende batteridirektiv sætter ikke specifikke begrænsninger på det genbrugte indhold af lithium-ion-batterier, hvilket betyder, at genbrugsvirksomheder normalt vil genbruge de lettest kan genbruge eller har de mest værdifulde materialer. Forslaget til den nye forordning vil sandsynligvis kræve, at genbrugsvirksomhederne indfører forskellige metoder til genanvendelse for at justere procentdelen af metaller, der genvindes.

Et problem ved at reducere kobolt i batterierne er, at værdien for genbrugsvirksomhederne reduceres. LFP genanvendes derfor slet ikke i Europa i øjeblikket. Denne hindring kan afbødes af den foreslåede batteriregulering med dens foreslåede genvindingsprocenter for kobolt, lithium og nikkel samt det foreslåede genanvendte indhold i produktionen af nye batterier. Det foreslåede direktiv vil også tvinge virksomhederne i batteriforsyningskæden til at være mere gennemsigtige med hensyn til at sikre genanvendelighed (som muliggør adskillelse).

Bæredygtighed af batterier

Nogle vil måske betragte bæredygtighed som en anden formulering for miljøudvikling, mens andre også overvejer de økonomiske og sociale konsekvenser. Hvad angår batterier, er det vigtigt at overveje alle aspekter af bæredygtighed, da batteriteknologi er en nøglehjørnesten i den grønne omstilling til et fossilfrit samfund ved at erstatte produkter, apparater og transportmidler, der kræver fossile brændstoffer.

Det er vigtigt at overveje alle aspekter af bæredygtighed, hvilket er i overensstemmelse med FN's udviklingsmål (Sustainable Development Goals (SDG'erne)), der har til formål at: "sikre, at alle mennesker kan nyde velstående og

tilfredsstillende liv, og at økonomiske, sociale og teknologiske fremskridt sker i harmoni med natur."

Bæredygtighed og bæredygtig udvikling omtales ofte som de tre P'er ift. den engelske udgave af mennesker, planet og velstand (People, Planet og Prosperity).

Mennesker: Der er betydelige sociale og miljømæssige konsekvenser i forbindelse med udvinding af flere af råvarerne i lithium-ion-batterier, især hvad angår konfliktminerale. Minerale betragtes som konfliktminerale, hvis de kommer fra politisk ustabile områder, og hvor mineralhandelen kan bruges til at finansiere væbnede grupper, udbrede tvangsarbejde og andre menneskerettighedskrænkelser og støtte korruption og hvidvaskning af penge. Der er flere primære råmaterialer, der bruges til at fremstille lithium-ion-batterier, som kan have en negativ indvirkning på hele værdikæden. Kobolt er det mest problematiske råmateriale af alle listede råvarer, da det hovedsageligt udvindes i lande med dårlig regulering og uorganiserede små gruber, dvs. udvinding i hånden ved hjælp af rudimentære og basale værktøjer, ofte uden tilstrækkeligt beskyttelsesudstyr. Over 50 procent af verdens kobolt udvindes i DRC (Den Demokratiske Republik Congo).

Planet: Batterier påvirker miljøet både positivt og negativt, og miljøpåvirkning påvirker mennesker. Både fordele og ulemper skal overvejes i forbindelse med den øgede efterspørgsel efter forskellige typer batterier for at undgå rebound-effekter. Drivhusgasemissionerne ved at producere et batteri er omtrent det samme som resten af bilen selv, og dermed er drivhusgasemissionerne fra produktion af en elbil cirka dobbelt så meget som for en bil, der kun kører ved hjælp af forbrændingsmotor. I andre påvirkningskategorier er det tydeligt, at en elbil også producerer væsentligt højere emissioner af andre typer under produktionen.

Velstand: Mange af bæredygtighedsmålene har til formål at forbedre forskellige områder relateret til miljø, mennesker og økonomiske muligheder. Økonomiske muligheder sigter mod at give anstændigt arbejde såsom sikre arbejdsforhold, lønninger til at leve af, indlevende lederskab og økonomisk vækst for dem i specifikke samfund. Fra et mere stramt virksomhedsperspektiv er den økonomiske del naturligvis vigtig. Hvis en virksomhed har et underskud, kan den ikke fortsætte med at fungere, medmindre den på en eller anden måde laver en vending af udviklingen. En virksomhed kan fokusere på sociale og miljømæssige påvirkninger, men hvis de ikke tjener penge, kan de ikke fortsætte deres levedygtige arbejde (socialt og miljø).

For at sikre bæredygtighed skal løsningen være økonomisk bæredygtig. Tidligere var virksomheder fokuseret på overskud opnået gennem en lineær forretningsmodel, hvor højere salg var lig med højere fortjeneste. Den automatiske samlebåndsproduktion favoriserer lineære forretningsmodeller. Bæredygtighed er en forretningstilgang til at skabe langsigtet værdi ved at overveje, hvordan en given organisation opererer inden for de tre P'er (People, Planet og Prosperity).

Bæredygtighed bygger på den antagelse, at udvikling af sådanne strategier fremmer virksomhedens levetid. Uden fokus på bæredygtighed kan der stilles spørgsmålstejn ved, hvor længe virksomheden kan fortsætte med at fungere, efterhånden som forventningerne til virksomhedernes ansvar øges. Gennemsigtighed bliver mere udbredt, og flere virksomheder erkender behovet for at handle på bæredygtighed. Professionel kommunikation og gode intentioner er ikke længere nok, da grønne krav undersøges, og greenwashing vil skade virksomhedens omdømme.

Uden et bredt fokus på bæredygtighed kan det blive stadig sværere for virksomheder at konkurrere på markedet. Disse overvejelser kan øge fokus på Norden som et velegnet sted for produktion, da den grønne energiforsyning kan hjælpe virksomheder med at opfylde deres bæredygtighedsmål og øge deres markedsværdi.

Vigtigste barrierer mod øget cirkularitet

Selvom der er mange muligheder og fordele ved den cirkulære økonomi, er der stadig flere barrierer, der begrænser stigningen i cirkulariteten. Vigtigste barrierer omfatter:

- **Virksomhedskultur**, som ofte kan være en stor hindring i forhold til at skifte fra en veletableret lineær økonomi til cirkulær økonomi, ændre forbrugernes tankegang, involvere hele livscyklussamarbejde og ændre tankegange i virksomheder.
- Mangel på **cirkulære designmuligheder** især inden for elektronik og batterier på grund af kompleksiteten af små komponenter og kompakte produkter, der gør demontering vanskelig for genbrugs- og renovationsvirksomhederne, og fordi batterier har forskellige dimensioner, former og sammensætninger af kemikalier og metaller, hvilket gør det udfordrende at etablere et effektivt standardiseret system for batterigenanvendelse.
- Manglende **lovgivning**, som kan hæmme CE, dog er Norden og EU stadig foran på grund af national lovgivning og kommende EU-lovgivning om batterier.
- Manglende **forbrugerinteresse og bevidsthed**, fordi nogle forbrugere simpelthen kan lide nye varer, før deres gamle er slidt op, hvilket er særligt for trendbaserede, højteknologiske produkter med konstant modeludvikling, såsom mobiltelefoner, hvilket afskrækker producenter fra at fremstille robuste og dyrere produkter, da der er mindre markedsefterspørgsel efter sådanne produkter for nogle produktsegmenter.
- **Lave råvarepriser**, fordi den svingende pris på råvarer, som plast eller metaller, hæmmer det økonomiske incitament til at købe genbrugsmaterialer, når der er lave råvarepriser. Dette afskrækker yderligere investeringer i forbedring af de nuværende genbrugssystemer, som kan hjælpe med til at reducere priserne på regenererede ressourcer. Desuden er nogle primære råvarer underlagt tilskud, hvilket gør markedsprisen på genbrugsmaterialer endnu mere ugunstig.
- **Sort batterimarked og ulovlig eksport**, fordi mellem 30 og 40 procent af elbilerne eksporteres inden slutninger af deres levetid, men graden af ulovlig eksport er ukendt, fordi der kun er få data om ulovlig eksport af WEEE. Dette fører til cirkularitetsudfordringer, som inkluderer, at batterierne ender til genanvendelse i andre dele af verden, hvilket resulterer i øget emission til transport, mindre effektive genbrugsfaciliteter og dermed lavere outputkvalitet, og endeligt en reduceret mængde genbrugsmaterialer til den nordiske batteriproduktionsindustri.

Best practice og design for øget cirkularitet

I dette afsnit præsenteres indhold til separate håndbøger til virksomheder og til forbrugere om bedste praksis og design for øget cirkularitet. For virksomheder gives inspiration fra konkrete case-eksempler, mens der til forbrugere gives råd om, hvad de kan gøre ved køb og brug af produkterne.

For virksomheder

Mange virksomheder udforsker i øjeblikket de utallige muligheder for at arbejde med cirkularitet af batterier og batteridrevne produkter gennem nye forretningsmodeller og forbedrede måder at bruge batterierne mere effektivt på. For at udløse disse innovative forretningspotentialer er der behov for ny praksis i indkøbs-, design- og produktionsafdelinger. Håndbogen indeholder inspiration til virksomheder, så de kan etablere disse nye praksisser. Grundlaget for inspirationsemnerne er en udvikling af Ellen MacArthur Fondens model, hvor fokus på forretningsmodeller er stærkere.

Fem forretningsmodeltyper er blevet undersøgt, og der er givet case-eksempler på virksomheder, der har taget disse tilgange og tiltag, som forbrugerne kan anvende for at understøtte batteriernes cirkulære økonomi. Modellerne dækker over:

- **Cirkulære forsyninger**, der beskriver hvordan bæredygtighed og cirkulær økonomi kan understøttes ift. opstrømsværdikæden og efterspørgsel af bæredygtige materialer.
- **Ressourcegenvinding**, der beskriver handlinger, der kan sikre genbrug og genanvendelse ved foranstaltninger ift. nedstrømsværdikæden.
- **Produktlevetidslængelse**, der inkluderer alle de handlinger, forbrugere og producenter kan anvende for at øge levetiden for produkter og komponenter i brugsfasen.
- **Delingsplatforme**, der hjælper med at mindske behovet for produkter ved effektivt at dele færre faciliteter blandt flere brugere.
- **Produkter som en service**, hvor produktejerskab aldrig overføres til forbrugeren, hvilket understøtter vedligeholdelse, forlængelse af produktets levetid og ressourcegendannelse.

For forbrugerne

Forbrugerne kan støtte udviklingen mod cirkularitet af batterier og batteridrevne produkter gennem nye forretningsmodeller og forbedrede måder at bruge batterierne mere effektivt på via deres indkøb og samtidig opnå økonomiske fordele for sig selv og være med til at beskytte miljøet.

Håndbogen beskriver principperne bag cirkulært design for bedre at kunne forstå følgende best practice-anbefalinger og foreslå, hvad forbrugerne kan gøre via deres handling i købsituationen og under brugen af de købte produkter.

Cirkulære måder at købe, bruge og bortskaffe batterier præsenteres sammen med case-eksempler på virksomheder, der har taget cirkulære initiativer inden for de fem

forretningsmodeltyper beskrevet ovenfor. Modellerne dækker over:

- **Cirkulære forsyninger**, der beskriver cirkularitet i de materialer, der indgår i produkterne.
- **Ressourcegenvinding**, der beskriver handlinger, der kan sikre genbrug og genbrug af batterier.
- **Produktlevetid forlængelse**, der inkluderer alle de handlinger, der kan øge levetiden for batteriprodukter og komponenter i brugsfasen.
- **Delingsplatforme**, der hjælper med at mindske behovet for produkter ved effektivt at dele færre faciliteter blandt flere brugere.
- **Produkter som en service**, hvor produktejerskab aldrig overføres til forbrugeren, hvilket understøtter vedligeholdelse, forlængelse af produktets levetid og ressourcegendannelse.

Anbefalede politik-muligheder

Baseret på analyserne er anbefalede politiske muligheder for Norden blevet givet på to kategorier af muligheder:

- Politiske anbefalinger til de nordiske lande for at forbedre cirkulariteten af batterier og udstyr
- Politiske anbefalinger til de nordiske lande for deres bidrag til at skabe de nødvendige rammebetingelser

De politiske anbefalinger til de nordiske lande om at forbedre cirkulariteten af batterier og udstyr fokuserer på eksisterende og kendte teknologier, herunder batterier, gennem disse aktiviteter:

- **Vedtage foranstaltningerne fra arbejdsdokumenterne for smartphones vedrørende relevante foranstaltninger for batterier på tværs af alle produktgrupper, der indeholder batterier, der falder ind under Ecodesign-direktivet.** Et af de mest omfattende sæt af foranstaltninger, der er relevante for produkter, der indeholder batterier, findes i arbejdsdokumenterne for smartphones, hvor både krav til miljøvenligt design og energimærke foreslås. Vedtagelse af disse tiltag kan være et godt eksempel til brug ved opstilling eller revision af krav til andre produktgrupper.
- **Udvikle en ny målemetode vedrørende batteriydelse, hvilket giver producenterne en højere grad af frihed til at udvikle de bedst egnede batterier til den specifikke applikation.** I stedet for at stille krav til cyklusser, kunne det være relevant at udvikle en målemetode, der beregner batteriets levetid, som skal passe til produktets forventede levetid.
- **Sikre kompatible batterier på tværs af produktgrupper med batterier, der har mange ligheder**, så aftagelige genopladelige batterier kan bruges på tværs af en række forskellige produkter.
- **Støtte batteriforslaget.** Den foreslåede batteriregulering er ret omfattende og

dækker mange relevante områder. I den nuværende politiske proces kan de nordiske lande diskutere internt og med andre medlemsstater, om der kan opnås fælles holdninger til, hvordan det kan understøttes.

- **Bruge grønne offentlige indkøb (GPP) til at øge efterspørgslen efter bæredygtige batterier**, hvor de nordiske lande kan foreslå Europa-Kommissionen og GPP's rådgivende gruppe at inkludere batterier i en teknisk undersøgelse, der sigter mod at opstille GPP-kriterier for batterier.
- **Støtte en vidtrækkende revision af Ecodesign-direktivet og skubbe på for inklusion af transportsektoren**, hvor Norden bør presse på for at fjerne undtagelsen for transportmidler i ecodesign-direktivet - eller i det mindste at undtagelsen ikke skal gælde for batterier til transportmidler. Dette kan indgå i den nuværende proces med initiativet for bæredygtige produkter, der ændrer eller erstatter det nuværende ecodesign-direktiv.

Politiske anbefalinger til, at de nordiske lande bidrager til at skabe de nødvendige rammebetingelser fokuserer på anbefalinger til, hvad de nordiske lande kan gøre for at bidrage til at skabe de rette rammebetingelser for, at de nordiske lande kan placeres centralt i et innovativt, bæredygtigt og konkurrencedygtigt batteriøkosystem i Europa gennem disse aktiviteter:

- **Positionering af de nordiske lande for at drage fordel af bæredygtighedskravene i den nye batteriregulering** foreslået af Kommissionen, som forventes vedtaget i løbet af 2022. De nordiske lande bør positionere sig til at støtte og efterfølgende drage fordel af de forventede (i) regler om genbrugsindhold; (ii) foranstaltninger til at forbedre andelen af alle batterier, som bliver indsamlet og genanvendt (iii) gradvis udfasning af ikke-genopladelige batterier; og (iv) krav til bæredygtighed og gennemsigtighed for batterier (CO₂-fodaftryk, etisk indkøb af råmaterialer, forsyningssikkerhed og fremme af genanvendelse, genbrug til andet formål og genbrug).
- **Forberedelse af nordiske projektudviklere til deltagelse i den tilgængelige økonomiske støtte til europæiske projekter, der demonstrerer og opskalerer innovative bæredygtige batteriteknologier og forretningsmodeller**, hvilket vil omfatte at stille offentlig støtte eller finansiering til rådighed for battericelleproduktionsprojekter for at give incitament, udnytte og reducere risiko for private sektorinvesteringer gennem Horizon Europe, Invest EU, LIFE og Innovationsfonden til støtte for innovative batterirelaterede implementeringsprojekter.
- **Facilitering af nordisk forskningsprojektdeltagelse i de forbedrede europæiske forsknings- og innovationsfinansieringsmuligheder for batteriteknologi**, som vil omfatte tilgængeliggørelse af forsknings- og innovationsmidler (Horizon Europe) til batterirelaterede innovationsprojekter og - på længere sigt - lancering af et stor-skala flagskibsforskningsinitiativ inden for fremtidige nye teknologier, som kunne støtte langsigtet forskning i avancerede batteriteknologier inden for 2025+tidsrammen.

- **Samarbejde med TSO'er (transmissionssystemoperatører) og nationale energimarkedsregulatorer for at sikre, at de nødvendige lovgivningsmæssige rammer og prismekanismer muliggør demonstration af bæredygtig batteriteknologi og opskalering** af batteriteknologi til decentral lagring af fluktuerende vedvarende energi. Dette er på den ene side essentielt for elektrificeringen af store dele af de nordiske økonomier og opfyldelse af klimamålene i 2030 og 2050, og på den anden side giver mulighed for at levere en række tjenester, som i øjeblikket ikke er prissat på markedet (frekvensrespons, reaktiv effekt, levering af systeminerti).

1 Introduction

1.1 Introduction to the study

The overall aim of this project is to promote the Nordic countries as a forerunner region in demanding and using sustainable design of consumer electronics and such appliances, and to identify key opportunities, barriers and challenges in the transition towards a more sustainable use of battery technologies, including the transport sector. The aesthetics of the design should meet with the overall sustainability: high quality, durability and smart assembly for refurbishing.

The project is funded by the Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers. The project has been carried out by Viegand Maagøe A/S (Denmark) and IVL Swedish Environmental Research Institute (Sweden) in the period 20 October 2020 to 31 December 2021.

A reference group with representatives from the Nordics has been established, who provided valuable input to the study. A number of organisations have been interviewed, who also have provided valuable input to the study, see Annex A.

1.2 Background

Batteries are expected to play an important role in the transition to more clean energy in the EU, the Nordics, and globally where batteries, e.g. can displace fossil based mobility solutions, store energy from the grid and overall be used to utilise better electricity produced from renewable sources. At the same time, batteries are also playing an important role in consumer products, where cordless alternatives are the main drivers in the market.

The transition to more battery-driven products is enabled by the batteries' advancements and more energy-efficient products, allowing them to be used in more consumer products such as e.g. speakers, vacuum cleaners, cars, etc. Although many batteries today are significantly improved over the last decade and holds more energy (greater capacity), the products powered by batteries have increased their performance, meaning that the battery life of many products has not improved significantly. This is a driver for both more efficient products and bigger and better batteries.

Ideally, the advancement in the efficiency of the products and better batteries will reduce the need for more batteries. However, this is not the case currently, and more batteries are needed to fulfil climate goals and meet the increasing demands of cordless products, which means that the demand for batteries is expected to grow rapidly in the coming years.

Even though increased use of batteries brings many benefits for the environment and the consumers, the increased consumption of batteries may lead to:

- Shortage of needed raw materials to produce the batteries
- Geopolitical concerns regarding the location of the raw materials (lithium,

nickel, cobalt, manganese, and graphite) and increased dependency of countries outside the EU

- Social concerns regarding local pollution and poor working conditions where the raw materials are mined
- High pollution related to the production of batteries as the manufacturing process is energy-intensive
- Concerns regarding the low share of batteries manufactured in Europe currently, meaning that European countries become heavily dependent on batteries produced outside of Europe
- More products may become obsolete due to degradation of batteries in cases, where they cannot be replaced or only with high cost

It is important to address these shortcomings of the increased use of batteries, but there is no straightforward solution. However, the idea of the circular economy may be a solution to minimise the shortcomings of the increased use of batteries.

1.3 This report

The study and the report have been structured in two parts:

- Part 1: Legal framework and relevant initiatives; today's practice regarding lithium-ion batteries; sustainability of batteries and key barriers towards increased circularity today
- Part 2: Best practice and design for increased circularity for businesses and for consumers (handbooks) and recommended policy options (policy brief)

The content of Part 2 has been transformed to separate inspirational best practice handbooks for businesses and for consumers, respectively, and to a separate policy brief with recommended policy options.

2 Legal framework and relevant initiatives

This section presents the current and expected future framework conditions for lithium-ion batteries in the Nordics. Legislation, standards and voluntary initiatives are important to consider within the objectives of this study. The current framework conditions may contain barriers for increased circularity today and may lack measures to remove barriers and to push for greater circularity for batteries.

Even though this report focuses on Nordic countries, it is relevant to consider the EU legislations as these regulations directly impact Nordic countries.

The following sections present:

- Relevant EU legislation and initiatives
- Relevant national legislation in the Nordics
- Other initiatives such as the Nordic Swan, EPEAT, Eco Rating scheme and the battery passport
- Relevant standards

Note that this section is not an in-depth review of all relevant legislation, initiatives and standards but a brief overview of the most relevant ones related to the scope of this study at the time of producing this report.

2.1 EU legislation and initiatives

EU legislation and initiatives have a direct or indirect influence on batteries and the products containing batteries. In this section, we describe the most relevant EU legislation and initiatives providing an overview of the current and expected future regulations and provide suggestions of potential measures that could impact more sustainable production, use and disposal of batteries.

2.1.1 The Battery Directive and the proposed Battery Regulation

2.1.1.1 Background

The first battery directive was published in March 1991: the Council Directive 91/157/EEC of 18 March 1991 on batteries and accumulators containing certain dangerous substances. This was replaced in 2006 by the Battery Directive 2006/66/EC. Since then, batteries and accumulators have played a continuously increasing role in our daily lives and the transition to a fossil-free future. Batteries are integral parts of many daily-used products, appliances and electric vehicles and other mobility products.

Currently, approximately 800,000 tons of automotive batteries, 190,000 tons of industrial batteries, and 160,000 tons of consumer batteries enter the European Union every year. This number is only expected to increase in the coming years. Hence, increased focus is put on batteries in the Nordics and Europe.

In May 2018, the European Commission announced as part of the action plan Europe on the Move, a Strategic Action Plan for Batteries¹ aiming at creating a competitive and sustainable battery ecosystem in Europe. The Action Plan contained among others that the Commission would "put forward battery sustainability 'design and use' requirements for all batteries to comply with when placed on the EU market (this comprises an assessment and suitability of different regulatory instruments such as the Ecodesign Directive and the Energy Labelling Regulation and the EU Batteries Directive)".

On this background, the Commission launched an Ecodesign and Energy Labelling preparatory study and impact assessment on batteries (performed by VITO, Viegand Maagøe and Fraunhofer ISI). Because the study revealed that the main part of the batteries used is for means of transportation, which is not in scope of the Ecodesign and Energy Labelling regulations, the Commission decided to use the content of the study for preparing a proposal for a new Battery Regulation.

On 10 December 2020, the Commission presented this proposal for Battery Regulation repealing the existing Directive 2006/66/EC^{2,3}. The proposal has three objectives: (1) strengthening the functioning of the internal market (including products, processes, waste batteries and recycles) by ensuring a level playing field through a common set of rules; (2) promoting a circular economy; and (3) reducing environmental and social impacts throughout all stages of the battery life cycle.

Next sections present the Battery Directive and the new Battery Proposal and these are further discussed in Section 2.5.

2.1.1.2 The Battery Directive 2006/66/EC

The directive aims at ensuring the protection and preservation of the environment. This is done by setting specific objectives of minimising the negative impact of batteries and waste batteries on the environment, maximising the separate collection of waste batteries, minimising the disposal of batteries as mixed municipal waste, and achieving a high level of material recovery. Furthermore, the directive aims at improving the environmental performance of both batteries themselves and the activities of all economic operators involved in the life cycle of batteries (producers, distributors and end-users) while also lowering the amount of dangerous substance contained in batteries⁴.

The Battery Directive applies to all batteries placed on the market within the European Union. It categorises batteries as portable (e.g. for power tools, laptops, smartphones and computers), industrial or automotive. The directive establishes objectives and targets (e.g. on collection and recycling); it specifies measures (such as phasing out mercury or establishing national schemes for collection) and enables actions (e.g. reporting or labelling) to achieve them.

The directive has been the EU's best tool in ensuring recycling and beneficial environmental handling of batteries on the European market and have therefore also impacted the Nordic Member States' handling of batteries. Overall, the

1. https://ec.europa.eu/transport/sites/default/files/3rd-mobility-pack/com20180293-annex2_en.pdf

2. https://ec.europa.eu/environment/pdf/waste/batteries/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf

3. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12399-Modernising-the-EU-s-batteries-legislation_en

4. [https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/654184/EPRS_BRI\(2020\)654184_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/654184/EPRS_BRI(2020)654184_EN.pdf)

directive is still in accordance with current needs and has not lost its relevance. No Member State has experienced unnecessary regulatory burdens related to the directive and a majority of participants in a public consultation see benefits incurred as a result of the directive implementation.

Still, the directive does not ensure that all batteries are properly collected and recycled at the end of their life, increasing the risk of releasing hazardous substances and wasting valuable and critical resources. Many of the components and resources included in these batteries and accumulators could be recycled, avoiding the release of hazardous substances to the environment and, in addition, providing valuable materials to important products and production processes in Europe. Also, the existing directive does not fully grasp the intentions of the circular economy. A revision of the directive was necessary to reflect circularity better, improve sustainability, and keep pace with technological developments.

However, instead of a revised directive, a new battery regulation was proposed repealing the existing directive.

2.1.1.3 The proposed Battery Regulation

Since 2006, batteries and waste batteries have been regulated at EU level under the Battery Directive. During the evaluation and revision of the directive, it was decided that a modernisation of the framework was necessary because of changed socioeconomic conditions, technological developments, markets, and the use of batteries. The demand for batteries is increasing rapidly and is expected to increase 14 times by 2030. This is mostly driven by electric transport; making this market an increasingly strategic one at the global level. Such global exponential growth in demand for batteries will lead to an equivalent increase in demand for raw materials, hence the need to minimise their environmental impact.

On 10 December 2020, the European Commission proposed a new Batteries Regulation to repeal the Battery Directive and to amend Regulation (EU) 2019/1020 on market surveillance and compliance of products.

The proposal for a regulation addresses the social, economic and environmental issues related to all types of batteries. The proposed regulation aims to:

- Ensure that batteries placed on the EU market become sustainable, high-performing, and safe throughout their life cycle. This means batteries that are produced with the lowest possible environmental impact and using materials obtained in full respect of human rights as well as social and ecological standards. Also, the batteries have to be long-lasting and safe, and at the end of their life, they should be reused (directly within the same application or indirectly in new applications), remanufactured or recycled, ensuring that valuable materials are preserved in the loop.
- Provide legal certainty to unlock large-scale investments and boost the production capacity for innovative and sustainable batteries in Europe and beyond to respond to the fast-growing market.
- Minimising the environmental impact of batteries on the production of batteries and at the same time facilitating the Commission's proposal to achieve climate neutrality by 2050.

- Boost the circularity of the battery value chain and promote more efficient use of resources with the aim of minimising the environmental impact of batteries and close the loop to maintain valuable and scarce resources for as long as possible in the European economy.
- Significantly improve the collection and recycling of portable batteries (currently 45% collection rate is achieved) ensuring that the materials of batteries we use at home are not lost for the European economy. Other batteries – industrial, automotive or electric vehicle ones – have to be collected in full. All collected batteries have to be recycled, and high recovery levels have to be achieved, particularly valuable materials such as cobalt, lithium, nickel, and lead.
- Facilitate the reuse of batteries from electric vehicles (if feasible) to have a second life, e.g., in stationary energy storage systems
- Ensure the use of new IT technologies, notably the Battery Passport and interlinked data space, will be key for safe data sharing, increasing transparency of the battery market and the traceability of large batteries throughout their life cycle.
-
- Drive new battery sustainability standards, promote the green transition globally, and establish a blueprint for further initiatives under its sustainable product policy.

An Impact Assessment was conducted to assess the needed measures to fulfil these goals with different ambition levels. In Annex B, the suggested measures and the Commission's preferred options are presented. More or less, the proposed Battery Regulation follows the preferred option from the Impact Assessment.

The main innovations envisaged by the Commission proposal include⁵:

- *the introduction, in the battery classification, of a new category of electric vehicle batteries, alongside the existing portable, automotive and industrial battery classes;*
- *progressive requirements to minimise the carbon footprint of EV batteries and rechargeable industrial batteries: a carbon footprint declaration requirement, applying as of 1 July 2024, complemented by classification in a carbon footprint performance category and related labelling (as of 1 January 2026); and a requirement to comply with maximum lifecycle carbon footprint thresholds (as of 1 July 2027);*
- *a recycled content declaration requirement, which would apply from 1 January 2027 to industrial batteries, EV batteries and automotive batteries containing cobalt, lead, lithium or nickel in active materials. Mandatory minimum levels of recycled content would be set for 2030 and 2035 (i.e. 12% cobalt; 85% lead, 4% lithium and 4% nickel as of 1 January 2030, increasing to 20% cobalt, 10% lithium and 12% nickel from 1 January 2035, the share for lead being unchanged);*

5. [New EU regulatory framework for batteries \(Europa.eu\)](#)

- *minimum electrochemical performance and durability requirements for portable batteries of general use (applying from 1 January 2027), as well as for rechargeable industrial batteries (from 1 January 2026). The Commission would assess the feasibility of phasing out non-rechargeable portable batteries of general use by the end of 2030;*
- *a new obligation of battery replaceability for portable batteries; safety requirements for stationary battery energy storage systems;*
- *supply chain due diligence obligations for economic operators that place rechargeable industrial batteries and EV batteries on the market. For this requirement on responsible raw material sourcing (as well as for those related to the carbon footprint and the recycled content levels), the Commission proposal envisages mandatory third-party verification through notified bodies;*
- *increased collection rate targets for waste portable batteries, excluding waste batteries from light means of transport (65% by the end of 2025, rising to 70% by the end of 2030);*
- *as regards recycling efficiencies, increased targets for lead-acid batteries (recycling of 75% by average weight of LABs by 2025, rising to 80% by 2030) and new targets for lithium-based batteries (65% by 2025, 70% by 2030). The proposed regulation also envisages specific material recovery targets, namely 90% for cobalt, copper, lead and nickel, and 35% for lithium, to be achieved by the end of 2025. By 2030, the recovery levels should reach 95% for cobalt, copper, lead and nickel, and 70% for lithium;*
- *requirements relating to the operations of repurposing and remanufacturing for a second life of industrial and EV batteries;*
- *labelling and information requirements. From 1 January 2027, batteries should be marked with a label with information necessary for the identification of batteries and of their main characteristics. Various labels on the battery or the battery packaging would also provide information on lifetime, charging capacity, separate collection requirements, the presence of hazardous substances and safety risks. Depending on the type of battery, a quick response (QR) code would give access to the information New EU regulatory framework for batteries 7 relevant for the battery in question. Rechargeable industrial batteries and EV batteries should contain a battery management system storing the information and data needed to determine the state of health and expected lifetime of batteries. This system should be accessible to battery owners and independent operators acting on their behalf (e.g. to facilitate the reuse, repurposing or remanufacturing of the battery);*
- *the setting up, by 1 January 2026, of an electronic exchange system for battery information, with the creation of a battery passport (i.e. electronic record) for each industrial battery and EV battery placed on the market or put into service.*

The proposal also envisages the development of minimum mandatory green public procurement criteria or targets.

2.1.2 The WEEE Directive, the European List of Waste and the transportation of Waste

A number of directives and regulations considers the end-of-life of batteries regarding requirements on how to handle worn-out batteries properly, and ensure that the batteries can be transported safely to the desired end-of-life processing. This section briefly presents the WEEE Directive, the European List of Waste and the transportation of waste.

2.1.2.1 The WEEE Directive 2012/19/EU⁶

The Waste Electrical and Electronic Equipment (WEEE) Directive implements the principle of "extended producer responsibility", where producers of EEE (Electrical and Electronic Equipment) are expected to take responsibility for the environmental impact of their products at the end-of-life. The WEEE Directive aims to reduce the environmental effects by setting targets for the separate collection, reuse, recovery, recycling, and environmentally sound disposal of WEEE.

Batteries are included in the scope of the WEEE Directive, and possible product design requirements or other initiatives made by the European Commission and the Nordic Council can therefore be used to assist the WEEE directive. E.g. by introducing new product requirements that enhance reuse, material recovery and effective recycling.

The evaluation study on the Batteries Directive 2006/66 tried to estimate the battery flows based on WEEE data and Eurostat data. However, they found several lacks in the reported data and had to add several additional sources and make own calculations to estimate the flows. Screening of battery chemical recycling rates (reported in WEEE data) in the Nordic countries also show inconsistency. E.g. Denmark did not report any recycling of lead content batteries, while Norway, Iceland, Sweden and Finland reported between 997 and 44,982 tonnes of recycled lead content batteries in 2018⁷.

As stated in the shortcomings of the Batteries Directive, it could be beneficial to collect data on lithium-ion batteries separately. The evaluation study conducted estimations based on other sources and estimate that half of the industrial batteries are related to mobility and transport applications⁸.

2.1.2.2 European List of Waste

The EU List of Waste⁹ provides a common reference for classifying waste produced in the EU. It complements the EU Waste Framework Directive and is also relevant in the Regulation on Waste Shipment. The last update to the EU List of Waste was in 2014 and did not include a classification for lithium-ion batteries. Therefore, many recyclers stress the importance of aligning the EU List of Waste so that appropriate waste codes can be assigned to lithium-ion batteries as well as the appropriate

6. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN>

7. Link to Eurostat data: <https://appsso.eurostat.ec.europa.eu/nui/show.do> or <https://ec.europa.eu/eurostat/web/waste/data/database>

8. Evaluation study of Batteries Directive 2006/66 – page 46

9. Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste (notified under document number C(2000) 1147) (Text with EEA relevance) (2000/532/EC)

waste streams produced as a result of the battery recycling process, such as black mass. This was emphasized in an interview we made with the company Fortum.

It may be that certain waste streams like black mass are not classified as waste or misclassified. In that case, it can leave room for interpretation and cause problems, such as the black mass dumping scandal in Sweden in 2020 and the 2019 scandal of illegal shipment of black mass to Poland - where black market actors exploited loopholes. In this sense, official recyclers cannot compete with black market actors, who exploit the loopholes. The knowledge of supervising authorities must also be clear, and they must have access to the right information on the hazardous properties of the waste streams.¹⁰

2.1.2.3 Transports of used batteries: Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste

Used lithium-ion batteries are classified as dangerous goods due to risks for thermal runaway that may cause violent fire, which is difficult to extinguish. There are also risks for emissions of hazardous gases from the batteries that could have negative health effects, start self-ignition or aggravate the course of fire. The legislation requires special packaging, marking and labelling depending on the degree of how damaged the battery is, and criteria are available for the assessment¹¹. However, in practice it is often a tricky task to do the judgement. Legislation also requires special training for the drivers and the transportation company shall have a safety advisor.

A number of recyclers interviewed also indicated the importance of updating and aligning the EU Waste Shipment Regulation to the proposed EU Battery Regulation and EU List of Waste. The reason for this is that the Basel Convention makes it illegal or highly difficult and costly to ship end-of-life or damaged batteries ("dangerous goods") internationally. However, a stakeholder has informed that the level of recycling infrastructure around the world that is capable of recycling the batteries properly remain low. As a result, many waste batteries are either destroyed without the recovery of valuable metals or electronic scrap is shipped with labels such as "under repair" to circumvent the Basel Convention, without the batteries actually being repaired and reused. The stakeholder claims overall, the difficulty and cost of internationally transporting batteries (in large part due to the restrictions or irregularities across legislations) makes it unprofitable or even impossible for efficient recycling.

2.1.3 The Ecodesign Directive and specific product regulations

The Ecodesign Directive establishes a framework for setting ecodesign requirements on energy-related products and provides consistent EU wide rules for improving the environmental performance of products, such as household appliances, information and communication technologies or engineering. The Framework Directive and specific product regulations under the Directive are important to consider as some of the energy-related products are battery-driven. Battery-driven products are often quite efficient, ensuring a proper runtime of the appliances powered by batteries.

10. Fortum (mechanical and hydrometallurgical recycler) interview with Martina Elander and Janne Koivisto conducted by Alexandra Wu and Erik Emilsson. Q2 2021.

11. UNECE, 2019. Manual of Tests and Criteria (rev.7). [online] Available at: <<https://www.unece.org/index.php?id=53091>>

The high efficiency of many battery-driven products has indirectly excluded many of these products from Ecodesign and Energy Labelling regulations as the saving potential regarding energy consumption in the use phase is low.

However, in recent years, a set of resource efficiency requirements have also been implemented in the Ecodesign product regulations due to the European Commission's Circular Economy Action Plans (December 2015¹², March 2020¹³) meaning that more battery-driven products are subject to be included in Ecodesign and Energy Labelling regulations.

Below, a short summary is presented of the resource efficiency requirements in existing and proposed regulations that are most relevant and interesting for the development of new circular economy initiatives for batteries i.e. products such as computers, servers, and data storage equipment containing batteries; the proposal for Ecodesign and Energy Labelling of smartphones and tablets and other resource efficiency requirements from recent Ecodesign regulations. These regulations are significantly different from previous ones pointing in a new direction with a higher resource focus.

It should be noted that a preparatory study for batteries - mainly for electric vehicles and electric grid support - was initiated in 2018 and finalised in 2020¹⁴, however, as mentioned previously, the content of the study was used for the proposed new Battery Directive because means of transport are not in scope of the Ecodesign Directive.

2.1.3.1 Computers and computer servers – Commission Regulation (EU) No 617/2013¹⁵

From the computers and servers regulation, only a few requirements are relevant in relation to batteries:

- If a notebook computer is operated by battery/ies that cannot be accessed or replaced by a non-professional user, manufacturers shall provide in the technical documentation, and make available on free-access websites and on the external packaging of the notebook computer, the following information:
*The battery[ies] in this product cannot be easily replaced by users themselves'.
The information provided on the external packaging of the notebook computer shall be clearly visible and legible and it shall be provided in all the official languages of the country where the product is marketed.*

2.1.3.2 Servers and data storage products - Commission Regulation (EU) 2019/424¹⁶

The servers and data storage products regulation implemented requirements that ensure that batteries can be removed easily, benefitting both repair and separation at end-of-life. An information requirement on cobalt content in the batteries is also a part of the regulation, ensuring that attention is brought to this conflicted mineral. The relevant resource efficiency requirements for batteries are:

12. [https://www.eumonitor.eu/9353000/1/j4nvke1fm2yd1u0_j9vvik7m1c3gyxp/vkcweekvmgza/v=s7z/f=/com\(2015\)614_en.pdf](https://www.eumonitor.eu/9353000/1/j4nvke1fm2yd1u0_j9vvik7m1c3gyxp/vkcweekvmgza/v=s7z/f=/com(2015)614_en.pdf)

13. <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN>

14. Documents Ecodesign preparatory Study for Batteries (ecodesignbatteries.eu)

15. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0617&from=EN>

16. <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1560854721218&uri=CELEX:32019R0424>

- From 1 of March 2020, manufacturers shall ensure that joining, fastening, or sealing techniques do not prevent the disassembly for repair or reuse purposes.
- From 1 of March 2020, product information indicating weight range (less than 5 g, between 5 g and 25 g, above 25 g) at the component level of cobalt in batteries must be stated.
- Instructions on the disassembly operations shall be available from the time a product is placed on the market until at least eight years after the placing on the market of the last product. The information shall be free of charge for manufactures, their authorised representatives, and importers to third parties dealing with maintenance, repair, reuse and upgrading. The information must be available upon registration on a website provided.
- The instruction on the disassembly operation must include the type of operation, the type and number of fastening techniques to be unlocked and the tools required.

2.1.3.3 Working documents for smartphones and tablets (Ecodesign and energy labelling)

The proposed requirements in the working documents for smartphones and tablets are very different from other Ecodesign regulations as no minimum requirements on the energy consumption in the use phase are proposed. However, the suggested requirements are well-aligned with the findings in the preparatory study, which found that the worse environmental impacts were related to the material phase of the product (mining and production). The combined list of requirements seems to extend the lifetime and thereby reducing the environmental impacts due to this product group. The lifetime extension is partly ensured by requirements ensuring reparability and robustness.

In the working documents for Ecodesign requirements, the following requirements related to batteries in smartphones were suggested:

1. Resource efficiency requirements
 - i. Design for repair and reuse: Including availability of spare parts, access to repair and maintenance information, the maximum delivery time of spare parts, maximum price of spare parts, disassembly requirements, requirements for preparation for reuse
 - ii. Design for reliability: Protection from dust and water, battery endurance in cycles, battery management and fast charging
 - iii. Recyclability requirements: Make available, on a free-access website, the dismantling information needed to access the battery or batteries, sequence of dismantling steps, tools or technologies needed to access the battery or batteries, requirements on the availability of the required
2. Information requirements
 - i. Manufacturers, importers or authorised representatives shall provide the technical documentation and make publicly available on free-access websites information on: How the components of the products are produced, amount of critical raw materials, recyclability rate, content on recycled materials in the product, ingress protection rating, minimum battery endurance in number of cycles, minimum battery endurance in cycles under conditions of fast charging (if applicable).
 - ii. Manufacturers, importers or authorised representatives shall provide user

instructions in the form of a user manual on a free access website on: How to access the device information from the battery management system and instructions for better maintenance.

- iii. Manufacturers, importers or authorised representatives shall provide user instructions in the form of a user manual on a free access website of the manufacturer, importer or authorised representative, and instructions shall be displayed on the device under certain conditions and shall include: A warning if fast charging is permanently selectable, a message shall notify the user that fast charging may have a negative impact on battery endurance
- iv. Manufacturers, importers or authorised representatives shall provide user instructions in the form of a user manual on a free access website of the manufacturer, importer or authorised representative, and on the sales packaging of the device and shall include: If the package does not include a charger the following information: "For environmental reasons this package does not include a charger. This device is compatible with chargers."

In the working documents for Energy Labelling, the label in Figure 2-1 is presented.

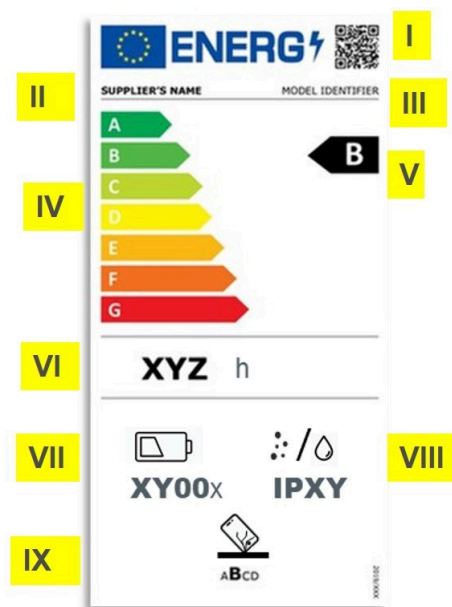


Figure 2-1: Suggestion for Energy Label for smartphones.

The label focuses on the energy consumption in the use phase. However, it should be noted that the preparatory study showed that most primary energy is used in the material and production phase, meaning that the main focus of the label is not put on the life cycle phase with the highest energy consumption. With more focus on the circular economy, it is relevant to discuss how to preserve the current impact of the energy label and highlight the importance of circular economy aspects.

2.1.3.4 Other resource efficiency requirements from recent Ecodesign regulations

The following resource efficiency requirements implemented in the Ecodesign regulation for washing machines¹⁷, among others, have been found relevant in connection with products containing batteries:

- Spare parts must be available to professional repairers for a minimum period of 10 years after placing the last unit of the model on the market. Some spare parts also have to be available for the end-user for minimum period of 10 years.
- Manufacturers, importers or authorised representatives of the machines shall ensure that the spare parts can be replaced with the use of commonly available tools and without permanent damage to the machine.
- The procedure for ordering the spare parts and instruction for repair shall be publicly available on a free access website of the manufacturer, importer or authorised representative, at latest two years after the placing on the market of the first unit and end when the requirements for spare parts, listed above, is ending.
- Maximum delivery time of spare parts in 15 working days.

2.1.4 Green Public Procurement (GPP)

GPP is a voluntary instrument that EU public authorities can use, when purchasing goods to contribute to sustainable consumption and production with their purchasing power. GPP does not set requirements specifically to batteries, but to the batteries used in certain products e.g. computers. Recently, updated EU green public procurement criteria for computers, monitors, tablets and smartphones have been published¹⁸.

The criteria apply to the following areas, under which relevant requirements for batteries are mentioned:

- Product lifetime extension
 - Continued availability of spare parts
 - Design for reparability
 - Rechargeable battery endurance
 - Minimum requirements for electrical performance
 - Information on battery state of health
 - Battery protection software
 - Intelligent charging
 - Further rechargeable battery endurance
- Energy consumption
- Hazardous substances
- End-of-life management
 - Secure computer collection, sanitisation, re-use and recycling
- Refurbished/remanufactured products
 - Rechargeable battery endurance
 - Information on rechargeable battery endurance
 - Minimum requirements for electrical performance
 - Further rechargeable battery endurance

17. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R2023&from=EN>

18. https://ec.europa.eu/environment/gpp/pdf/210309_EU%20GPP%20criteria%20computers.pdf

The GPP requirements related to cost-competitive offers seen in a life cycle costing (LCC) perspective is a valuable contribution to the circular economy, where it is not the cheapest battery that is the most economic beneficial solution if considering the lifetime of the product. Setting such requirements to batteries should create an economic incentive to produce and sell batteries with a longer lifetime. Being able to replace the batteries will also prolong the lifetime of the products with batteries and increase battery recycling as batteries can more easily be removed from the product.

Furthermore, the GPP provides incentives to produce batteries with a high endurance and quality by making sure they are tested according to international standard i.e. EN 61960-3:2017.

2.1.5 Other relevant directives and regulations

Below is some of the other relevant Directives and regulations mentioned, highlighting different aspects that are relevant to consider in relation to lithium-ion batteries.

2.1.5.1 CE marking - Regulation 765/2008¹⁹

The Regulation on CE marking creates the premise of the internal EU market and established the legal basis for accreditation and market surveillance and enforced the CE marking. Therefore, it is of relevance for battery manufacturers. Amongst others it defines the responsibilities of the manufacturer, e.g.:

- carry out the applicable conformity assessment or have it carried out, e.g. verify compliance with applicable European Directives
- draw up the required technical documentation and EU Declaration of Conformity (EU DoC)
- fulfill the traceability requirements by, e.g., keeping the technical documentation and the EU Declaration of Conformity for predefined time limit, ensuring that the product is marked with clear identification and affix the conformity marking (CE marking and where relevant other markings) to the product in accordance with the applicable legislation, e.g. the collection symbol for batteries (see the Batteries Directive below).

This is applicable to all battery products and devices that use batteries. When a device with an original battery is converted with for example a lithium-ion battery retrofit kit the full CE marking procedure needs to be redone including new technical documentation, EU DoC, serial number, etc.

2.1.5.2 EU Directive 2011/65/EU - RoHS Directive²⁰

The Restriction of Hazardous Substances (RoHS) Directive aims to reduce hazardous substances from electrical and electronic equipment (EEE) that is placed on the EU market. A number of hazardous substances are listed in the Directive along with maximum concentration values that must be met. The RoHS Directive

19. EUR-Lex - 32008R0765 - EN - EUR-Lex (europa.eu)

20. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0065&from=EN>

does contain some exemptions, where it has been decided that it may not be possible to manufacture some products without the use of one or more of the banned substances.

The RoHS directive explicitly states that the RoHS directive shall apply on batteries and accumulators. Any design criteria or other initiative shall therefore aim at reducing the use of hazardous substances. This could include requirements such as labelling of hazardous materials that are subject to exemptions under the RoHS Directive.

2.1.5.3 REACH Regulation 1907/2006²¹

The Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) is regulating the use of chemicals in Europe. REACH addresses the production and use of chemical substances and their potential impacts on human health and the environment. It requires all companies manufacturing or importing chemical substances into the European Union in quantities of one ton or more per year to register these substances with the European Chemicals Agency (ECHA). The ECHA databases contain over 120,000 unique substances/entries at the start of 2016. One of the obligations is to inform customers about the 'Substances of Very High Concern' (SVHC) that are listed on the 'Candidate List' and contained in products in concentrations higher than 0.1% weight by weight per article. These materials may be found in batteries, probably as an electrolyte solvent. A further obligation for these substances is to inform the customer, if necessary, about how to safely use the product. The authorisation procedure aims to assure that the risks from Substances of Very High Concern are properly controlled and that these substances are progressively replaced by suitable alternatives while ensuring the good functioning of the EU internal market. The Candidate List of substances of very high concern contains at least two substances known for use in Li-ion batteries²²:

- 1,2-dimethoxyethane or ethylene glycol dimethyl ether (EGDME, C₄H₁₀O₂) which is an electrolyte solvent that are very persistent and very bio-accumulative (vPvB)
- 1,3-propanesultone or 1,2-oxathiolane, 2,2-dioxide (C₃H₆O₃S) which is an electrolyte fluid in lithium ion batteries which is carcinogenic

According to the REACH regulation batteries are identified as articles with no intended release of the substances they contain. Battery producers are users of chemicals.

2.1.5.4 EU Conflict Minerals Regulation²³

The Conflict Minerals Regulation requires EU based importers of tin, tantalum, tungsten and gold to ensure their minerals are sourced responsibly and that their supply chains do not help to fund armed conflict or other illegal practices. This regulation is highly relevant as many of the raw materials used on batteries are considered to be conflicted minerals.

21. <https://echa.europa.eu/da/regulations/reach/legislation>

22. https://ecodesignbatteries.eu/sites/ecodesignbatteries.eu/files/attachments/ED_Battery_Task%201_V29_final.pdf

23. https://ec.europa.eu/commission/presscorner/detail/en/IP_16_3931

The regulatory requirements in the regulation (for tin, tantalum, tungsten and gold) specifies that EU importers of these minerals must:

- Establish strong company management systems
- Identify and assess risk in their supply chains
- Design and implement a strategy to respond to identified risks
- Carry out an independent third-party audit of supply chain due diligence
- Report annually on supply chain due diligence.

The regulation also indirectly affects smelters and refiners globally, as EU based importers are required to identify these businesses in their supply chains and check whether they too have the correct due diligence practices in place.

Companies that use these minerals in their products (i.e. non-importers, such as manufacturers) do not have obligations under the regulation. However, they are invited to publish information about their due diligence activities.

2.1.6 Batteries in the context of EU strategic dependencies

Europe and the Nordic countries in particular are major importers and exporters, and openness to trade and investment is a strength and a source of growth and resilience. However, the COVID crisis caused disruptions in global supply chain and led to shortages of certain critical products in Europe. Against this background Europe needs to further improve its open strategic autonomy in key areas. This was recognized in the EU's 2020 Industrial Strategy²⁴ and further developed in the 2021 Industrial Strategy Update.

In the 2021 Industrial Strategy update, the European Commission presented in-depth review analyses of 6 strategic areas, where the EU has dependencies²⁵. The reviews looked into the nature of possible strategic dependencies, their impact as well as relevant policy responses, which in some cases are already ongoing. One of these areas is lithium-ion batteries (LIBs).

Batteries are key to enabling the Europe's green and digital transformation. They are essential to achieving the European Green Deal ambition for the EU to become climate neutral by 2050. They also help companies become world leaders in clean products and technologies. Batteries are particularly important for the production of electric vehicles, but also increasingly used for energy storage and in other industrial applications such as machinery, power tools, or forklifts.

While there are different battery technologies, lithium-ion is a key component for many types of batteries due to its superior performance, compared to various well-established and mature battery technologies.

Global demand for LIBs is projected to increase to 4,000 GWh by 2040 and European demand for LIBs is expected to reach 400 GWh by 2028. But, EU had just 3% of global production capacity of LIB cells in 2018 vs 86% in Asia.

A key issue in this respect is access to relevant raw materials for battery production. The EU produces just 1% of all battery raw materials and to cover the needs of the mobility and energy storage sectors, the EU needs access to 7–18 times more lithium and 2–5 times more cobalt by 2030.

24. European industrial strategy European Commission (europa.eu)

25. In-depth reviews of strategic areas for Europe's interests European Commission (europa.eu)

Another key issue is access to processed materials and components. Only 8–9% of processed materials and components come from the EU whereas 84% of processed materials and components come from Asia and although several investments in battery materials have been announced in the EU, additional ones are needed.

2.1.7 Strategic Action Plan

Given the importance of LIBs, in 2018 the Commission adopted a Strategic Action Plan²⁶ to develop a European value chain. This brought together a set of measures to support national, regional and industrial efforts to build a battery value chain in Europe, embracing raw materials extraction, sourcing and processing, battery materials, cell production, battery systems, as well as re-use and recycling. As a response, public and private investments have been mobilised at scale over recent years, through the European Battery Alliance and EU investment funds for research, pilots, demos, scale-up and roll out through the EU Energy Transition Funds under the Multiannual Financial Framework MFF in the last budget period up to 2020 and the new budget period 2021–2027.

2.1.8 Sustainable batteries for a circular and climate neutral economy

In continuation of the European Green Deal and the Circular Economy Action Plan, the EC proposed in December 2020 to modernise EU legislation on batteries, to ensure that batteries placed on the EU market will become sustainable, high-performing and safe all along their entire life cycle (see Section 2.1.1.3). This means that batteries shall be produced with the lowest possible environmental impact, using materials obtained in full respect of human rights as well as social and ecological standards. Furthermore, batteries shall be long-lasting and safe, and at the end of their life, they should be repurposed, remanufactured or recycled, feeding valuable materials back into the economy.

2.1.9 European Battery Alliance

The European Battery Alliance (EBA)²⁷ launched in 2017 and supported by the Commission and the European Investment Bank (EIB), brings together EU national authorities, regions, industry research institutes and other stakeholders in the battery value chain. EBA is supporting the development of an innovative, competitive and sustainable battery value chain in Europe. In particular, it is helping to address the lack of battery manufacturing capacity in the EU. Its expected outcomes are to build at least 15 giga-factories in the EU by 2025 and supply battery cells to power 6 million electric cars (360 GWh) by 2025. Europe could become the second largest manufacturer of Li-ion cells by 2024 with its share of global production capacity potentially increasing to 14.7% by 2024 and 16.6% by 2029, compared to 5.9% in 2019.

The European Battery Alliance has actors from the whole value chain that could be

26. [com20180293-annex2_en.pdf \(europa.eu\)](#)

27. [ABOUT EBA250 - European Battery Alliance](#)

important actors in achieving Circular Economy goals in the battery industry in the Nordics. It is furthermore a vehicle for access to research partnerships and EU funding through grants, loans and guarantees. EBA has companies from Finland, Sweden and Norway represented in their recycling and second life activities.

2.1.10 EU funds for research, pilots, demonstrators, scale-up and roll-out in batteries

2.1.10.1 Horizon 2020 and Horizon Europe

Under Horizon 2020, EUR 270 million were allocated for batteries related R&D in 2019–2020. Furthermore, EUR 925 million proposed for the new European Partnership for an Industrial Battery Value Chain under Horizon Europe (2021–27).

The Batteries Partnership (a European Partnership under Horizon Europe) has the vision to establish best in the world sustainable and circular European battery value chain to drive the transformation towards carbon-neutral society²⁸. The private sector members (industry, research and NGOs) have structured themselves in BATT4EU²⁹, an international non-profit association established in Belgium. Two Finnish companies active in recycling and second life activities are members.

The Partnership ambition is to enable Europe to manufacture and commercialise by 2030 the next-generation battery technologies, through results-oriented innovation programme, which will enable the rollout of the zero-emission mobility and renewable energy storage, thus directly contributing to the success of the European Green Deal.

This is reflected in recent and forthcoming tenders under Horizon Europe³⁰:

Deadline 19 October 2021:

- Environmentally sustainable processing techniques applied to large scale electrode and cell component manufacturing for Li ion batteries (Batteries Partnership)
- Sustainable, safe and efficient recycling processes (Batteries Partnership)
- Sustainable processing, refining and recycling of raw materials (Batteries Partnership)

Deadline 6 September 2022:

- Furthering the development of a materials acceleration platform for sustainable batteries (combining AI, big data, autonomous synthesis robotics, high throughput testing) (Batteries Partnership)
- Sustainable processing and refining of battery grade graphite (Batteries Partnership)
- Streamlined collection and reversed logistics, fully automated, safe and cost-efficient sorting, dismantling and second use before recycling (Batteries Partnership)

28. https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_hepartnerships-european-industrial-battery-value-chain.pdf

29. <https://bepassociation.eu/>

30. Search Funding & Tenders ([europa.eu](https://ec.europa.eu/eu-funding-tenders/))

2.1.10.2 Innovation Fund

The EU Innovation Fund³¹ launched in July 2020 creates financial incentives for projects to invest in the next generation of technologies needed for the low-carbon transition, boost growth and competitiveness for EU companies, and support innovative low-carbon technologies in all Member States. An estimated EUR 10 billion grant support will be awarded under the Innovation Fund programme up to 2030 in annual calls for large-scale and small-scale projects.

Storage technologies are one of the eligible areas and under the first small-scale call, the Swedish Green Foil project (Low CO₂ Footprint Battery Foil/Current Collector for Li-ion Batteries Production) received funding for a project focused on increasing the downstream manufacturing capabilities of a rolling mill to be able to deliver aluminium battery foil, for use as a cathode current collector, which is required as input material when producing electric vehicle battery cells.

2.1.10.3 Important Projects of Common European Interest (IPCEI)

Important Projects of Common European Interest (IPCEI) are strategic projects that represent a very important contribution to economic growth, jobs and competitiveness for the EU industry and economy. IPCEIs make it possible to bring together knowledge, expertise, financial resources and economic actors throughout the Union.

The First IPCEI on Batteries³² under the European Battery Alliance was approved by the commission in December 2019, and includes partners from seven member states (including Finland and Sweden). EU will provide up to approximately EUR 3.2 billion in funding, which is expected to unlock an additional EUR 5 billion in private investments in a European battery value chain. The project involves 17 direct participants, mostly industrial actors, including small and medium-sized enterprises (SMEs). The direct participants will closely cooperate with each other and with over 70 external partners, such as SMEs and public research organisations across Europe.

The project supports the development of highly innovative and sustainable technologies for lithium-ion batteries (liquid electrolyte and solid state) that last longer, have shorter charging times, are safer and more environmentally friendly than those currently available. The project involves ambitious and risky research and development activities to deliver beyond the state-of-the-art innovation across the batteries value chain, from mining and processing the raw materials, production of advanced chemical materials, the design of battery cells and modules and their integration into smart systems, to the recycling and repurposing of used batteries.

Innovation will also specifically aim at improving the environmental sustainability in all segments of the battery value chain. It aims to reduce the CO₂ footprint and the waste generated along the different production processes as well as develop environmentally friendly and sustainable dismantling, recycling and refining in line with circular economy principles.

Within repurposing, recycling and refining, the project aims to design safe and innovative processes for collection, dismantling, repurposing, recycling and refining of recycled materials. Three Nordic partners are involved in this area; BASF (FI), Fortum (FI) and SEEL (SE).

31. Innovation Fund Climate Action (europa.eu)

32. State aid: €3.2 billion public support battery value chain (europa.eu) & IPCEI Batteries: IPCEI Batteries (ipcei-batteries.eu)

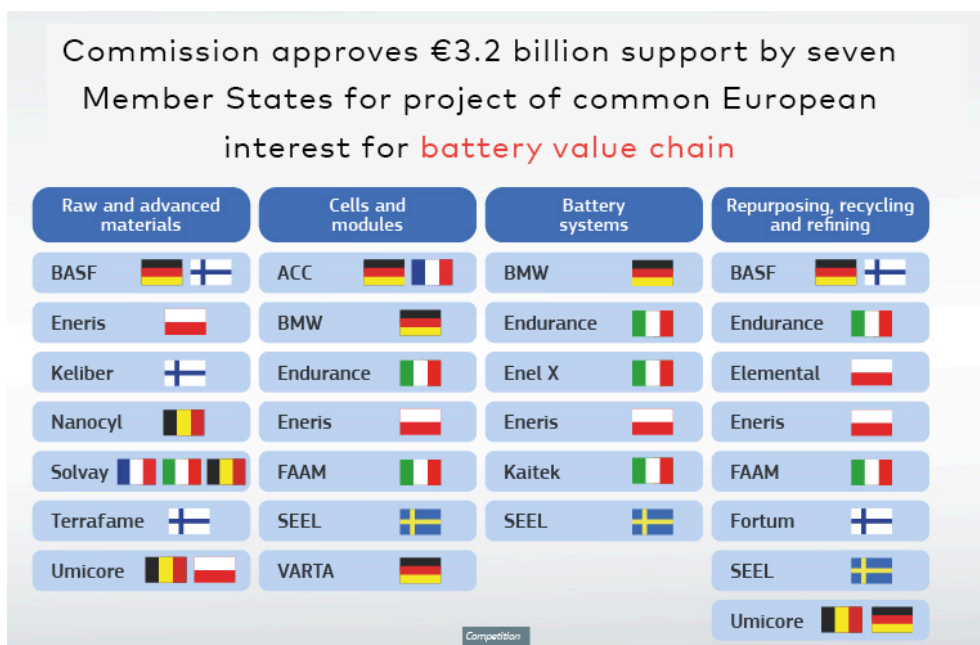


Figure 2-2: First IPCEI on Batteries - The direct participants, the Member States supporting them and the different project areas

The Second IPCEI on Batteries³³ under the European Battery Alliance was approved by the commission in January 2021. It involves 42 companies from 12 Member States and will provide 2.9 billion euros as state aid in support of 46 projects which in turn will generate 9 billion euros, in private investment.

The project will help revolutionise the battery market by focusing on beyond-state-of-the-art LIBs as well as on next-generation post-lithium-ion battery technologies. It will also foster new manufacturing processes with higher energy efficiency and lower carbon footprint across the entire value chain. The government of Germany has taken a coordinating role in this second battery IPCEI.

Within recycling and sustainability, three Nordic partners are involved under the Second IPCEI on Batteries; Fortum (FI), Keliber (FI) and Valmet Automotive (FI).

2.1.11 New legislative framework and developing a European skilled battery workforce

In connection with the launch of the Second IPCEI on Batteries the EC highlighted two critical enablers for the IPCEI projects on Batteries to be successful.

The first key enabler is the approval of the proposed regulatory framework on batteries (expected 2022) to ensure industrial players in Europe a predictable legal environment that supports them in innovating and preparing for the expected surge in e-mobility.

The second key enabler is enhanced reskilling and upskilling so that the European battery industry of tomorrow has a labour force to match (according to industrial estimates, some 800,000 workers will need to be trained by 2025).

33. State aid: Commission approves aid in battery value chain (europa.eu)

2.2 National legislation

This section covers national legislation related to batteries, that goes beyond EU legislation.

2.2.1 Battery waste sorting

The waste sorting approaches vary from country to country depending on the given waste management systems the given countries have implemented.

In Denmark, standard batteries like AA or AAA must be sorted separately and placed in a plastic bag by the other bins or in a designated container depending on the municipality and type of household, after which they are collected at the curb with the other waste fractions³⁴. Batteries can also be sorted and delivered within waste electronic if it is too complicated separating the two products. Some apartment buildings have WEEE bins, while most households must deliver WEEE at the nearest recycling station.

Sweden offers a similar system, where citizens can dispose batteries for recycling through their local municipality's collection scheme, which also varies in curb side collection in some regions or customer drop-off at local recycling centres. Batteries must be removed from the electronic component if possible. Otherwise, it is disposed within the WEEE. Large shops that sell electronics in Sweden are required to take all types of WEEE, even from non-customers. Smaller shops must accept WEEE similar to what a customer is buying³⁵.

Sellers putting portable batteries on the market have a requirement for take-back of their batteries, while the requirements for other types of batteries vary from a certain amount of collection points to mandatory takeback by the producers or partly voluntary takeback by resellers. In Norway and Finland, consumers mainly rely on handing batteries in stores, as any store that sell batteries must accept the same type of battery. Same system is in place for waste electronic, but recycling stations also accept batteries and waste electronic.

2.2.2 Producer responsibilities

All EU or EEA Member States follow the Directive 2006/66/EC (see Section 2.1.1) on batteries end-of-life treatment, thus the overall treatment of batteries is similar in all Member States, but with small variations between them.

In all Member States, the producer responsibility for battery manufacturers (and importers) includes liability of three main tasks: 1) registration of the production/import of batteries through the local environmental authority, 2) responsibility for collection and waste management of their batteries, and 3) provision of customers information on disposal practices in guides or at the sales point. The latter two tasks

34. <https://mst.dk/affald-jord/affald/saerligt-for-borgere-om-affald/batterier/>

35. https://www.avfallsverige.se/fileadmin/user_upload/Publikationer/Avfallshantering_2018_EN.pdf

are often done collectively through an organisation financed by the battery manufacturer and importer subscription³⁶.

In Denmark, producers are furthermore obligated to create nationwide information campaigns to promote sustainable use, collection, treatment and recycling of batteries. This is done through the collective industry organisations that the producers subscribe to. In Finland, producers need to do public information campaigns and give guidance, so that private households and other users are given valid information regarding, for example, to the health and environment effects of batteries, the recycling requirements, recycling points and markings.^{37 38} In Sweden, producers are not liable to deliver information campaigns to consumers, as the state is fulfilling this task³⁹.

In Sweden, small producers under a certain size are exempt from participating to the waste management and recycling of batteries.

Norway is, despite not being in the European Union, following Directive 2006/66/EC as an EEA member, but with smaller amendments to the directive. Only batteries sold separately, are required to follow the specific producer responsibility for batteries, while batteries sold in EEE must follow the WEEE and comply with the given producer responsibility in the WEEE regulation.

2.3 Other initiatives

This section describes other initiatives relevant for batteries, such as label schemes. The list is long and the requirements many, and the ones listed here are found most relevant for the purpose of the study.

2.3.1 Nordic Swan - Rechargeable batteries and portable chargers⁴⁰ & Primary batteries⁴¹

The label for secondary rechargeable batteries focuses on capacity and durability of batteries to ensure long battery life thereby reducing resource consumption. Nordic Swan also set requirements to the quality and safety standards of batteries and portable chargers⁴². The label for primary batteries (non-rechargeable) has a focus on battery operation time and shelf life to ensure a long lifetime for the battery and thus reducing resource consumption.

The most important requirements that goes beyond the requirements found in EU legislation are:

- Established CSR policy to ensure responsible use and sourcing of limited raw materials and conflict free minerals.
- Fully charged Nickel Metal Hydride (NiMH) batteries and cells when leaving the

36. <https://elretur.dk/dit-producentansvar/batterier/>

37. Pirkanmaa Ely Interview with Matti Lenkkeri conducted by Erik Emilsson. Q2 2021.

38. https://www.finlex.fi/en/laki/kaannokset/2011/en20110646_20140528.pdf

39. <https://erp-recycling.org/en-fi/producer-responsibility/#:-:text=Producer%20responsibility%20Batteries-,The%20producer%20of%20portable%20batteries%20and%20accumulators%20has%20a%20legal,their%20own%20name%20or%20trademark.>

40. <https://www.nordic-ecolabel.org/product-groups/group/?productGroupCode=030>

41. <https://www.nordic-ecolabel.org/product-groups/group/?productGroupCode=001>

42. <https://www.nordic-ecolabel.org/product-groups/group/?productGroupCode=030>

production site.

- Compliance with stringent requirements for both battery operation time, shelf life, safety and quality.

Especially the requirement to CSR policy is interesting for this study, because it covers an aspect that goes beyond the environmental sustainability of batteries and can be used to ensure that the future initiatives taken by the Nordics also ensure sustainability related to people.

2.3.2 EPEAT Ecolabel

EPEAT (Electronic Product Environmental Assessment Tool) is a global rating system for greener electronic using three levels – bronze, silver and gold – established by Global Electronics Council (GEC). EPEAT has developed set of criteria, which they use to evaluate the environmental performance of products including for batteries in electronic products. Some of the criteria are required to get the label and others are optional. To receive the gold label, 75% of the optional criteria must be met. In addition to requirements already mentioned in Ecodesign regulation and other label schemes the following are found most relevant⁴³:

- Long life rechargeable battery (computers)
- Provision of a removable rechargeable battery take-back program (computers)
- Battery removability/replacement (mobile phones)
 - Performed by qualified repair service providers or authorized repair providers
 - Instructions for replacement of battery must be provided
 - Possibility of replacing battery without tools

Relevant areas for the current study include:

- Setting requirements to long life rechargeable batteries and making sure that they can easily be replaced, can contribute to extended lifetime of the products in which the batteries are used.
- Requirements to a takeback program can also ensure the optimal end-of-life scenario for batteries, making sure that they can be reused if possible or otherwise recycled with the highest possible rate.

2.3.3 Industry Eco Rating scheme for mobile phones

In May 2021, an industry initiative, the Eco Rating for more sustainable mobile phones, has been launched by five European mobile operators (Deutsche Telekom, Orange, Telefónica, Telia Company and Vodafone)^{44 45}. The aim is to help consumers identify and compare the most sustainable mobile phones and encourage suppliers to reduce the environmental impact of their devices.

A range of new consumer phones from 12 mobile phone brands (Bullitt Group –

43. <https://greenelectronicscouncil.org/wp-content/uploads/2019/04/List-of-Criteria-2018-v2.pdf>

44. <https://www.teliacompany.com/en/news/press-releases/2021/5/new-pan-industry-eco-rating-scheme-launched-for-mobile-phones/>

45. <https://www.ecoratingdevices.com/>

Home of CAT and Motorola rugged phones, Doro, HMD Global - Home of Nokia Phones, Huawei, MobiWire, Motorola / Lenovo, OnePlus, OPPO, Samsung Electronics, TCL / Alcatel, Xiaomi and ZTE) will be assessed by the Eco Rating initiative, with others expected to be announced in the future.

Using information provided by device manufacturers, Eco Rating applies an evaluation methodology across 19 different criteria, culminating in a single score (1–100) for each device. In addition, the Eco Rating provides guidance in five key areas:

- **Durability:** The robustness of the device, the battery life and the guarantee period for the device and its components.
- **Repairability:** Covers the ease with which the device can be repaired, including mobile phone design and supporting activities that could increase the useful life of the product by improving its reparability, reusability and upgradability potential. A higher score indicates how these aspects are supported.
- **Recyclability:** How well the device components can be recovered and disassembled, the provided information to allow it, and how well materials can be recycled.
- **Climate efficiency:** The greenhouse gas emissions of the device during its whole lifecycle. The better the score here, the lower the climate impact is.
- **Resource efficiency:** Assesses the impact caused by the amount of scarce raw materials required by the device (e.g. gold for the manufacturing of electronic components) towards the resources' depletion; the better the score here, the lower the impact is towards the availability of materials.

2.3.4 Battery passport under the Global Battery Alliance

The Global Battery Alliance's Battery Passport⁴⁶ is a rather new initiative and still under development, but could be an important initiative in achieving sustainability that goes beyond the battery itself. The Battery Passport provides guiding principles covering issues from circular recovery of battery materials, ensuring transparency of GHG emissions and their progressive reduction and to eliminate child and forced labour.

Most relevant guiding principles that go further than requirements already mentioned are⁴⁷:

- Prioritizing energy efficiency measures and substantially increase the use of renewable energy as a source of power and heat when available
- Fostering battery-enabled renewable energy integration and access with focus on developing countries
- Supporting high quality job creation and skills development
- Immediately and urgently eliminating child and forced labour, strengthening

46. <https://www.mining.com/battery-passport-guiding-principles-on-value-chain-data-launched-at-world-economic-forum/>

47. <https://weforum.ent.box.com/s/jhkma0recrok7f7cggyr05mig0rju74m>

communities and respecting the human rights of those employed by the value chain

- Fostering protection of public health and the environment, minimizing and remediating the impact from pollution in the value chain.
- Supporting responsible trade and anti-corruption practices, local value creation and economic diversification.

The Battery Passport guiding principles can be used to set requirements in the Nordics, that makes sure that those activities that are performed outside the Nordics are performed environmentally sustainable and protecting public health of those working in the field.

2.4 Standardisation

Standardisation is an important tool in setting requirements to batteries and product design because standards ensure that all actors test, measure, verify etc. using the same methodology

In the area of batteries much standardisation work is ongoing, which can be used to set future requirements to design, recycling, products, information, production etc. A list of all relevant standardisation work directly related to batteries is provided below.

The standardisation groups CLC/SR 35 and IEC/TC 35 work with standardisation of batteries. No standards for circular economy or the lifecycle of batteries in the two standardisation groups have been identified.

2.4.1 Standards related to lifecycle assessment

ETSI's TC EE is a standardization group that develops standardization method for the cradle-to-grave life cycle assessment of the environmental impact of ICT equipment and services, providing an industry-agreed method to evaluate greenhouse gas emissions⁴⁸. They have created the standards listed in Table 2-1, which creates a basis for sustainable production and use of ICT equipment. Furthermore, the ISO has developed principles and a framework for life cycle assessment, that can be implemented in battery industry.

48. <https://www.etsi.org/newsroom/news/372-news-release-21-november-2011>

Table 2-1: ETSI's TC EE relevant sustainability standards

Standard	Description of standard ⁴⁹
ETSI ES 203 199 V1.3.1 (2015-02)	Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services
ETSI TS 103 199 V1.1.1 (2011-11)	Environmental Engineering [EE]; Life Cycle Assessment (LCA) of ICT equipment, networks and services; General methodology and common requirements
ETSI TR 103 476 V1.1.2 (2018-02)	Environmental Engineering (EE); Circular Economy (CE) in Information and Communication Technology (ICT); Definition of approaches, concepts and metrics
ISO 14040	Describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.
ISO 14044	Specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

49

The principles and requirements set in the standards by ISO and ETSI can be used to generate requirements for batteries, that ensure a level play field of recycling, production, use and reporting.

2.4.2 EN 50614:2020 – Requirements for the preparing for re-use of waste electrical and electronic equipment

The aim of the WEEE standardisation^{50 51} is to assist treatment operators in fulfilling the requirements for the WEEE Directive without placing unnecessary administrative burdens on operators of any size, including SMEs. EN 50614:2020 is an important part of the WEEE standardisation, that ensures transparency and similarity in collection and recycling of batteries.

The standard is applicable to the processes relating to the preparing for re-use of WEEE (including batteries). The standard assists in quantifying re-use, recycling and recovery rates in conjunction with EN 50625-1 (standard covering general collection, logistics & treatment requirements for WEEE). In case of treatment operation (including the collection and logistics of WEEE) other than preparing for re-use, the EN 50625 series applies (no specific collection standard available for batteries). Preparing for re-use processes includes the removal of whole components or parts

49. <https://www.etsi.org/standards#page=1&search=LCA&title=1&etsiNumber=1&content=1&version=0&onApproval=1&published=1&historical=1&startDate=1988-01-15&endDate=2021-01-20&harmonized=0&keyword=&TB=&stdType=&frequency=&mandate=&collection=&sort=1>

50. <https://www.evs.ee/en/evs-en-50614-2020>

51. https://ec.europa.eu/environment/waste/weee/standards_en.htm

where they are intended to either be used in the repair of faulty equipment or sold as re-use parts.

2.4.3 EU repair standards related to circular economy

An important step in reaching EU's goals for circular economy is standardisation that ensures high durability, material efficiency, repairment and recyclability. The Commission has therefore mandated CEN/CENELEC to develop standards for material efficiency under Ecodesign and a first set of horizontal standards should be expected in 2020.

The following standards are included in Mandate 543 with the focus on material efficiency of ErPs:

- Deliverable WI 65684 – TR 45550 Definitions related to material efficiency (proposal available)
- Deliverable WI 65683 – TR 45551 Guide on how to use generic material efficiency standards when writing energy related product specific standardization deliverables (status unknown)
- Deliverable JTC010003 – EN 45552 General method for the assessment of the durability of energy related products (in force)
- Deliverable WI 65685 – EN 45554 General method for the assessment of the ability to repair, reuse and upgrade energy related products (in force)
- Deliverable WI 65686 – EN 45553 General method for the assessment of the ability to remanufacture energy related products (in force)
- Deliverable JTC010001 – EN 45555 General methods for assessing the recyclability and recoverability of energy related products (in force)
- Deliverable WI 65709 – EN 45556 General method for assessing the proportion of reused components in an energy related product (in force)
- Deliverable JTC010002 – EN 45557 General method for assessing the proportion of recycled material content in energy related products (in force)
- Deliverable WI 65687 – EN 45558 General method to declare the use of critical raw materials in energy related products (in force)
- Deliverable WI 65688 – EN 45559 Methods for providing information relating to material efficiency aspects of energy related products (in force)

The standardisation work in EU confirms that there is an increased focus on making circular economy a reality and making sure that all actors play by the same rules. The standards could be used to set concrete requirements for repairability and recyclability of batteries.

2.5 Discussion on the legal framework

Batteries used in the Nordic countries are already regulated by several regulations and directives such as REACH, RoHS, WEEE, and the Battery Directive. Below are presented a selection of the shortcomings and challenges related to the current framework condition discussed.

Currently, the most important legislation for batteries is the Battery Directive, which has proved efficiency in achieving the purpose of the Directive, but to some degree, it has lost track with the increased focus on the Circular Economy in the society. The most critical shortcomings of the Battery Directive are that:

- The directive does not require reporting or systematic analysis of battery lost, meaning the difference in batteries reported as placed on the market and the batteries collected for recycling. Lithium-ion batteries are currently reported as "other batteries", which is problematic because Lithium-ion batteries are typically used in e-mobility, which is a market that is expected to increase significantly.
- The hazardous substances contained in Lithium-ion batteries are not considered.
- The collection target is 45%, which was only met by 14 Member states. This means more than half of the batteries placed on the EU market is not collected.
- The collection and recycling efficiency targets set by the Directive give no incentive for performance above the minimum.
- The Directive does not specify a methodology for evaluating the environmental performance of batteries nor address other battery features such as durability, safety requirements, energy efficiency etc.
- Regarding the environmental aspects of the Directive, it does not address the re-use of batteries. No definitions for re-use, preparing for re-use or second use are included in the directive, causing an unclear legal situation. Furthermore, there is no definition for recycling efficiency regarding recovery of battery materials – no priority to high-quality recycling, as opposed to downcycling, is indicated.
- The rules for calculating the recycling efficiency are a shortcoming an issue; not the calculation as such, but the availability and quality of the data from foreign recyclers not allowing for calculating the efficiency adequately. Additionally, no control system is in place to verify the reported recycling efficiencies, resulting in an unlevelled playing field.
- The Directive does not clarify if micro-batteries are in scope.
- The struggle for battery raw material is not covered adequately in the Directive. The struggle for raw materials results in the resource efficiency of the materials being of higher importance. It should therefore be considered if more targets and provisions related to resource efficiency should be introduced. These targets

could also include critical raw materials or Lithium that are of high importance for battery production.

These shortcomings have led to the proposal of a new battery regulation, as already mentioned. Still, the shortcomings are relevant to consider when the new proposal is discussed, as the regulation is still just a proposal, where multiple changes can occur. If measures with lower ambition levels are supported instead of the current suggestions, it is essential to consider whether the shortcomings of the Directive are addressed.

Regarding the proposed Battery Directive, it is clear that the proposal introduces ambitious requirements regarding batteries addressing the shortcoming of the Directive. However, currently, it is not clear how the final regulation will be, but stakeholders participating in this study have provided following inputs:

- **On the minimum recycling and secondary material content targets:** Some recyclers interviewed indicated that the targets are good as proposed^{52 53}. However, industry association Teknikföretagen expressed concerns that the material recovery rates may be unrealistic to obtain by 2030 due to the delay in time between the batteries enters the market and reach their end-of-life and the time needed for technologies and innovation to become established.⁵⁴
- **On the impact of minimum recycling targets on marginal costs:** The minimum recycling targets bring considerations for marginal costs for recyclers for each additional unit of material recovered. For example, the proposed EU Battery Regulation sets a 90% recycling target for cobalt. A recycler may reach a recycling rate close to 90%, but the treatment cost may exponentially increase for each marginal increase in the recycling rate. Similarly, the proposed Battery Directive also brings considerations on which metals recyclers will increase marginal effort to recycle because targeting one metal may come at the loss of another (e.g. nickel vs. cobalt).⁵⁵
- **On the impact of minimum recycling targets on market structure:** One concern from small recyclers and pre-processors is that refineries that cannot reach the recovery targets may be pushed off the market and replaced by large scale recyclers, which can result in logistical and transport changes impacting small pre-processors like Akkuser, needing to increase cost resulting in reduced competitiveness⁵⁶. However, there are several metal refineries in Nordic countries with a long experience and good expertise of the battery metals refining. Utilizing these refineries in processing of black masses from different pre-processors would be an efficient option. But if the recycling efficiency in the existing infrastructure is just below the target, this route cannot be used, and instead the new facilities should be built which would take lots of resources. All the operators are developing the processes so most likely this will not be a problem in the future⁵⁷. Furthermore, the regulation affects car manufacturers because the requirements and targets of batteries will be on the car

52. Fortum (mechanical and hydrometallurgical recycler) interview with Martina Elander and Janne Koivisto conducted by Alexandra Wu and Erik Emilsson. Q2 2021.

53. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

54. Teknikföretagen Interview with Elinor Kruse and Emilia Käck conducted by Johan Holmqvist & Erik Emilsson. Q2 2021

55. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

56. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

57. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

manufacturer and not the battery manufacturer.⁵⁸

- **On the impact of collection targets:** Currently, the proposed regulation states that the collection point has the right either to transfer the batteries to Producer Responsibility Organisations (PROs) (as currently done) or to other authorised waste recyclers (a new addition). This can be problematic because alkaline batteries have a negative value and co-containing Lithium-ion batteries have a positive value. So, PROs could end up receiving and processing all the alkaline batteries, but cobalt batteries would be sold by collection points to recyclers so that PROs cannot get them back.⁵⁹
- **On support to SMEs:** The complexity and length of the regulation can have competitiveness impacts because larger companies have more resources and capacity to fully digest and manage the regulation and compliance, while SMEs have less. It was advised that support could be given to SMEs and smaller companies to understand the regulation, build systems for the battery passport, obtain IP rights, and report.⁶⁰

Finally, the following points were highlighted in interviews with stakeholders:

- Global societies have built themselves very deep into a linear system that is efficient and cheap, where producer and consumer decisions are based primarily on value and financial incentives. As such, it is almost always cheaper to opt-in for the linear option, where producers are incentivised to produce for the linear system rather than for a circular system, including the design aspects and after-use phase.⁶¹
- The same can be said for regulatory design. The Waste Shipment Regulation, for example, is focused on disposal – which is based on the linear perspective. Structuring regulations from the circular perspective would mean that resources would be seen as circular and cycled as many times as possible.⁶²
- Regulatory changes are needed to support the reuse market because commercial reuse actors like Inrego are operating in an economy designed for production and recycling. Certain legislations have been affecting them negatively and show that they do not consider the secondary market. There are two examples of this: first, EEE is not classified as waste during the transportation for reuse since the law was created without the consideration that products will be transported for re-use. This skips the phase of reusable EEE on the secondary market and poses a regulatory cost burden on second-hand reuse actors. Second, in Sweden a tax was presented on chemicals in new products targeted at manufacturers but also does not work fully as the legislators did not fully understand how the reuse industry would develop when legislating. Thus, reuse actors also needed to take on that cost burden. These are examples of inefficient legislations that disincentivise second-hand business models.⁶³

The industry stakeholders are considering their competitiveness in the market. Even though some stakeholders are concerned about some of the requirements, most of

58. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021

59. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

60. Teknikföretagen Interview with Elinor Kruse and Emilia Käck conducted by Johan Holmqvist & Erik Emilsson. Q2 2021

61. Inrego interview with Sebastian Holmström conducted by Johan Holmqvist & Alexandra Wu. Q2 2021.

62. Fortum (mechanical and hydrometallurgical recycler) interview with Martina Elander and Janne Koivisto conducted by Alexandra Wu and Erik Emilsson. Q2 2021.

63. Inrego interview with Sebastian Holmström conducted by Johan Holmqvist & Alexandra Wu. Q2 2021.

them seem to agree that changes are needed to support the shift to more circular businesses. Depending on one stakeholder, their view on the proper ambition level may vary greatly, but as often seen in the European Commission, the industry seems to be a more careful regarding their support to new environmental requirements, as the requirements affect the industry directly. Other stakeholders, such as environmental NGOs, often support stricter requirements as they consider each regulatory intervention an opportunity to be exploited as best as possible. ECOS, EEB, DUH T&E has provided the following comments⁶⁴:

- *Introducing manufacturing requirements to ensure optimal performance as well as replaceability, disassembly, reparability and reusability;*
- *Ensuring that carbon footprint rules incentivise real world use of green energy with independent verification of industry data, in particular from third countries;*
- *Ensuring better collection of spent batteries by introducing a deposit return system for portable batteries, waste collection targets and incentivises for the collection of electric vehicle batteries, including light means of transport;*
- *Implementing mandatory tests to determine whether it is technically possible and economically reasonable to reuse a battery;*
- *Increasing the ambition of the battery material recovery targets, especially for lithium, and aligning them with current best practice.*
- *Enforcing the effective phase-down of disposable batteries by replacing them with rechargeable batteries whenever it is clearly a preferred option;*
- *Ensuring the ethical sourcing of raw materials throughout all stages of battery manufacturing;*
- *Proposing ambitious targets and a common methodology for the calculation and verification of recycled content used in the production of batteries, ensuring that only post-consumer-recyclates from spent batteries are included in the calculation*

The environmental NGOs highlight some interesting views on the proposal and, in general, support stricter requirements. ECOS, EEB, DUH T&E has created a joint policy paper⁶⁵ that further explains the abovementioned bullets. Overall, the industry and NGOs have different ambition levels, which also are reflected among EU Member States. Some Member States have clearly supported the regulation and pushed for an earlier implementation date, while other member states are concerned about the proposal impacts on member states where they already have legislation that works well⁶⁶. Overall, the different member states have opposing views on the proposal, which can affect the final regulation and postpone and even cancel it.

64. <https://ecostandard.org/wp-content/uploads/2021/03/Enhancing-the-sustainability-of-batteries-JointPolicy-Paper.pdf>

65. <https://ecostandard.org/wp-content/uploads/2021/03/Enhancing-the-sustainability-of-batteries-JointPolicy-Paper.pdf>

66. <https://www.euractiv.com/section/batteries/news/brussels-in-balancing-act-to-gain-eu-support-for59-battery-regulation/>

It is important to consider the impacts on the industry, the administrative burden, and European industry competitiveness. However, from a sustainability point of view, it is clear that support must be given to the proposal, which in the long term may prove to be an investment in a stronger industry less dependent on conflict minerals, which ensures a green production of batteries. Today, the linear economy has been determining for the current industry, the legislation, and society. Even though some Member States have legislation that works well, it is not necessarily efficient regarding the circular economy. The review of the Battery Directive clearly presented several shortcomings that need to be addressed.

Furthermore, it is found that recent Ecodesign Regulations are setting circular economy requirements for products also benefitting the design and recycling of batteries. Examples are listed below:

- An information requirement related to the replaceability of batteries on all applications could help the user in choosing products that are easier to maintain, thus prolonging the lifetime of the battery-related product.
- Requirement of ease of disassembly used on a wider range of products could help prolong the lifetime of battery-related products, as the user can easily switch the battery at the battery's end-of-life. The requirement could also benefit the recycling of the products, as it would be easier to separate the battery from the electronic equipment.
- The information requirement related to cobalt could also improve the recycling rate of Lithium-ion batteries.
- If batteries (especially larger batteries) are considered a piece of equipment that can be repaired. Then the above-mentioned resource efficiency requirements can benefit an increase in reparation of batteries.

3 Today's practice regarding lithium-ion batteries

This section provides an overview of the most important aspects of lithium-ion (LIB) and similar battery technologies. The information feeds into specific recommendations on best practice and policy recommendations in Sections 6 and 6.3.3, respectively.

The section is structured following the life cycle of the batteries, as illustrated in Figure 3-1.

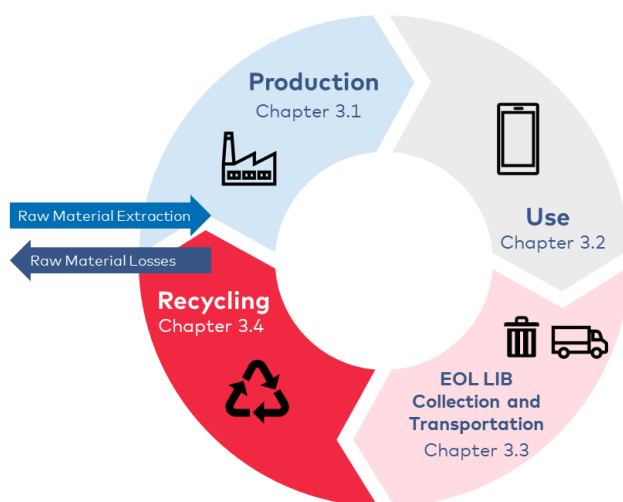


Figure 3-1. Illustration of the structure of Section 3, which follows the life cycle of a battery

Lithium-ion batteries and similar battery technologies are cornerstones in the transition towards a more sustainable future that reduces our dependency on fossil-fuel-dominated transport and energy sector by storing renewable energy and support demand flexibility. Batteries also provide consumers with the freedom of using products and appliances without the need for a cord. The trends show that in many consumer and industrial product categories, battery powered products e.g. power tools are becoming more common and are seen as a mainstream market trend, whereas just ten years ago they were considered niche products. Thus, batteries both increase the possibilities to store green energy and increase flexibility in consumers' daily lives.

The circle in Figure 3-1 is typical for product's life cycles, but what is special with lithium-ion batteries is that often they have a so-called second life in other applications than what they are designed for. This is especially valid for vehicle batteries and is elaborated more in detail in Section 3.2.

3.1 Production

This section presents how lithium-ion batteries work; the different components in a battery pack; how they are produced; which different chemistries that are used for which applications including their pros and cons. It also presents current and future volumes used for different applications and future development of new battery types are also presented.

3.1.1 The LIB supply chain

LIB production is very complex and involves several steps, from mining to battery pack production. Extraction of metals occurs in different parts of the world; however, China is currently dominating regarding cell production including cathode and anode production. Today they control more than 70 percent of the battery value chain⁶⁷. Some raw materials are critical (high supply risks and very economic important) for EU including cobalt, graphite and lithium⁶⁸. See Figure 3-2 for the production of an NMC cell containing Nickel, Cobalt, Manganese and Lithium in the cathode of the battery. See Section 3.1.2 for explanations of the different chemistries.

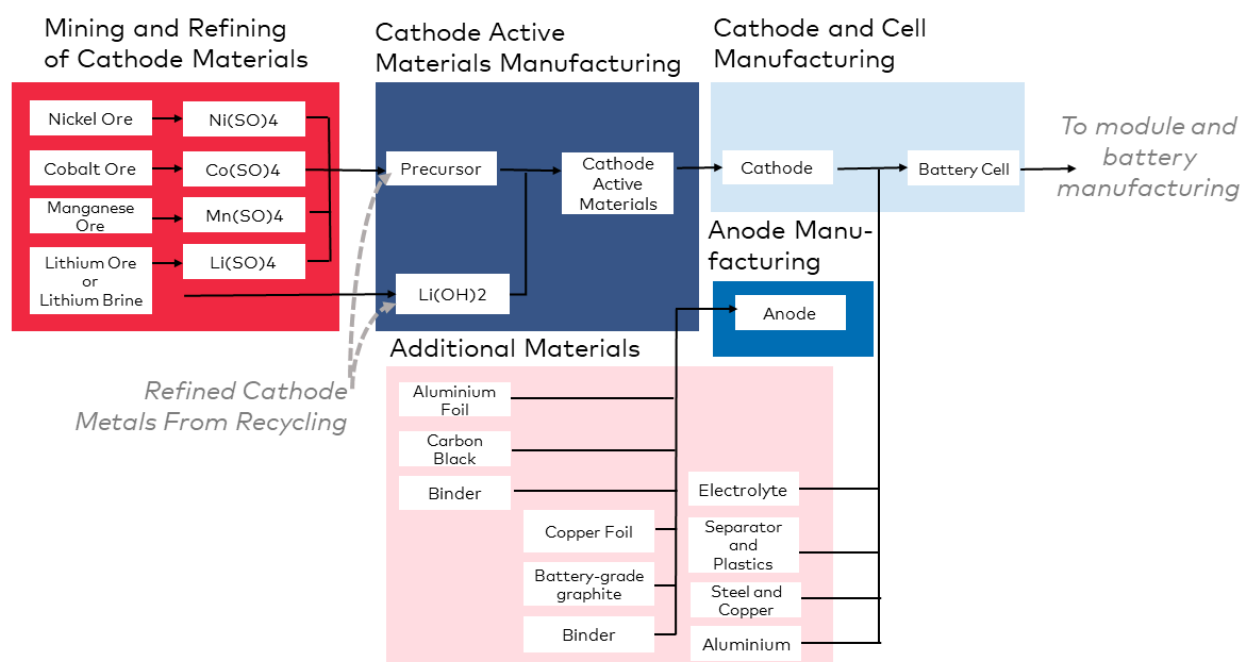


Figure 3-2. Lithium-ion cell production. The boxes represent the parts or materials. The arrows between the boxes often involve process steps. The figure shows the production steps with metals from natural resources. However recycling is also done to some extent for some battery producers, mainly in China⁶⁹. This diagram is based on a manufacturing process flow sheet.

67. Circular Energy Storage (2021) The lithium-ion battery life cycle report.

68. European Commission (2020). Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. A critical raw materials for EU has high economic importance and high supply risk for EU.

Metals are mined for the cathode, which occurs in different parts of the world. They are refined to sulphates or in the case of lithium, sometimes used as hydroxide. After mining and refining, the active cathode material is produced. Anode material is produced by mining or synthetic production of graphite and thereafter it is placed on a copper foil using a binder. In the cathode and cell manufacturing plant the cathode is made by applying the active materials onto an aluminium foil by using a binder. Thereafter, the battery cell is constructed with the anode, cathode, electrolyte, separator, plastics, steel, copper and aluminium.

The extraction of metals is highly impacting the environment and people working and living near the extraction sites, see further in Section 4.

3.1.2 LIB chemistries and their applications

A lithium-ion battery is rechargeable and the first commercial one was launched in 1991. It was such a breakthrough for the society that the invention of LIBs was awarded the Nobel price to the researchers Akira Yoshino, John B. Goodenough and M. Stanley Whittigham in 2019.

A very simplified picture of a rechargeable battery cell is found in Figure 3-3. The principle is that the small lithium ions are moving from the anode to the cathode while the battery is discharged and at the same time the released electrons cause electricity in a cable outside the battery.

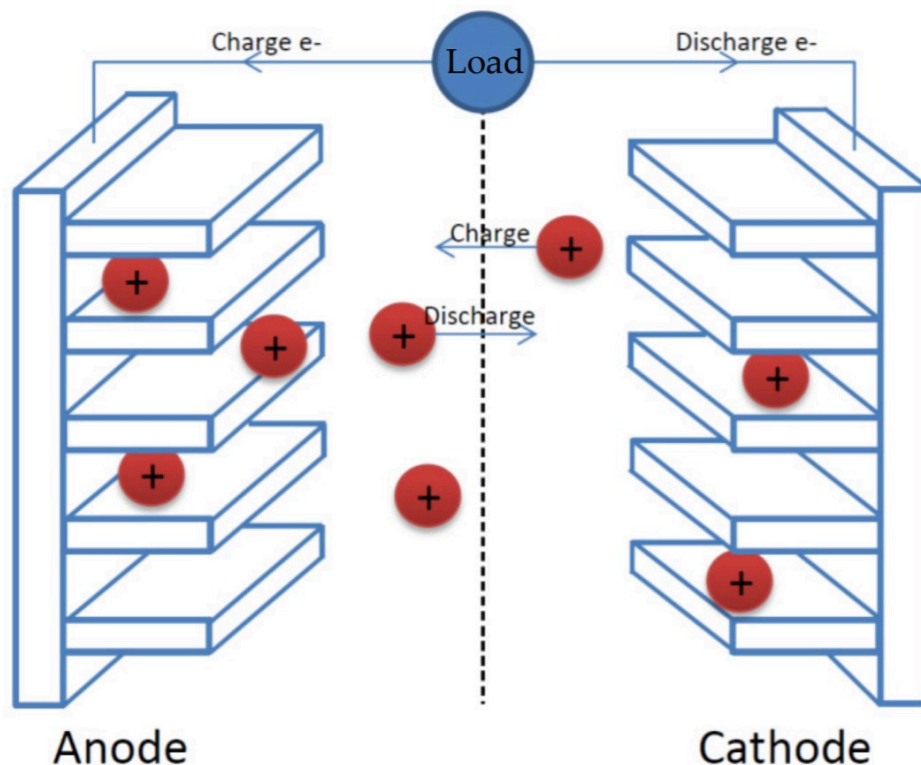


Figure 3-3. Simplified picture of a re-chargeable battery cell, such as in a lithium-ion battery.⁷⁰

69. Circular Energy Storage (2021) The lithium-ion battery life cycle report.

70. Romare Mia and Lisbeth Dahllöf, 2017. The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries. IVL report C243

The cathodes are made of different chemistries depending on the application and the anode is usually based on graphite with the exception of LTO chemistry, see Table 3-1.

Table 3-1. Chemistries for different applications of lithium-ion batteries.⁷¹

Chemistry	Cathode	Anode	Applications
LCO	LiCoO_2	Graphite	Mobile phones, laptops, tablets, cameras
LFP	LiFePO_4	Graphite	Electric cars (with lower demand of range) energy storage systems (ESS), power tools, utility vehicles, HEV buses, replacement of lead-acid batteries
LMO	LiMn_2O_4	Graphite	Older (and recently: new and relatively cheap) models of electric cars, power tools, medical devices, e-bikes, e-scooters
NCA	LiNiCoAlO_2	Graphite	Electric cars (Tesla), laptops, medical devices, e-scooters
NMC	LiNiMnCoO_2	Graphite	BEVs, power tools, energy storage systems (ESS), medical devices, e-bikes, industrial
LTO	LiNiMnCoO or LiMn_2O_4	$\text{Li}_4\text{Ti}_5\text{O}_{12}$	Electric buses (good for opportunity charging), e-bikes

The cells also contain a separator between anode and cathode, aluminium substrate in the cathode, copper substrate in the anode and electrolyte as also described in Section 3.1.1. The pack contains the battery cells put in modules, battery management system (BMS), cooling system and casing, see Figure 3-4.

71. <https://batteryuniversity.com/article/bu-205-types-of-lithium-ion>, Q2 2021

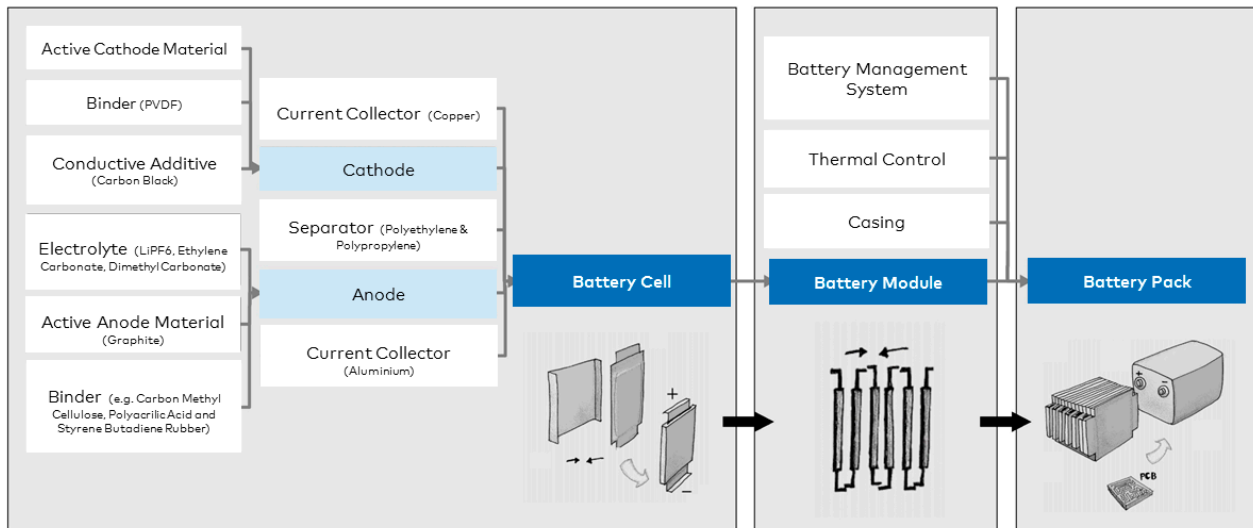


Figure 3-4. A diagram of the different components of a battery pack, a battery module, and a battery cell.^{72 73 74}

The cell chemistries have different pros and cons and some are more recently developed than others as summarised in Table 3-2.

Table 3-2: Comparison between technical properties of battery chemistries⁷⁵.

Chemistry and commercialization year	Specific energy capacity [Wh/kg], from low (red) to high (green)	Life span, from low (red) to high (green)	Specific power, from low (red) to high (green)	Safety, from low (red) to high (green)	Cost, from high (red) to low (green)	Performance, from low (red) to high (green)
LCO, 1991	150-200					
LFP, 1996	90-120					
LMO, 1996	100-150					
NCA, 1999	200-260					
NMC, 2008	150-220					
LTO, 2008	50-80					

The anode is, as mentioned above, usually made of natural or synthetic graphite. The LTO chemistry regards the anode, for the other chemistries, the abbreviations regard the cathode.

The way in which batteries are used varies between applications. Powertools require

72. 2018 Ellingsen L., Hung C. Research for TRAN Committee

73. Update of bill-of-materials and cathode materials production for lithium-ion batteries in the GREET® model

74. 2013 Olofsson Y., Romare M., Master of Science Thesis: Life Cycle Assessment of Lithium-ion Batteries for Plug-in Hybrid Buses

75. Romare Mia and Lisbeth Dahlöf, 2017. The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries. IVL report C243

high power and usually do not have high requirements for energy mass density, while light BEVs need a higher energy capacity to last for driving long distances. The chemistries with highest energy mass density are LCO (the oldest on the market in the list), NCA and NMC. These chemistries are thus well suited for products that need relatively small batteries to either fit into a smaller space (such as in laptops, smartphones and other smaller devices), or to keep a low weight (for energy efficiency) in vehicles, or a combination of both. However, LCO, NCA, and NMC batteries are not so safe regarding safety risks such as catching fire. Ageing is also an issue for LCO batteries as well as specific power, which is a reason for why LCO is not well suited for vehicles.

LFP batteries do not have a very high specific energy capacity (i.e., energy mass density), but the specific power, safety, and lifespan are quite good, which is why they are suitable for buses (which usually drive close to charging stations), energy storage systems (ESSs) (which are stationary) and power tools. They are also used for cars where the range has not the highest priority. In 2020, the "blade" design of LFP batteries which uses only 50% of the volume in the vehicle compared to traditional LFP batteries was launched⁷⁶. They are or will be used both in cars with lower demand regarding range (BYD, VW⁷⁷, Tesla) and heavy duty battery-powered EVs. They are cheaper and safer than NMC and NCA chemistry. Also, Chinese authorities have tightened the safety requirements and are therefore promoting LFP batteries⁷⁸.

LTO batteries have low specific energy capacity, but are also cheaper, which is why they are used in buses that are to be charged often and for e-bikes. LFP and LTO batteries have the longest life spans. LMO batteries are usually for cars, but have been replaced by NMC, NCA and LFP batteries due to the inferior performance. But there may be a small comeback for manganese rich chemistry (LMO) as VW have announced for volume cars, but a variation of the "old" LMO type of chemistry⁷⁹.

A quantitative view of actual use of different chemistries of lithium-ion batteries in different market segments in Europe is found in Figure 35. The main use of the batteries is for cars as calculated in energy storage capacity, followed by portable batteries and after that, industrial, heavy electric vehicles, energy storage systems (stationary, ESS (Energy Storage Systems), personal mobility, uninterruptible power supply (UPS) and for maritime usage.

76. <https://www.rsa.no/en/nyhet/?title=BYD+Blade-batteri+er+klar+til+%C3%A5+revolusjonere+elbil-markedet%21&id=17903403> Q3 2021.

77. https://www.greencarreports.com/news/1131590_volkswagen-chases-tesla-into-the-battery-business-to-enable-its-ev-shift Q3 2021

78. omEV newsletter (October 9, 2020 issue) <https://omev.se/>, Q4 2020 (in Swedish)

79. <https://www.electrichybridvehicletechnology.com/features/dtechex-commentary-on-vws-long-term-high-manganese-cathode-strategy.html>, Q3 2021

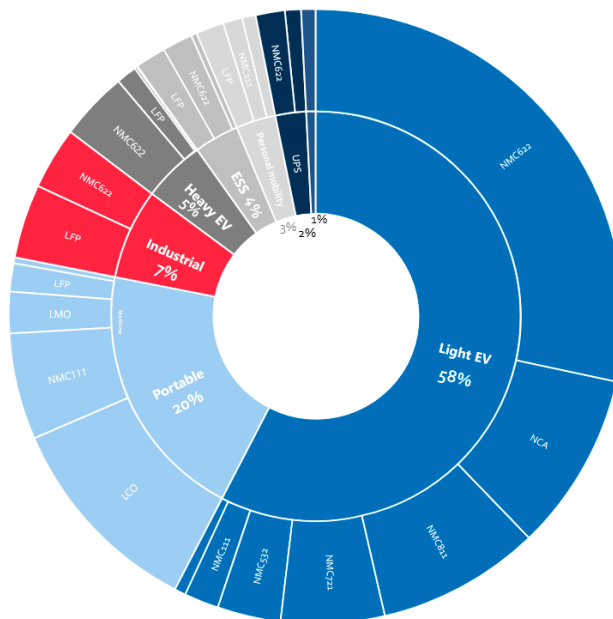


Figure 3-5: Current placed on market of different chemistries in Europe (EEA and Switzerland) measured in GWh⁸⁰ (Portable: Computers, laptops, smartphones, power tools; Personal mobility: E-scooters and other smaller mobility devices; Light EV: Cars; Heavy EV: buses and trucks; Industrial: For industrial applications such as forklifts; ESS: Energy Storage Systems (Stationary); UPS: Uninterruptible power Supply; Maritime: ships)

The figure distinguishes between different NMC metal ratios. I.e. the NMC532 cathode has an approximately 5:3:2 ratio of nickel:manganese:cobalt. Chemistries with higher nickel content (e.g. NMC811) are newer chemistries than those with lower nickel content (e.g. NMC111).

To summarize the figures above, the most common chemistry for portable devices excluding power tools is LCO; for power tools NMC, but LFP or LMO are also possible, and for cars NMC or NCA are the most popular in Europe. For HEVs (hybrid electric vehicles), NMC 622 is currently popular, and for e-scooters NCA.

The shapes of the cells are categorized into three different types: cylindrical, pouch, and prismatic. All are used for automotive applications. In new slim laptops, lithium-polymer cells with gel-based electrolyte and no casing is used. Cylindrical cells are the most important for power tools and they are also used in the laptop industry and for personal mobility.

3.1.3 Trends for future LIB and other battery chemistries

The trends for coming years for the battery chemistries in products is not only relevant for the raw material required at the production, but also for the volumes of batteries entering recycling. This is because the chemistries determine the amount of specific raw materials (e.g., cobalt and nickel), which can be recovered. More information about LIB recycling is found in Section 3.4.

80. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com/copy-of-placed-on-market-3> (paid subscription) Q3 2021

There is much research going on for new chemistries, and the main drivers are energy density increase to increase the range for cars, to reduce costs and reduce the need for critical raw materials such as cobalt. Safety is also high up on the agenda. As seen in an extraction from the roadmap in the EU research initiative Battery 2030+ in Figure 36 the trends are leaning towards using more nickel (and less cobalt) in the batteries and towards higher energy density, and in 2030 we can expect, for example, solid state batteries and lithium metal as anode. It is also likely that the market for already-developed chemistries like LFP and manganese batteries will become more important. The re-introduction of these chemistries is a current trend in the automotive sector. The reason that consumers and companies find the lower range acceptable for automotive applications is that the vehicles can be made cheaper and safer at the same time.

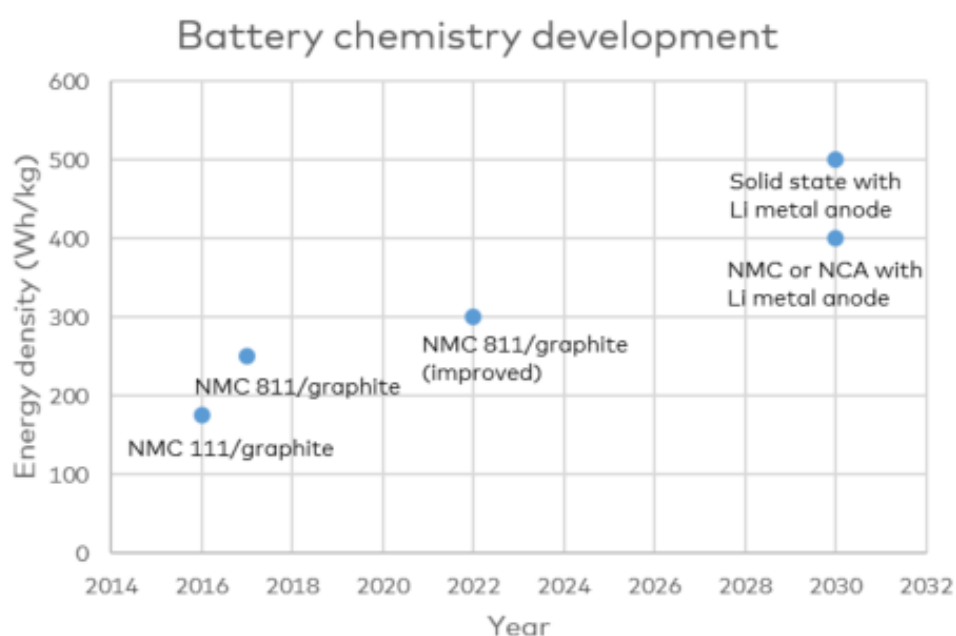


Figure 3-6. Battery chemistry development. Extracted from the European roadmap for battery development for a climate neutral society.⁸¹

According to the roadmap in the European project Battery 2030+ a holistic view is important and therefore identification of the battery chemistries and proper recycling technology are included as important aspects as the chemistry itself⁸². Chapter 3.4 will discuss the recycling of LIBs.

New types that are not lithium-ion based may become important for niche products, for example sodium batteries. According to the Swedish company Altris, they have similar performance as LFP, but ageing is not yet fully known, and the physical volume is currently higher compared to LIBs⁸³. Future applications of sodium batteries may be cheaper cars where LFP is currently used, e-bikes/scooters, power-

81. <https://battery2030.eu/research/roadmap/> Q2 2021

82. <https://battery2030.eu/research/roadmap/> Q2 2021

83. Altris, 2021. Personal communication with CEO Adam Dahlquist in Q2 2021

tools, stationary storage, buses and construction equipment⁸⁴. Interesting is that CATL recently has launched their first sodium-ion battery⁸⁵.

Below in Figure 3-7 are the current and projected chemistries placed on market for lithium-ion batteries in Europe as measured and calculated by the company Circular Energy Storage⁸⁶. The author compared his forecast of the total volume with nine other forecasts and concluded that five of the nine forecasts were lower and four higher in volume. The author also states that silicon-based anodes, solid or gel-based electrolytes as well as new cell formats will be introduced at scale and probably new battery types will be marginal and used for niche applications during this period.

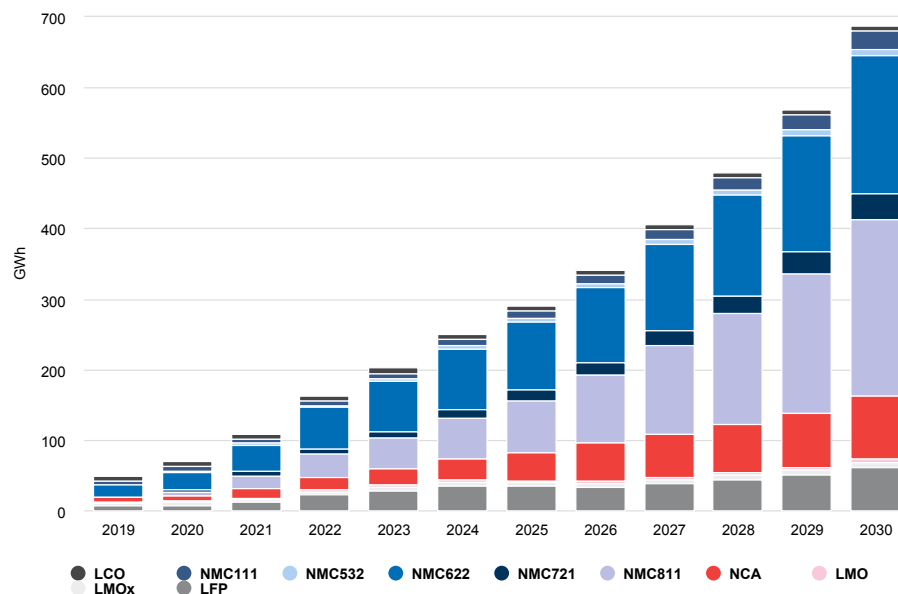


Figure 3-7. Current and future lithium-ion chemistry volumes placed on market in Europe measured in GWh⁸⁷

It is important to remember that the scenario in this graph is based several assumptions, which may or may not be true for the future. In this and the previous Section 3.1.2 the discussion about the battery chemistries has shown that there are many directions for future development of the market. For example, LFP and manganese chemistry may have a greater “comeback”, and maybe sodium-ion batteries will replace lithium-ion ones earlier than expected. Thus, future developments in battery chemistries may change the direction in which battery technologies are found in different market segments, and the market as a whole.

84. <https://battery2030.eu/research/roadmap/> Q2 2010

85. <https://www.greencarcongress.com/2021/07/20210730-catl.html> Q3 2021

86. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com> (paid subscription) Retrieved from the Internet and re-calculated in Q3 2021.

87. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com> (paid subscription) Retrieved from the Internet and re-calculated in Q3 2021.

3.1.4 Trends for sales and stock of LIBs based by application in the Nordics

The following section will discuss the trends for the sales of LIBs by application rather than by battery chemistry. Data for all of the EU has been collected and prepared by Circular Energy Storage and is at a higher resolution than what is available for the Nordics. Although the data for the EU is different than that of the Nordics, the general trend is most likely similar. Thus, both European and Nordic statistics are shown below.

As mentioned previously, today the key market sectors in the EU for LIBs are automotive and to a smaller extent portable devices. The growth for markets sold in each market in the coming 10-15 years will probably mainly be on the automotive side, which we can see in a scenario for Europe below in Figure 3-8. The increase in volumes of batteries in portable devices appears to be much smaller in comparison to automotive applications. LIBs for stationary energy storage (ESS) will begin increasing between mainly between 2021 and 2025 while maritime batteries hit an increase between the years 2025 and 2030. To get an idea on how much these volumes of batteries placed on market would be per person, data shows that the number was roughly 0.2 kWh/European inhabitant in 2021.⁸⁸

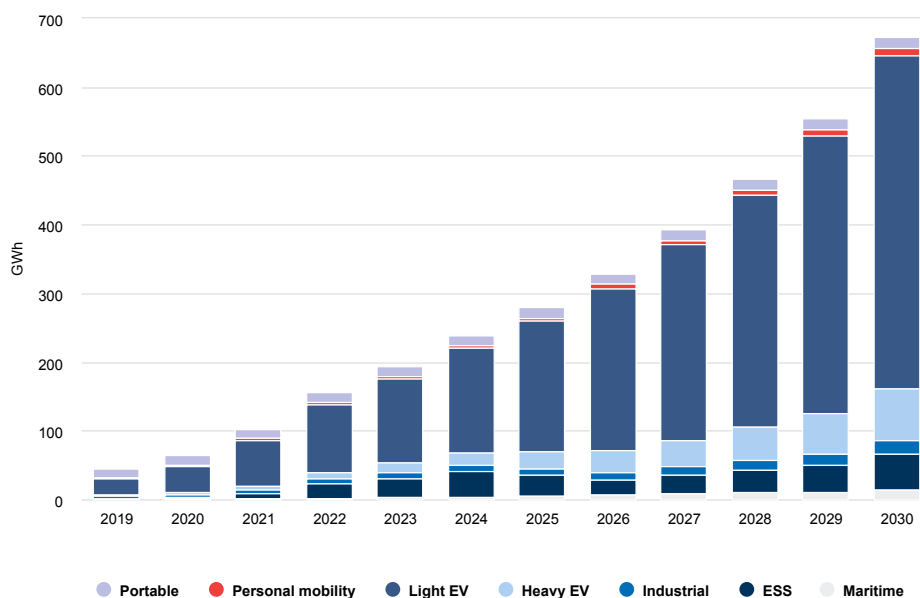


Figure 3-8. Actual and predicted amount of lithium-ion batteries placed on market in EU (Including UK) for different usage.⁸⁹

Statistics and scenarios for the Nordic sales are shown in Figure 3-992 below, and here it is clear that sales for pure electric (BEV) passenger cars are dominating the growth. Other important products - which are growing considerably up to 2030 - are passenger car PHEVs, busses, and LCV (light commercial vehicles). Also batteries in power tools and tablet and smartphones have been sold more and will continue to

88. https://europa.eu/european-union/about-eu/figures/living_en, <https://www.worldometers.info/world-population/uk-population/>, Circular Energy Storage (2020) <https://www.circularenergystorage-online.com/copy-of-placed-on-market-3> (paid subscription) Q3 2021

89. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com> (paid subscription) Q3 2021

increase until 2030. In terms of battery mass, the weights for other small electronics (e.g. notebooks, portable speakers, vacuum cleaners) and e-bikes have quite a small percentage of the total weight of batteries sold.

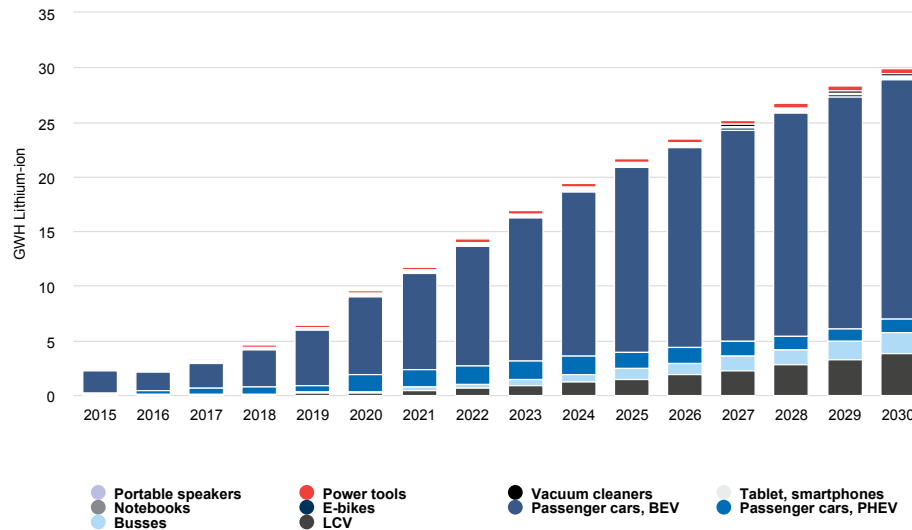


Figure 3-9. LIB sale development by products in the Nordics.

Figure 3-10 shows the battery sales per capita, excluding the passenger cars, buses and LCVs from Figure 3-9⁹⁰. Compared to the graph for Europe in Figure 3-5, the trends show that the use of batteries for each individual is increasing.

Almost all categories are growing, except for tablets & smartphones and notebooks, which seem to stabilise. The growth in the other categories (portable speakers, power tools, vacuum cleaners, and e-bikes) may be due to the adoption of battery powered products, which were less common in the past.

90. Product battery sales and stock are not reported on country level, because the estimates are based on European market developments and divided by the share of people living in the Nordics. The assumptions used do therefore not allow for differences, in product battery sales, on a country level. However, it is also assumed that the Nordic countries have similar consumer buying behavior of the battery driven products show in the related graph.

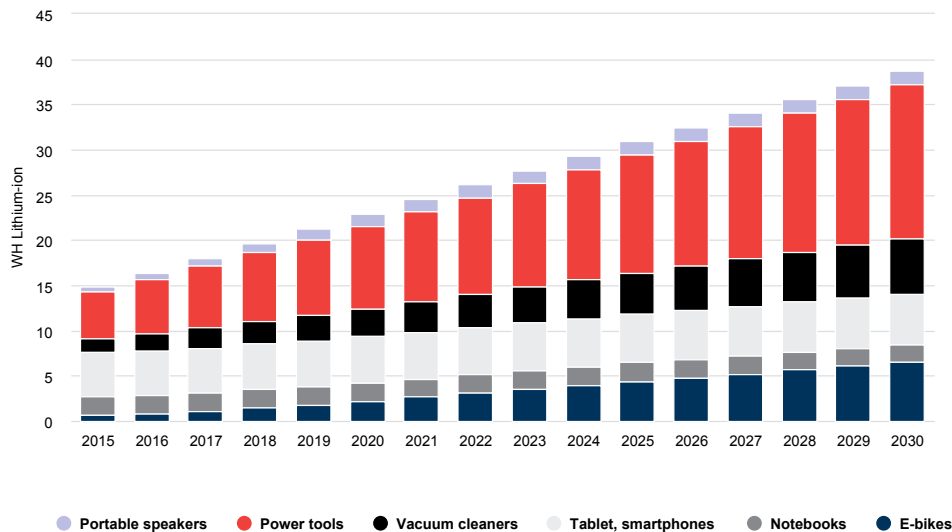


Figure 3-10. LIB sale development by products in the Nordics, per capita.

Figure 3-11 shows the battery weight for sales of electrified vehicles by country, per capita, in the Nordics. The top three in 2020 are Norwegian passenger cars (BEV), Swedish passenger cars (BEV), and Danish passenger cars (BEV). In 2030 the trend is that Finnish passenger cars (BEV) will overtake both the former Danish and Swedish top places in 2020. Norwegian LCVs are also expected to increase in up to 2030.

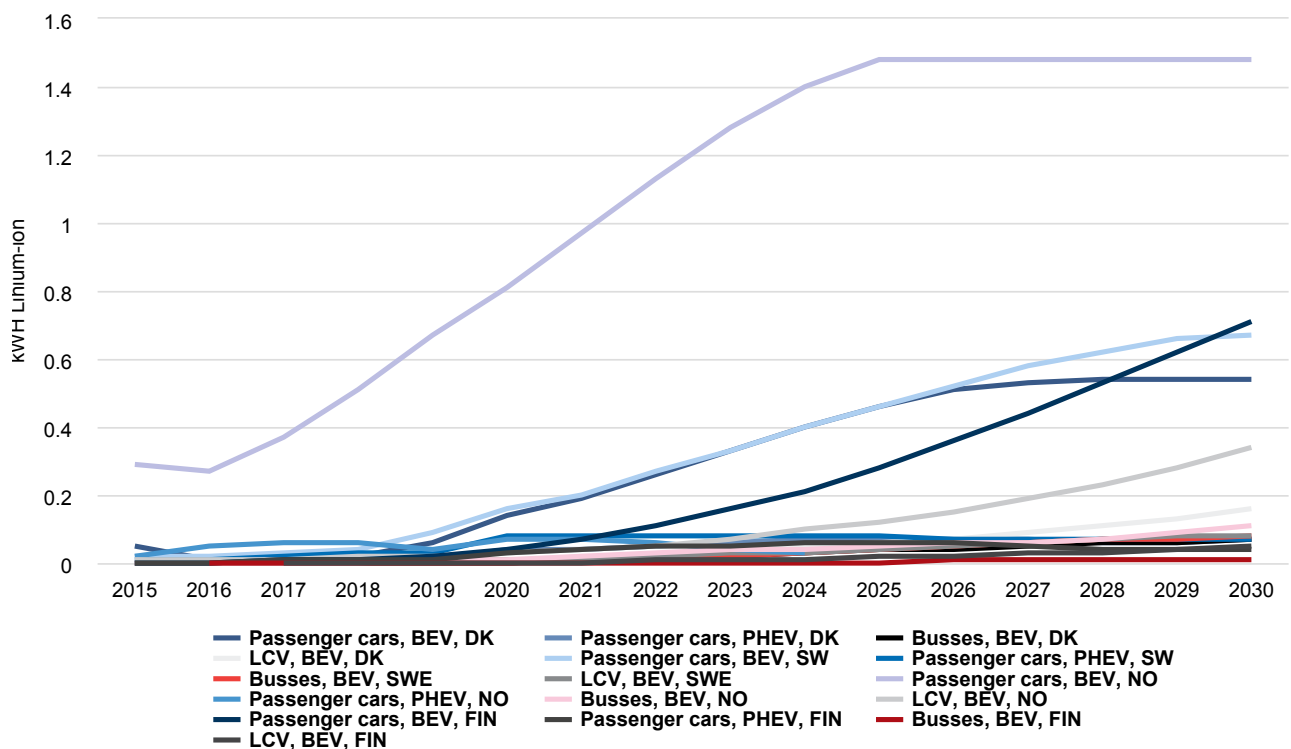


Figure 3-11. Vehicle battery sales, by country, per capita.
2015–2020 Historic data, 2020–2030 Forecasted data

Figure 3-12 shows LIB stocks by product in the Nordics. Not surprisingly, the largest stock is from passenger cars (BEV), but also passenger cars (PHEVs), LCVs, and buses are notable. The volumes of other applications are so small that they are barely legible. Note that some categories are not included in this graph due to lack of data, such as stationary energy storage, industrial, heavy EV and maritime batteries, which were included in the similar chart for EU in Figure 3-8.

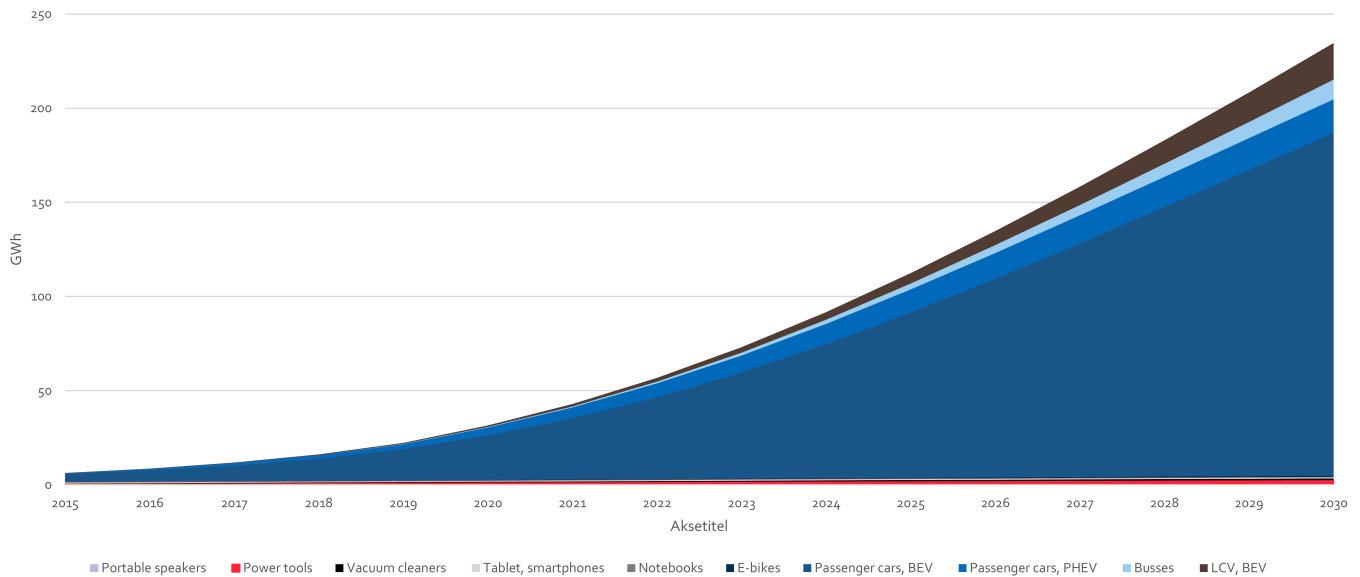


Figure 3-12. LIB stock by product in the Nordics

Figure 3-13 shows the product battery stock in the Nordic per capita. The pattern of the stock is similar to the pattern of sales of other battery driven products. The stock of batteries used in power tools, vacuum cleaners and e-bikes is expected to grow. While the share of tablets/smartphones, notebooks and potable speakers are expected to remain more or less at the same level, as now, because the market is more saturated.

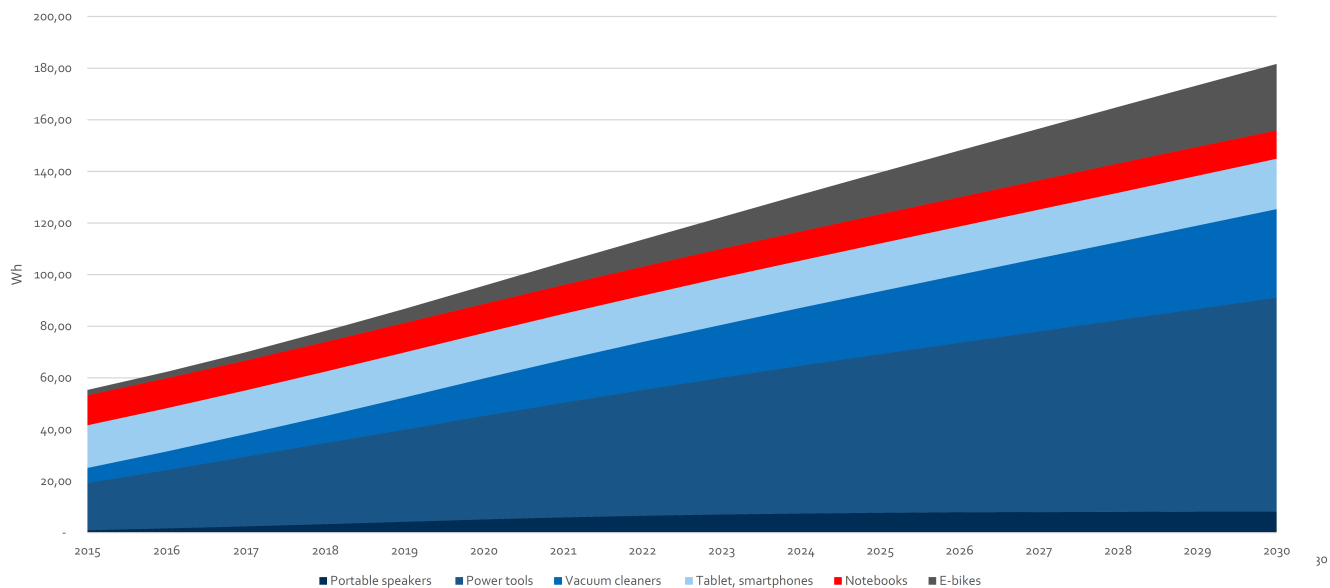


Figure 3-13. LIB stock by product in the Nordics, per capita.

Looking at vehicles batteries per capita in Figure 3-14, the high penetration rate of passenger BEVs in Norway compared to the rest of the Nordics is very clear. This is a result of the progressive policy carried out by the Norwegian government, who has set a goal that all new passenger cars and light vans sold should be zero-emission by 2025⁹¹. Finland, Sweden and Denmark also have a high amount of kWh per capita.

The Nordics have set ambitious targets for busses and LCV (e.g. Norway have set a target of 75% zero emission busses in 2030⁹²), however, the stock per capita is rather low, which could be caused by a number of reasons, such as the personal car being the prefer method of transportation and the fact that busses can carry more people.

91. <https://www.regjeringen.no/en/topics/transport-and-communications/veg/faktaartikler-vei-og-ts/norway-is-electric/id2677481/>

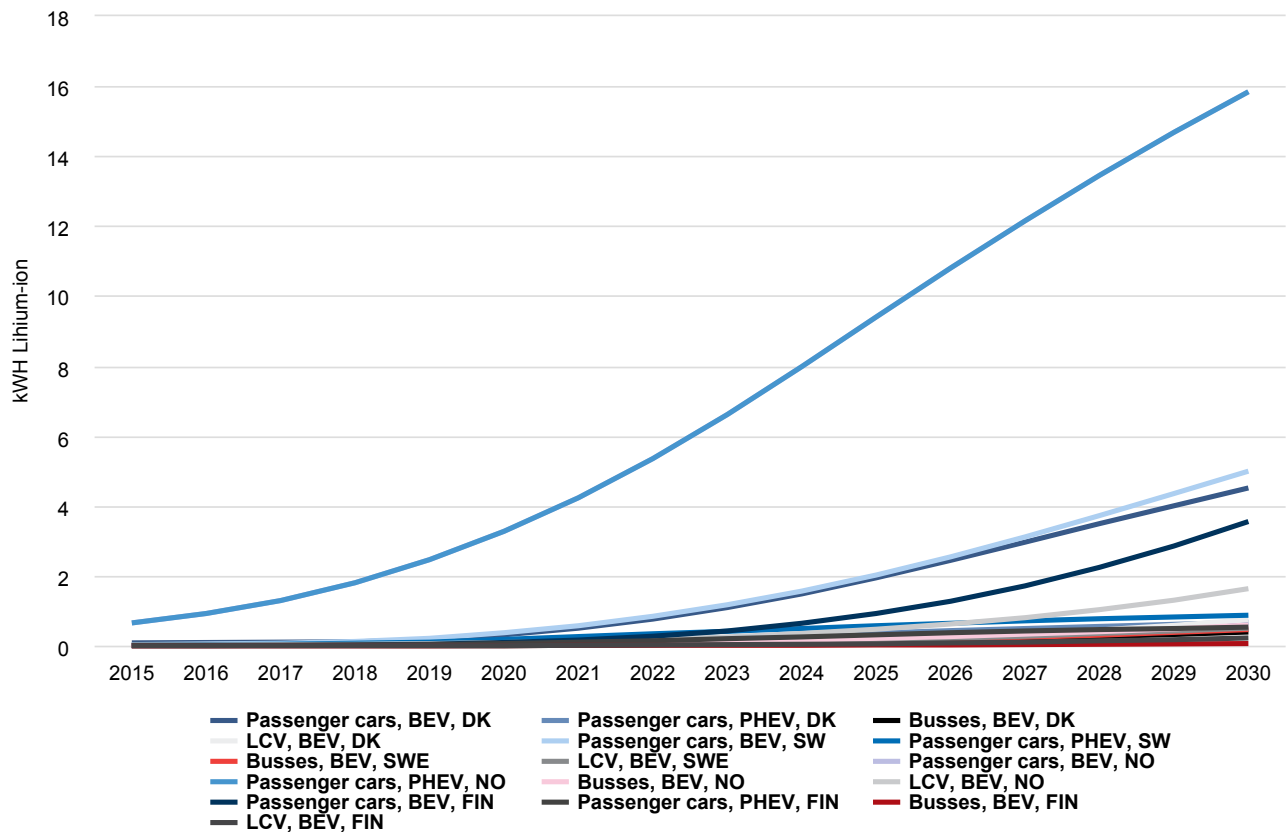


Figure 3-14. Vehicle battery stock, by country, per capita.
2015–2020 Historic data, 2020–2030 Forecasted data

3.2 Use

The main use is for automotive application and the second largest use is for portable devices, assuming that the pattern seen in Europe also applies for the Nordics, see Figure 3-5.

For some usages, for example for power tools, high power and thus high C-rate (high current) is needed from the battery, but the energy storing capacity may be lower. Since it varies how much time you use the tool per use, the battery is often overdimensioned for private use.

If the replaceable battery can be used for different appliances, the battery is probably overdimensioned for some of the applications. For other applications, you may need the full capacity and even have a spare battery for longer use.

For portable batteries for portable electronics such as smartphones, laptops, tablets, loudspeakers, the batteries are built-in and laymen often may not be able to replace them; especially for waterproof products.

For lightweight EVs, energy storage capacity is key together with low weight i.e. high energy density. The batteries are usually difficult to replace, but for some brands it is easier such as for Nio where the design is for battery swapping as a supplement to battery charging⁹².

92. <https://www.nio.com/nio-power>.

Charged batteries are to more or less extent safe because different chemistries have different risk for catching fire. LFP cathodes and LTO anodes are safer than other chemistries. Also, there are differences in quality affecting the risk. To avoid excessive wear, the BMS (Battery Management System) used in appliances and vehicles, controls the charging and the use of the battery. Nevertheless, there is always a certain risk for catching fire while charging or when the battery is in use and therefore it is important to handle the battery with care and be observant on failure.

3.2.1 After first use: Reuse or remanufacturing

Especially for replaced automotive batteries, typically, the batteries still have energy capacity left, which give opportunities for refurbishment or remanufacturing and achieving a second life in vehicles or in other application e.g. for energy storage in buildings or as electric grid support. As long as there is a market and a value of these second life batteries, a larger part of the technical lifetime of the batteries are likely to be achieved before scrapped.

It is very costly to send batteries to recycling in Europe while shipping them to China, you may get better paid by the recycler, who is often also producer of new battery precursor materials.

For heavy duty vehicle purposes, a certain range is often a requirement, and often there is a need for battery replacement if state of charge reaches about 70–80% of the factory capacity. Contrary, many private car owners may accept shorter ranges and will not replace the battery, even though it is below e.g. 70%–80% for cost reasons.

How long batteries will last depend not only on ageing, but to a large extent how fast they are charged and discharged, and also how deeply they are discharged before charging. It is better to keep the battery stored at a high state of charge.

Light EVs will last for on average 15 years mainly depending on how they are used. Larger batteries are expected to last longer than smaller batteries for the same use, since often, they are not as deeply discharged. Batteries for busses are used much more and therefore replaced earlier. The bus design makes them easy to replace. Replacing batteries may be part of the business model, which may include second-use of replaced batteries e.g. for stationary energy storage.

Regarding heavy-duty trucks, the usage will differ a lot, but the business model may be the same as for busses including second-use.

Usually the mobile devices (mobile phones, notebooks, etc.) are handed in before the batteries are worn out, although more and more people keep them longer. When the battery is worn out, some people use a power bank, keep the device plugged in, or will have the battery replaced at a repair shop. You may also hand the old one in when buying a new device and they are then often refurbished and sold.

For EV batteries, it is common to send for a second life for industrial or commercial

energy storage^{93 94 95}. In Sweden for example, many used EV batteries are sent to the real estate market and used in the rooftops of buildings to store energy produced by solar panels⁹⁶. Before second use, adaption of the new type of use is needed using data from the BMS, which in many cases is not satisfactory for the purpose of next life. There may also be issues regarding prediction of ageing of the used batteries and therefore warranty if batteries are unexpectedly rapidly ageing.

According to Inrego, for electronic devices, the main approach currently is to fully replace the batteries with new ones rather than to repair old batteries. This is because: 1) the labour and resources involved to repair old batteries is expensive, and it is not profitable to repair old batteries but cheaper to buy new ones instead. 2) Consumers also have a high expectation for battery quality and charging life. For example, when the battery health falls below 80%, consumers often would want a new one, and 3) there are currently no standard processes or underlying legislation for repairing electronics batteries. It can be dangerous and environmentally hazardous to do it (e.g., when the battery is opened). Most of the batteries from used devices are sent directly to recycling.⁹⁷

Currently, the largest volumes in Europe of second life batteries in use, approximately 305 MWh, are for energy storage systems for the grid market, but in China the volumes are much higher.^{98 99}

3.3 End of life LIB collection and transportation

This section presents what happens when LIBs reach their last EOL. The last EOL means the battery will no longer serve any functions for any application.

3.3.1 After the battery's last EOL (Users, Collectors and Black Market)

After the user is no longer using the product and wants to scrap it, the ownership of the battery becomes of high importance. The Extender Producer Responsibility (EPR) for batteries means that the company placing the batteries on the market is responsible for their collection when they are scrapped by the consumer. Usually, it is solved by dedicated collector companies, such as for example Elkretsen¹⁰⁰ in Sweden, Batteriretur in Norway, and Recser Oy & ERP Finland ry in Finland¹⁰¹. Another word for these companies, which take over the EPR obligations for producers, is Producer Responsibility Organisations (PROs).

However, if the responsibility changes, it can have some effects on the industry. According to Christian Rosenkilde at Norsk Hydro, scrap yards are generally looking more dynamically for the highest bidder and do not really care who to sell it to, while

93. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021.

94. Fortum (mechanical and hydrometallurgical recycler) interview with Martina Elander and Janne Koivisto conducted by Alexandra Wu and Erik Emilsson. Q2 2021.

95. Urecycle interview conducted by Alexandra Wu. Q1 2021.

96. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021.

97. Inrego interview with Sebastian Holmström conducted by Johan Holmqvist & Alexandra Wu. Q2 2021.

98. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com/copy-of-recycled> (paid subscription) Retrieved from the Internet and re-calculated Q3 2021.

99. Circular Energy Storage (2021) The lithium-ion battery life cycle report.

100. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021.

101. Environment.fi https://www.ymparisto.fi/en-us/Consumption_and_production/Waste_and_waste_management/Producer_responsibility/Batteries_and_accumulators Retrieved Q3 2021.

OEMs likely have more concern about sustainability and would thus be more interested in who they sell it to.¹⁰²

Sometimes it should be decided if a battery should go for a second life or recycled. Christian Rosenkilde at Norsk Hydro informs that knowing the content of batteries can help in considering if it is more optimal to use the batteries for second life or for recycling. E.g., new chemistries have less cobalt, so one old NMC111 battery can be used for producing perhaps five NMC811 batteries.¹⁰³

There are no legal requirements for the owner of a battery to send it for recycling when it is no longer used by the consumer, which is why many end-of-life batteries for consumer electronics may stay in with the original owner for many years instead of getting recycled. For EV batteries, like LFP batteries, batteries may be disassembled from buses and left in storage indefinitely until a purpose for them is found.

Many small batteries are not collected for battery recycling because they are integrated into the device and cannot be disassembled. They may therefore end up in electronic (WEEE) recycling instead where there is only little chance for the battery metals to be recycled. It is not always the consumers responsibility, when recycling of small electronics does not take place. A recent Swedish survey from 2020 showed that 36% of respondents answered that they leave end-of-life batteries in battery boxes, 28% in recycling centres, 19% in waste separation rooms near households, 8% in storage at home, and 2% throw them in the non-recycleable waste bin (combustible waste).¹⁰⁴

EV batteries are supposed to be removed during the pretreatment process to comply with the ELV Directive (Directive on end-of-life vehicle), and the percent of batteries for which it takes place should be high as it directly correlates with the stock available for the recycling industry. Obtaining batteries for recycling relies on getting the batteries from the EOL EVs, but the value of LIBs creates an incentive for illegal dismantling.

The EU is already losing track of a large part of the vehicle stocks, shown to be about 38% vehicles in a 2014 study¹⁰⁵. Some additional reasons for the high number in the study include lack of tracking of vehicles between country borders in the EU, and lack of collection points.¹⁰⁶ Tracking will be important to ensure that as much of the LIBs are returning to recycle, to ensure circularity.

102. Norks Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

103. Norks Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

104. Natruvårdsverket. Batterier och elavfall, attitydundersökning 2020. Link: <https://www.naturvardsverket.se/producentansvar-batterier>. Accessed Q3 2021.

105. 2017. Oeko-Institut. Assessment of the implementation of directive 2000/53/eu on end-of-life vehicles (the ELV directive) with emphasis on the end of life vehicles of unknown whereabouts.

106. 2020 William Bergh. Master Thesis at Lund University. Mapping the European Reverse Logistics of Electric Vehicle Batteries.

3.3.2 Flows of batteries available for recycling in the Nordics

This section will present the recycling rates and discuss the impact of the battery chemistry and trends. The data here differs from Figure 3-7 and Figure 3-8 (sales figures) since here data are for EOL batteries each year, not for batteries sold each year. Most recycling data are still currently only available for the EU, but it is complemented with input from experts in the recycling industry.

Below in Figure 3-15 and Figure 3-16, trends are shown from which type of applications the batteries available for recycling come and what kind of chemistries we expect will to be available for recycling in the near future in Europe as measured and estimated by the company Circular Energy Storage.

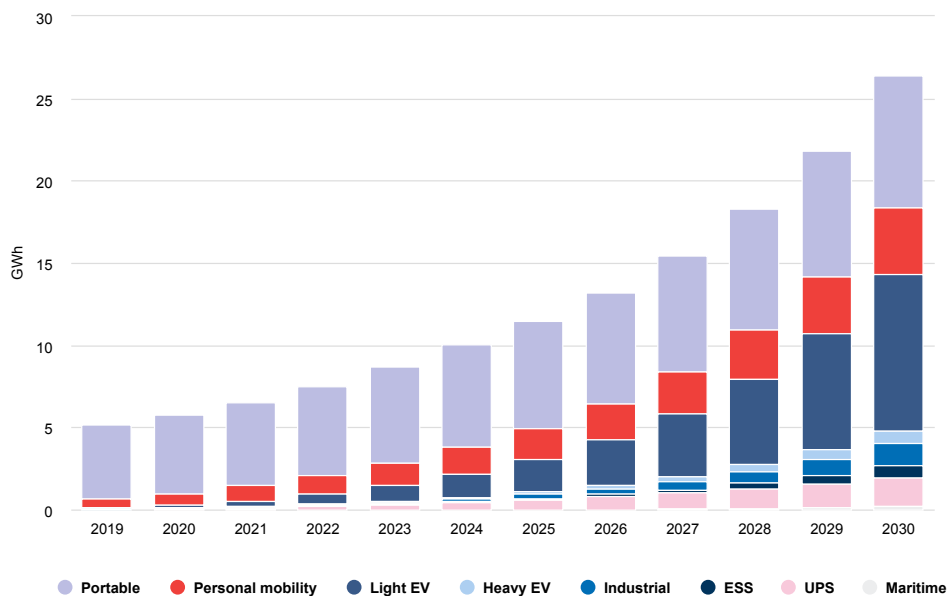


Figure 3-15. Current and projected lithium-ion batteries available for recycling in Europe¹⁰⁷

107. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com> (paid subscription) Retrieved from the Internet and re-calculated in Q3 2021.

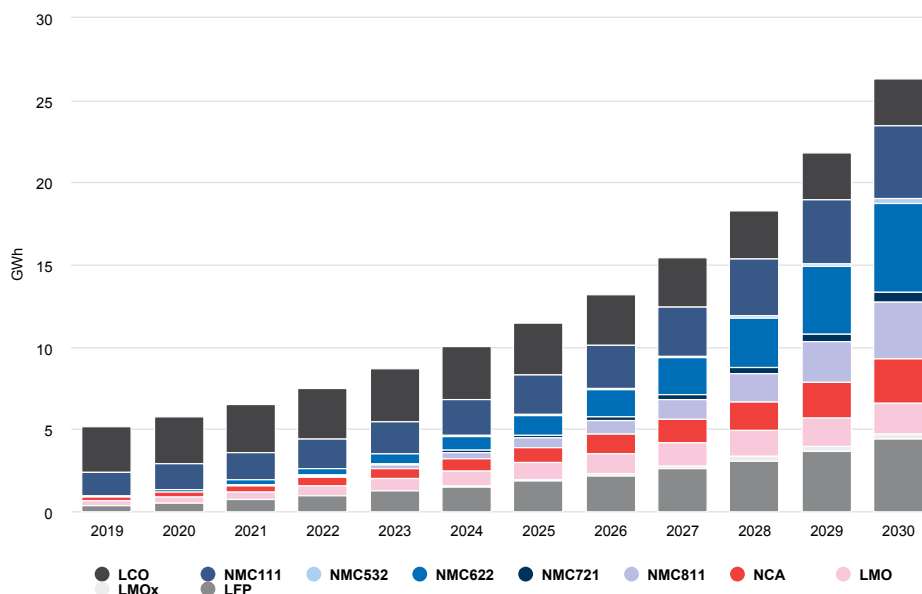


Figure 3-16. Current and projected lithium-ion battery chemistries available for recycling in Europe¹⁰⁸

Looking at Figure 3-10, it is clear that the batteries available for recycling shift from being almost entirely from portable devices to being dominated by light EVs, personal mobility and UPS (uninterruptable power supplies) in 2030. Figure 3-11 shows that the trend in battery chemistries available is moving from mainly LCO and NMC111 to being mostly NMC622, NMC111, LFP, and NMC811. For both, the volumes are increasing from just over 5 GWh to just over 25 GWh in the coming decade, a 400% increase.

Until now, the volumes of used batteries sent for recycling from automotive have been very low, since it turned out that they last in a car for about 14 years¹⁰⁹, whereas bus batteries have a shorter life. So, the scrapped car batteries come from in-warranty replacements, road accidents and end-of-life vehicles. For buses the scrapping is more planned and occurs when the battery reaches a certain state of health of after a certain number of kilometres driven.

Figure 3-15 and Figure 3-16 show only part of the batteries that are available for recyclers, as there is also scrap from battery production and batteries from recalled EV LIBs. Norsk Hydro has seen that although the larger volumes of EOL EV LIBs arriving at recyclers were shown to become significant in about 2025, the number of recalls of LIBs in EVs have been much higher than previously anticipated. These battery packs with design flaws are recycled, and the EVs from which they came have to be replaced with new batteries. Production scrap is another source of battery material available for recycling to battery recyclers. Recyclers are generally able to get information from the producers about the chemistry in the production scrap, so it is easier to recycle.

108. Naturvårdsverket. Batterier och elavfall, attitydundersökning 2020. Link: <https://www.naturvardsverket.se/producentansvar-batterier>. Accessed Q3 2021.

109. Nordic Council of Ministers, Nordic Council of Ministers Secretariat. Dahllöf L., Romare M., Wu A., Mapping of lithium-ion batteries for vehicles: A study of their fate in the Nordic countries.

3.4 Recycling

This section will describe several aspects of battery recycling in the Nordics: the processes and technologies available, some of the major actors in the EoL LIB supply chain and some points on the current recycling rate in the Nordics.

3.1.4 Recycling technologies overview

There is a lot of variation when it comes to recycling between what types of recycling is performed and what actors are involved. Even within the bigger recycling categories, such as hydrometallurgy or pyrometallurgy, there can be major differences in how companies perform the recycling. Figure 3-17 shows the main steps and some of the options for technologies available for recycling LIBs. Differences that different actors in the recycling chain choose may include: what metals and other materials are recovered, what percentage of cobalt/nickel/lithium/manganese are recovered, what type of solvents are used in hydrometallurgical recycling and what type of pretreatment is done.

Note that LIB recycling pre-treatment is different from vehicle pre-treatment. During the vehicle pre-treatment, the lithium ion battery and surrounding electronics are removed from the vehicles whereas during LIB pre-treatment, the LIBs undergo special processes for recycling.

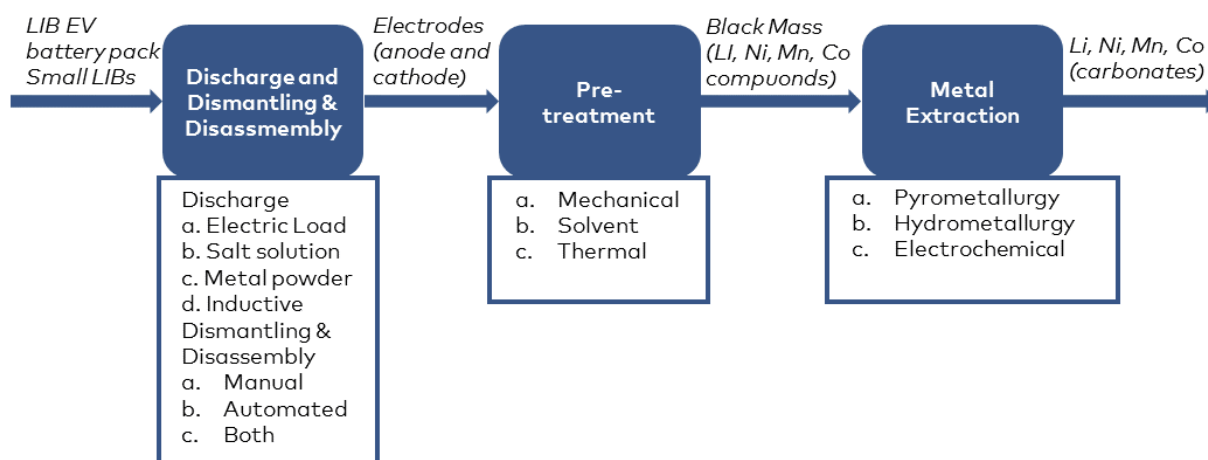


Figure 3-17. Simplified overview of options for recycling steps and technology choices for LIBs. Inspired by Bae H. & Kim Y. (2021)¹¹⁰ and Nembhard N. (2019)¹¹¹. Only the recovery of the cathode metals is shown in this figure.

110. Bae H., Kim Y. (2021) Technologies of lithium recycling from waste lithium ion batteries: a review. Material Advances

111. Nicole Shantelle Nembhard. (2019) Master Thesis. Safe, Sustainable Discharge of Electric Vehicle Batteries as a Pretreatment Step to Crushing in the Recycling Process. KTH.

The main categories of recycling today are hydrometallurgical or pyrometallurgical with subsequent hydrometallurgy. Both have different pros and cons with regard to costs, recovery efficiency, flexibility/adaptability to different battery chemistries, the need for a disassembly step, and energy use, see Table 3-3.

Table 3-3. Comparison between the two common recycling techniques used today and their aspects¹¹²

	Pyrometallurgical with subsequent hydrometallurgy	Hydrometallurgical
Costs	Relatively cheap	Relatively expensive
Recovery efficiency	Low	High
Flexibility	Flexible to different chemistries	Not flexible, but to some extent within the same chemistry
Disassembly need	Minimal	High
Energy use	High	Low

Pyrometallurgy means heating of batteries to smelt the metals while hydrometallurgy uses acids or bases for dissolving them. But first dismantling of parts and other pre-treatments need to be done. In the future, mechanical recycling is wished for when research has found a suitable technology, although researchers have also promoted hydrometallurgical for many years ahead because of economics compared to pure mechanical. On the other hand, some steps prior to leaching may be mechanical¹¹³. For hydrometallurgical recycling knowledge about the cathode chemistry is important why it is recommended to clearly mark the battery with this information, perhaps with electronic tags to facilitate sorting.

An advantage with pyrometallurgy is that the battery chemistries can be mixed in the process while the hydrometallurgical is sensitive to the chemistry, but on the other hand, in hydrometallurgical recycling more metals are recovered. For hydrometallurgical recycling the process needs to be adjusted depending on the chemistry but it is feasible at least for the families of chemistries such as for example NMC. Therefore, it is important with marking of the chemistry on the cells.

In the further future, 100% mechanical recycling is expected, so that the battery materials can be recycled to the battery quality form and not, as today, to the starting materials in pure forms.

Figure 3-18 is a simplified picture of the common recycling routes.

112. Fortum (mechanical and hydrometallurgical recycler) interview with Martina Elander and Janne Koivisto conducted by Alexandra Wu and Erik Emilsson. Q2 2021.

113. Dahllöf et al. (2019). Mapping of lithium-ion batteries for vehicles - A study of their fate in the Nordic countries. TemaNord TN2019:548, IVL Svenska Miljöinstitutet C442

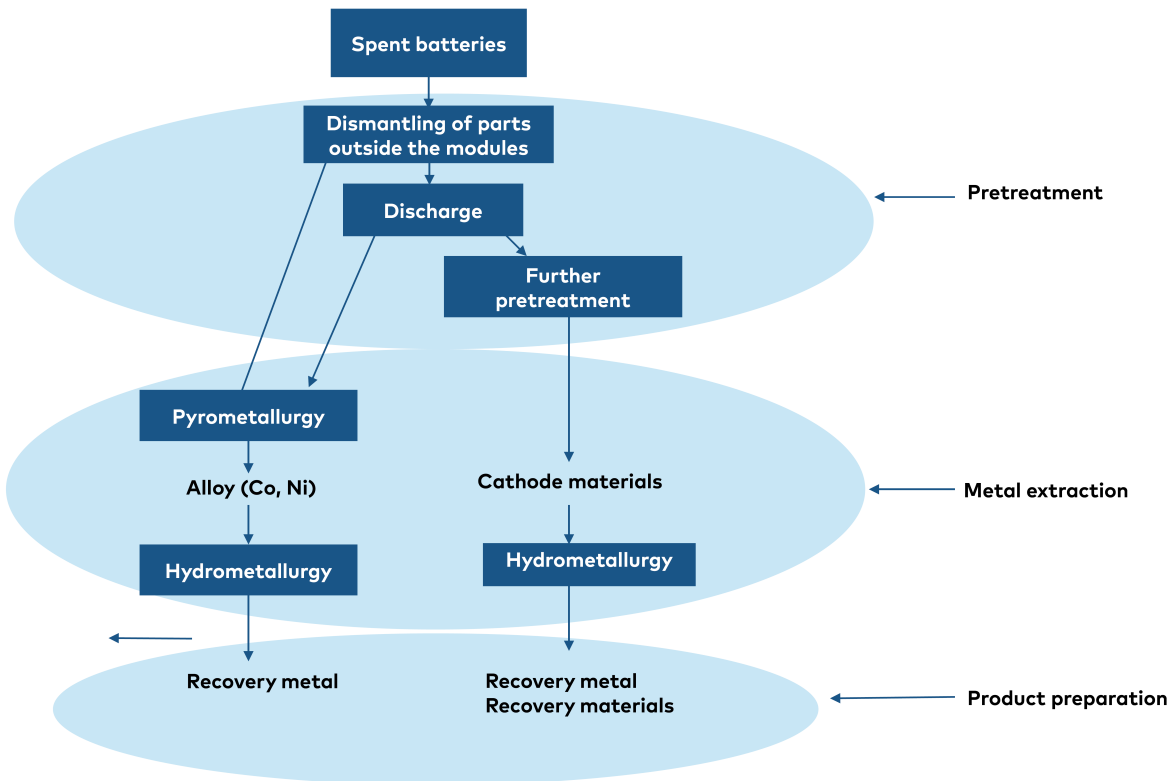


Figure 3-18. A picture showing the most common recycling techniques for lithium-ion batteries. (Dahllöf et al.,2019)

For safety reasons, the discharging of batteries is an important step in recycling or long-term storage. Smaller batteries will likely not have the same method of discharging as larger EV batteries. There are several techniques that can be used for discharging a battery and the technologies are still being developed. The larger batteries have more charge, have more mass, and come from different products than smaller batteries.

There is a way to automate the disassembly, at least partly. There are a lot of visual systems, which they are already using in Hydro. Batteries weigh typically from 10 to 100 kilograms in the current trends. The weight of the batteries will therefore require machinery for disassembly¹¹⁴.

There are several different steps for pre-treatment to choose between and the recycling process may be split between different actors. For example, Stena Recycling have started their battery recycling activities with discharging and disassembling car batteries sorting the electronics for WEEE recycling, and in future, as a phase 2, they aim at producing black mass and at the same time recover more plastics, metals, and electrolyte. As a last step, in phase 3, they plan for metal extraction to recover the battery cell raw materials. In the meantime, they sell intermediate products for further recycling¹¹⁵.

In battery recycling, the chemistry of the electrodes matters, especially the cathode. Most of the value is found in the cathode, which is where valuable metals such as

114. Norks Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

115. Marcus Martinsson at Swedish Electromobility Centre presentation Q2

cobalt, nickel, and lithium are found. Mobile phones, tablets and computers use Li-ion batteries with high-quality Co content (>12%), and this high Co concentration means that it is profitable both for the producers of these products and the recyclers to try to recycle the metals in these batteries. On the other hand, tool batteries usually contain around 6%, which is why it is not as profitable to handle (recyclers typically do not pay for these batteries but charge a fee for recycling them).

According to URecycle, the battery chemistries they receive have changed significantly over the past year, where in the beginning of 2020 they received mostly (around 80%) LFP batteries which has dropped now to 20% in the beginning of 2021. Currently most of the batteries they receive are NMC, which has a higher material recovery value. Even with a gate fee charged to customers due to low volumes, there is high confidence that NMC materials will be traded like any other Ni-Co product since it has a positive market value.¹¹⁶

On the other hand, URecycle also indicated that due to the low value of lithium carbonate (the only valuable component in LFP), there is low incentive to recycle this material even with higher gate fees charged to customer, which may explain decreasing supply of secondary material.¹¹⁷

LFP chemistry is currently not recycled in Europe, because of low economic value of the raw materials, but future legislation as well as current transport legislation for used batteries pushes for European recycling of these batteries. In contrast, LCO chemistry has the highest values due to the cobalt content.

On the trend of decreasing cobalt content in products, there were two rather different responses. Akkuser believes that the change in technology will not affect them so much because they believe cobalt will still be used due to its stabilising properties.¹¹⁸ They believe it is too early to consider this because they are still receiving high volumes of other, older chemistries (such as Ni-Cd) even though it has not been the major battery type on the market for around 15 years. They are therefore not so concerned due to the lag time of the availability of chemistries at the recycling stage and that high Co content batteries will remain available for another 30 years or so.¹¹⁹

On the other hand, URecycle indicated that decreasing cobalt content would disincentivise recyclers to take in batteries for recycling because Co is the valuable component.¹²⁰ Such a trend can be seen in LFP, for example, given that its material value is so low that the majority of the current volumes is not being accepted by European recyclers to produce black mass (after pre-treatment, see figure 3-17). Rather, they are being shipped internationally (including to the far east likely as illegal flows) as batteries, because it is perceived that there is no value in processing them in the EU or the Nordics.¹²¹ This means that decreasing Co content alone, in the absence of other controlling factors such as legislation, can disincentivise EU and Nordic recyclers from processing the waste streams and in turn increase the risk of illegal flows. Also, for longer future, if LFP and LMO has a come back right now as we see for VW and BYD in Europe, around 2035 we may see an increase of these chemistries for recycling in Europe.

116. Urecycle interview conducted by Alexandra Wu. Q1 2021.

117. Urecycle interview conducted by Alexandra Wu. Q1 2021.

118. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

119. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

120. Urecycle interview conducted by Alexandra Wu. Q1 2021.

121. Urecycle interview conducted by Alexandra Wu. Q1 2021.

3.4.2 The state of recycling and recyclers

Currently, the volumes of batteries are not sufficient for hydrometallurgy of black mass in the Nordics.¹²² There are also other challenges that have to be overcome for a functioning LIB recycling.

The current battery directive does not place specific limitations on the recycled content of lithium-ion batteries, meaning that recyclers would usually recycle the easiest-to-recycle or most valuable materials. The proposal for the new regulation will likely require recyclers to introduce different methods of recycling in order to adjust the percentage of metals which are recovered.

One problem when reducing cobalt in the batteries is that the value for the recycler is reduced. LFP is therefore not recycled at all in Europe at the moment. This obstacle may be mitigated by the proposed battery regulation with its proposed recovery rates of cobalt, lithium and nickel as well as the proposed recycled contents in the production of new batteries. The proposed directive will also force the companies in the battery supply chain to be more transparent regarding ensuring recyclability (enabling disassembly).

In future there may be other techniques for recycling, such as for example direct recycling where the battery materials are recycled while keeping the internal structure of the materials intact, saving overall environmental impact. Using this method of recycling being developed by Argonne National Laboratories in the US, ReCell, GHG emissions could be reduced from 73% of production of cathode cells with virgin metals for pyrometallurgy or 65% for hydrometallurgy, to only 25%.¹²³

Norsk Hydro informs that it is not straightforward to dismantle EV LIBs. Currently, all producers put the batteries together differently and a lot of glue is being used in the rivets. LIBs are currently not made or assembled with recycling as a priority. The focus of EV manufacturers is safety during assembly and use during the EVs' lifetime. The reason for why it is not done with more focus on recycling is cost because it is slightly more cumbersome to do it. In Europe there is a gate-fee (but in China they pay for used batteries). If automobile producers see that there is an economic or legal reason to create batteries that are more recyclable, they will do it. There is no concern with the OEMs for producing easy-to-recycle batteries. The OEMs are not focusing on this now because they think that these demands will come later. Their focus right now is just on producing electric cars.¹²⁴

Recycling from batteries in cars is costly for recyclers. Disassembly is an essential part of recycling and disassembly of each battery of the average vehicle is costly for the recycler if they are not designed with recycling in mind. The costs for disassembly are paid by the recycler and they are proportional to the time it takes to disassemble them, as well as the tools required and knowledge of the recyclers. Most car manufacturers build-in their batteries to minimize the risk of battery changes by third parties, which increase the time to separate the battery from the car. The result of the high cost for batteries is that battery recyclers will not buy the materials and they will therefore not be recycled. And since recycling is an essential

122. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021.

123. Linda Gaines at Swedish Electromobility Centre presentation Q2 2021 (April 27th 2021)

124. Norsk Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

part of the circular economy, this means that the market forces are not sufficient for circularity and that government intervention may likely be necessary to obtain circularity in the LIB supply chain. Important, also to consider, is that recycling itself has environmental impact and therefore the recycling techniques need to be further developed and design for recycling of the products improved.

Due to the nature of LIBs, the health, safety, and perceived danger of recycling for recyclers (and users) is also relevant. Costs pertaining to handling LIBs as hazardous substances is big for recyclers. Some of the risks include flammable or toxic gases, exposure to high voltages and high temperatures for workers or the batteries' users. There is no standardized method of disassembly or discharging batteries, which makes this unknown territory.

3.4.3 Major Battery Recyclers and Actors

Table 3-4 shows the major LIB recycling actors in the Nordics. Additional information about the companies can be found in Appendix A.

Table 3-4. Major Nordic recyclers and description of recycling technologies used.

Recycler	Country	Short description on recycling technology
Akkuser	Finland	Akkuser collects, sorts, treats and transforms LIB streams (not from EVs) into raw materials that are sold to existing metal refineries. They do not do black mass recycling. They use a pre-processing mechanical process involving shredding followed by magnetic separation. Since 2019, the new processing line includes more pre-shredders and accommodate bigger batteries. Aims to increase 100–200 tonnes per year in the coming year, but will need to import from other EU countries to reach these capacities. The cobalt output is sold to cobalt refineries who aim to produce precursors for cathodes. ¹²⁵
Finnish Minerals Group	Finland	A state-owned holding company focused on the battery material value chain looking into covering more of the value chain by adding on recycling to its other investments. ¹²⁶
Fortum	Finland	Mechanical plant processes 3,000 tonnes of batteries per year (equivalent to 10,000 EVs) ¹²⁷ Fortum is also investing into an expansion of its recycling capacity by building a new hydrometallurgical plant in Harjavalta which will recover metals from EV LIBs, expected to begin operations in 2023. ¹²⁸
Glencore Nikkelverk	Norway	A refiner of cobalt and nickel that can also process black mass and cathode material. ¹²⁹
Norsk Hydro	Norway	Norsk Hydro is cooperating with Northvolt in Hydrovolt, where Norsk Hydro is responsible for recycling aluminium. They are also looking at covering more of the LIB supply chain in the future. ¹³⁰
Boliden	Sweden	Boliden produces 25,000 to 35,000 tonnes nickel in nickel matte, which is processed further by external partners. Boliden also produces 1,000 to 2,000 tonnes crude nickel sulphate at Rönnskär and Harjavalta smelters. They also recycle lead-acid batteries and PCB from electronics. ¹³¹
Revolt (Northvolt)	Sweden	Revolt is Northvolt's recycling program, which has a pilot plant in Västerås, and a planned full-scale recycling plant by 2022. Northvolt's target is to use 50% recycled materials in its new cells by 2030. ¹³²
Stena	Sweden	Stena Metall is involved in all the steps prior to black mass recycling: reuse, dismantling, shredding and separation. Currently they do not recycle black mass. ¹³³ Stena Recycling has more recently stated that they will open a new plant in Halmstad which will recycle 95 percent of a lithium ion battery, including lithium, nickel, and cobalt. Sorting will be done in Stena's over 90 facilities in Sweden and recycling in Halmstad. ¹³⁴

125 126 127 128 129 130 131 132 133 134

125. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

126. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com/copy-of-recycled> (paid subscription) Retrieved from the Internet in Q3 2021.

127. Fortum interview with Martina Elander and Janne Koivisto conducted by Alexandra Wu and Erik Emilsson. Q2 2021.

128. <https://www.fortum.com/media/2021/06/fortum-makes-new-harjavalta-recycling-plant-investment-expand-its-battery-recycling-capacity>

129. Circular Energy Storage (2020) <https://www.circularenergystorage-online.com> (paid subscription) Retrieved from the Internet in Q3 2021.

130. Norsk Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

131. Boliden <https://www.boliden.com/operations/products/nickel> Extracted Q3, 2021.

132. Northvolt <https://northvolt.com/articles/announcing-revolt/> Accessed Q3 2021.

133. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021.

134. Stena Recycling <https://www.stenarecycling.com/news/stena-recycling-invests-heavily-in-new-battery-recycling-plant/> Retrieved Q3 2021.

Outside of the Nordics there are actors that in some way or another affect the Nordic recycling industry, see Table 3-5.

Table 3-5. Recyclers outside of the Nordics, but that affect the Nordic recycling industry.

Recycler	Country	Short description
Chinese battery recycling industry	China	Although not in the Nordics, China is currently dominating the LIB recycling industry, with about 50% of the batteries that reached End of Life there in 2019. They also have access to whole closed loop systems and a high amount of the worldwide extracted raw materials for the LIB industry.
Remondis	EU	Recycles black mass. Bought Swedish recycler Swedish Ad Infinitum AB.
Umicore	Belgium	Big European recycler using ultra-high temperature processes. Their capacity is 7500 tonnes/year. Processes black mass, but not on a consistent basis on the market.
Veolia	France	Veolia, in a consortium with Solvay and Groupe Renault, will use hydrometallurgy to recycle BEV and PHEV LIBs. A proof of concept has been done and a scaled-down production unit is the next step.

Most newcomers of li-ion battery recyclers are focusing on EV. The data on EV battery volumes are available in Norway but not Finland and Sweden.

Expected average battery processing capacities is probably around 1,000–3,000 tonnes/year for other EU recyclers. These capacities can give a picture of the typical capacities recycled, but with the expected supply of used EV batteries for recycling in the future, the market may be looking at 10s' of thousand tonnes per year.¹³⁵

135. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

4 Sustainability of batteries

The sustainability of batteries can be assessed in many different ways, and the understanding the term sustainability may differentiate from person to person. Some may consider sustainability as another wording for environmental development, while others also consider the economic and social impacts. However, regarding batteries, it is important to consider all aspects of sustainability, as battery technology is a key cornerstone in the green transition towards a fossil-free society by replacing products, appliances, and transport means that requires fossil fuels.

But at the same time, it is crucial to consider shift of the sustainability impact due to the increased demand of batteries. When more batteries are needed, more critical resources are mined, and many of these resources are mined under poor working conditions, and there is a risk of local pollution close to the mines. These shifts in sustainability impact are highly related to the economic incentives to mine the critical raw material and the consumers' willingness to pay for products, including batteries.

The continuous development in energy efficiency and increased focus on this is also an indirect effect of batteries. A study by EDNA¹³⁶, compares standby energy consumption for wireless devices, such as smart speakers, smart phones, wireless printers, or smart TVs. They found that even though the wireless standby capabilities were almost the same, smartphones were much more efficient compared to the non-battery powered devices. Smart speakers used 3.5 times more energy on standby compared to smart phones. When the product always has access to electricity through a cable, the manufacturers have little motivation for improving the standby consumption. Designers of mobile devices know that energy efficiency is crucial for the time that a consumer can use the product without charging it. However, improved energy efficiency of our consumer electronics can lead to increased usage, thus resulting in the same overall energy consumption and more wear on the batteries.

It is therefore important to consider all aspects of sustainability, which is in line with the Sustainable Development Goals (SDGs) that aims to:

"ensure all human beings can enjoy prosperous and fulfilling lives and that economic, social, and technological progress occurs in harmony with nature."

Sustainability and sustainable development are often referred to as the three Ps (People, Planet, and Prosperity) and visually presented in Table 4-1. These are detailed in the following.

136. EDNA, 2019, Bridging the Network Standby Gap Between Mobile and Mains-powered Products



Figure 4-1. People, Planet, and Prosperity in relation to sustainable development.

4.1 People

Besides direct environmental and economic impacts, several other issues should be considered when assessing the advantages and disadvantages of using batteries. There are significant social and environmental consequences in connection with the extraction of several of the raw materials in lithium-ion batteries, particularly regarding conflict minerals. As global warming and environmental pollution affect people in the end, we have included the impacts from metal extraction in this chapter although the effects are indirect via nature.

Minerals are considered conflict minerals if they are sourced from politically unstable areas and where the¹³⁷:

"minerals trade can be used to finance armed groups, fuel forced labour and other human rights abuses, and support corruption and money laundering"

While the international focus on conflict minerals has so far been on tantalum, tin, tungsten and gold (3TG), cobalt is also being increasingly recognized as a potential conflict mineral even though it is not a part of the conflicted mineral regulation.

The primary raw materials used to manufacture Lithium-ion batteries, which can have adverse impacts on its entire value chain, are identified below¹³⁸:

- **Cobalt** is the most problematic raw material of all listed raw materials, as it is mined mainly in countries with poor regulation and disorganized small-pits (Artisanal and Small-Scale Mining – ASM, i.e., mining by hand using rudimentary and basic tools, often without adequate protective equipment). Over 50 percent of the world's cobalt is mined in the DRC (Democratic Republic of the Congo). Just over half of the cobalt produced worldwide goes to the production of lithium-ion batteries and the battery sector. Cobalt is primarily extracted as a by-product of nickel and copper production, thereby driving cobalt production. However, cobalt extracted from ASM sources is primarily driven by price increases, which rose sharply from 2016 to 2018, partly due to speculation and due to increasing demand for lithium-ion batteries. However, prices plunged sharply again during 2019.

Cobalt is often connected with severe abuse of human rights and local pollution:

137. <https://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/regulation-explained/>

138. <https://ecodesignbatteries.eu/>

- Human health issues: Artisanal miners typically work under hazardous conditions without basic protective equipment such as work clothes, gloves and masks. As a result of chronic exposure to mineral dust, miners often have the potentially fatal “hard metal lung disease”, in addition to respiratory sensitization, asthma, shortness of breath and certain skin conditions. Many miners also work long hours and report constant bodily pain.
 - Child labour: As a source of local livelihood, children often join their families to work in the mines to supplement household income. In the DRC, where cobalt mining is prevalent, about 40,000 children are estimated to work in the mines, some as young as seven years old. The working hours can be long, some reaching 12 hours per day. Even children who go to school may work in the mines during the weekend, holidays, and before/after school.
 - Abuse and exploitation: In many cases, artisanal mines are operated by armed rebel groups. Corruption and exploitation can be commonplace in the mines and in the open trading markets to which ore from artisanal mines are gathered and sold. Child workers are also susceptible to financial exploitation since they are not able to independently verify the weight and grade of the ore they sell to the traders, who can thus take advantage of the children. Armed guards may at times also demand payment from workers and threaten violence if the workers are not compliant. Workers' rights to safe working conditions, fair wages and working hours are not enforced or regulated.
 - Environmental pollution occurs due to toxic chemicals being leached in the mining process and released into water bodies, as well as deforestation to clear lands for mines, ultimately impacting local wildlife, biodiversity and in the end humans.
-
- **Lithium** comes primarily from Australia (40 percent) and Chile (36 percent), which are relatively stable countries without a high risk of negative social and environmental problems. Lithium extracted in Australia comes from traditional mining, as this is to be extracted from lithium-containing rocks. This method is relatively energy-intensive and therefore causes large greenhouse gas emissions. Lithium in Chile is extracted from salt lakes, which is a less energy-intensive process, but which, on the other hand, has a high water consumption in areas that are already low on water reserves, potentially impacting people in the area. Also impacts on biodiversity are severe. These impacts affect local people as well as the eco-systems as such.
 - **Nickel** extraction and processing are related to many pollution cases both from the mining itself and from the refining process. Nickel is extracted mainly from sulphur-containing ore, which forms sulfuric acid in contact with air and water. If this is not purified or used for producing sulphuric acid, there is a great risk of leakage to the surrounding environment, with major consequences for animal and plant life. In the refining process, sulphur dioxide can be emitted into the air and form acid rain. Canada and Russia account for the bulk of the world's nickel production, while change deposits of nickel are found mainly in tropical places (Indonesia and the Philippines) in areas of high biodiversity, which are cleared for access to nickel ore. These environmental impacts affect local population as well as the affected eco-systems.

- **Manganese** occurs widely in countries where ASM mining is widespread (South Africa, Gabon and China). There is a great risk of social and environmental problems. Excessive manganese intake, either through inhalation of dust or through ingestion of water, can lead to serious neurological diseases. In addition, manganese can occur along with radioactive metals, which are both a risk to the miner and the local environment.
- **Graphite** is primarily produced in China (73%), where working conditions in general for miners are poor, and ASM is widespread. The biggest problem from the extraction is the dispersal of very fine graphite dust, which settles on the vegetation and inhibits its growth or eventually kills it. In addition, prolonged inhalation of graphite dust can cause several respiratory diseases. Large amounts of acid are consumed in the graphite refining process, constituting a risk to the local environment affecting humans if not handled properly.
- **Copper, Iron, Aluminium and Phosphate** are in high demand for many different purposes and are therefore also produced in very large quantities worldwide. In particular, copper, iron and aluminium are often extracted from ore with a relatively low content of the sought-after metal, and large amounts of water and chemical substances are therefore used to extract the metals. Together with the residual ore, it is stored in huge dams (tailing ponds), as it can have significant environmental consequences if discharged into the surrounding ecosystem affecting local population in the end. There are a number of examples of tailing ponds where the dams are ruptured due to overload.

4.2 Planet

As already mentioned, batteries impact the environment both positively and negatively and environmental impact affects people. Both the pros and cons need to be considered in connection with the increased demand for different types of batteries to avoid rebound effects.

The increased demand for batteries also increases the demand for materials used in their production, including the conflicted minerals. In addition to the human rights concerns, there are also negative environmental impacts from the mining and production of batteries. Table 4-1 shows the environmental impacts for several categories of producing a 60 kWh battery, representative of a VW ID.3 or a Tesla Model 3 in the standard range configuration.

Table 4-1. Environmental impacts from a 60 kWh battery. Based on the assumptions for the preparatory study of batteries.¹³⁹

	Unit	Raw materials	Battery production	Total production
Greenhouse Gases in GWP100	kg CO ₂ eq.	4234	2217	6452
Acidification, emissions	g SO ₂ e.	113324	9836	123160
Volatile Organic Compounds (VOC)	g	1169	1060	2230
Persistent Organic Pollutants (POP)	ng i-Teq	2453	262	2716
Heavy Metals	mgNi eq.	24906	834	25740
Polycyclic Aromatic Hydrocarbons (PAH)	mgNi eq.	12432	124	12556
Particulate Matter (PM, dust)	g	7756	369	8125

From Table 4-1, it is clear that different environmental impacts are connected with the production of a battery for a car. However, it can be difficult to relate to, e.g., emissions of greenhouse gasses and when it is considered a high emission. For comparison, it is obvious to compare the emissions from a battery with a conventional car. It is further assumed that the conventional car chassis and a chassis of an electric car are comparable.

139. <https://ecodesignbatteries.eu/>

Table 4-2. Environmental impacts from the production of 60 kWh battery, a conventional car and an electric car.¹⁴⁰

	Unit	Production of 60 kWh battery	Production of a medium-sized car	Total production of an electric car
Greenhouse Gases in GWP100	kg CO ₂ eq.	6452	5415	11867
Acidification, emissions	g SO ₂ e.	123160	20546	143706
Volatile Organic Compounds (VOC)	g	2230	155	2385
Persistent Organic Pollutants (POP)	ng i-Teq	2716	24193	26909
Heavy Metals	mgNi eq.	25740	15156	40896
Polycyclic Aromatic Hydrocarbons (PAH)	mgNi eq.	12556	6782	19338
Particulate Matter (PM, dust)	g	8125	4.723	12848

According to Table 4-2, the greenhouse gas emissions of producing a battery is about the same as the rest of the car itself, and thus the greenhouse gas emissions from production of an electric car are about twice as much as they are for a car that runs on only an internal combustion engine. In other impacts categories, it is clear that an electric car also produces significantly higher emissions of other types during the production.

Although the different impact categories are important, the Paris agreement and other national and international initiatives has placed a lot of focus on greenhouse gas emissions, meaning that most Life Cycle Assessments will consider greenhouse gas emissions as the most important impact category. Recently there have been several studies focusing on the greenhouse gas impacts of producing batteries¹⁴¹, but even more recently there have been measurements of production emissions in real factories (rather than in pilot plants) which have produced more realistic figures¹⁴². A Swedish report financed by the Swedish Energy Agency has found that the number can vary between 61-106 kg CO_{2e} per kWh battery capacity¹⁴³, with the variation in part being due to the source of energy (both electricity and heat) used in the cathode materials refining and cell production stages. The methodology of LCAs also

140. The production of batteries are based on <https://ecodesignbatteries.eu/>, while the production of a conventional car is based on: <https://mst.dk/service/publikationer/publikationsarkiv/2020/jun/prisen-for-cirkulaere-indkoeb/>

141. <http://www.energimyndigheten.se/globalassets/forskning--innovation/transporter/c243-the-life-cycle-energy-consumption-and-co2-emissions-from-lithium-ion-batteries-.pdf>

142. <https://www.ivl.se/download/18.14d7b12e16e3c5c36271070/1574923989017/C444.pdf>

143. <https://www.ivl.se/download/18.14d7b12e16e3c5c36271070/1574923989017/C444.pdf>

affect the results, and one example is the PEFCRs which provides rules that make LCAs on different battery products or methods more comparable. Another area for uncertainty is the variation of emissions from the mining and refining stages which could come from different countries or regions. Often these values are lumped up into one value in LCA studies, but it can have a big effect on the battery greenhouse gas emissions¹⁴⁴. Thus, the value of global warming potential for battery production is large and can vary significantly based on a few key factors; recent studies have shown that battery production emissions are around 61-106 kg CO_{2e} per kWh of energy that can be stored in the battery.

The energy consumption in the actual production of battery-grade materials and batteries is very energy-intensive; hence the greenhouse gas emissions of the energy mix is of great importance in the different studies, see Table 4-3.

Table 4-3. Emission factor from battery production in different countries and the total emissions of greenhouse gases. In it assuming that the production of a 60 kWh battery requires 8333¹⁴⁵ kWh of electricity.

	Emission factor g CO _{2e} /kWh electricity (2018)	Emissions from production kg CO _{2e}
The Nordics ¹⁵²	60	500
EU average ¹⁵³	283	2358
Germany ¹⁵⁴	399	3325
China ¹⁵⁴	613	5108

146 147 148

The carbon intensity of electricity varies greatly in different counties and regions assessed. The carbon intensity is expected to decrease in most cases, but currently, the Nordic regions are frontrunners in the transition towards a clean energy supply. It may make sense to consider increasing the battery production in Nordic countries to ensure a steady supply of batteries with lower impacts than batteries produced today. Care should be taken, as the energy grid is connected, and increased consumption of green energy in the Nordics will reduce the available amount of green energy for other countries¹⁴⁹. Still, the ambition in the Nordics is to have a green electricity supply, meaning that increased consumption of electricity in the Nordics leads to increased investments in fossil-free power generation overall. This may not be the case in all countries due to different ambition levels.

144. https://www.researchgate.net/publication/335454324_Globally_regional_life_cycle_analysis_of_automotive_lithium-ion_nickel_manganese_cobalt_batteries

145. Based on the assumptions from the preparatory study for batteries. Note that the values in the has been recalculated to fit with a 60 kWh battery. The study is available at: <https://ecodesignbatteries.eu/>

146. Relative CO₂ intensity on downward path – Nordic Energy Research

147. <https://www.iea.org/data-and-statistics/charts/development-of-co2-emission-intensity-of-electricity-generation-in-selected-countries-2000-2020>

148. Based on the assumptions from the preparatory study for batteries. Note that the values in the has been recalculated to fit with a 60 kWh battery. The study is available at: <https://ecodesignbatteries.eu/>

149. The high share of renewable energy also often comes at an extra cost: the increased demand for resources, in the production of e.g., windmills and PV-panels.

Considering the large emission related to batteries, it may seem strange that batteries are highlighted as an important part of the solution not to exceed the 2°C goal set in the Paris Agreement. The pros of batteries are that they are a key enabler to decouple the dependency of fossil fuels and replace fossil fuels with green power from renewable sources. This can be in connection with energy storage systems that can help balance the future energy supply where greater fluctuations in the energy supply are expected.

Batteries are also a key to reduce the emissions of greenhouse gases in the transport sector. As shown in Table 4-2, an electric car emits approximately twice as much CO₂ as a conventional car including the use phase of the car. Nevertheless, due to lower emissions in the use phase, an electric car will emit less greenhouse gases over the entire lifetime¹⁵⁰ unless it is rarely used. Below in Figure 4-2 an illustration that shows how quickly an electric car becomes environmentally favorable is presented.¹⁵¹ Impacts from recycling is much lower than impacts from production.

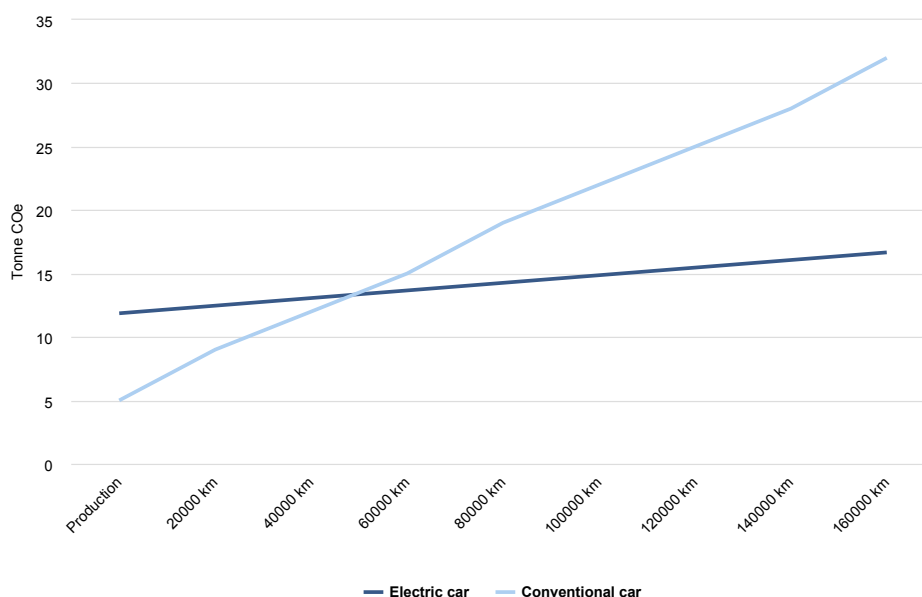


Figure 4-2. Comparison between the emission of CO₂ from an electric car and a conventional car including both the production and use phases. Note that the CO₂ emission from the electricity powering the electric car on a fixed Nordic electricity mix.

Relatively quickly is the electric car emitting less CO₂, and depending on how many kilometers the car will drive over its lifetime, the benefit of electric cars will only increase. With the assumption made in Figure 4-2, the electric car has twice the impacts in the production phase but over the car's entire life, only less than half the emission compared to a conventional car. It is clear that from a greenhouse gas perspective, the large batteries are a cornerstone in the green transition that helps

150. https://www.klimaraadet.dk/da/system/files_force/downloads/baggrundsnotat_-_hvor_klimavenlige_er_elbiler_sammenlignet_med_benzin-_og_dieselmotorer.pdf

151. Values regarding production are based on Table 4-2 and the emission in the use phase are based on: https://www.klimaraadet.dk/da/system/files_force/downloads/baggrundsnotat_-_hvor_klimavenlige_er_elbiler_sammenlignet_med_benzin-_og_dieselmotorer.pdf

store renewable energy and reduce the emission from the transport sector. If batteries are produced with renewable energy, the benefits become even greater.

Looking at smaller batteries found in battery-driven products such as vacuum cleaners, power tools, computers etc., the benefit of using batteries is reduced over the years. Previously battery-driven products have been a driver for more efficient products to ensure proper function and runtime. However, strictly looking at the environmental performance today, a battery-driven product emits more greenhouse gases over its life than a corded alternative if the efficiency of the products is comparable. The production of a battery is way worse than producing a simple cord from an environmental point of view. Furthermore, losses occur in the battery when charging and discharging, and the battery may need to be replaced at some point to match the product's lifetime. All meaning that corded products are preferable.

4.3 Prosperity

The triple bottom line theory is systemic through its view of people, the planet, and prosperity. This is reflected in the Sustainable Development Goals that:

"Ensure all human beings can enjoy prosperous and fulfilling lives and that economic, social, and technological progress occurs in harmony with nature."

Many of the Sustainable Development Goals aim to improve various areas related to the environment, people, and economic opportunities. Economic opportunities aim to provide decent work such as safe working conditions, living wages, compassionate leadership, and economic growth for those in specific communities.

From a more strictly company perspective, the economic part is, of course, important. If a company has a deficit, it cannot continue to operate unless it somehow makes a turnaround. A company can focus on social and environmental impacts, but if they do not make any money, they cannot continue their liveable work (social and environment). To ensure sustainability, the solution must be economically viable.

Previously, companies were focused on profits obtained through a linear business model where higher sales equalled higher profits. The entire assembly method focused on selling as many products and increasing the mark-up by lowering the production cost. Low production costs for many battery-driven products could be obtained by the high-speed automatic assembly, which has high initial investment costs but often is the most economically viable option when the focus is on high sales¹⁵². Figure 4-3 the correlation between the assembly cost per product and the annual production for three different assembly methods.

152. Mital, A. et al., 2014. Product Development, Elsevier. Available at: <http://www.sciencedirect.com/science/article/pii/B9780127999456000144>

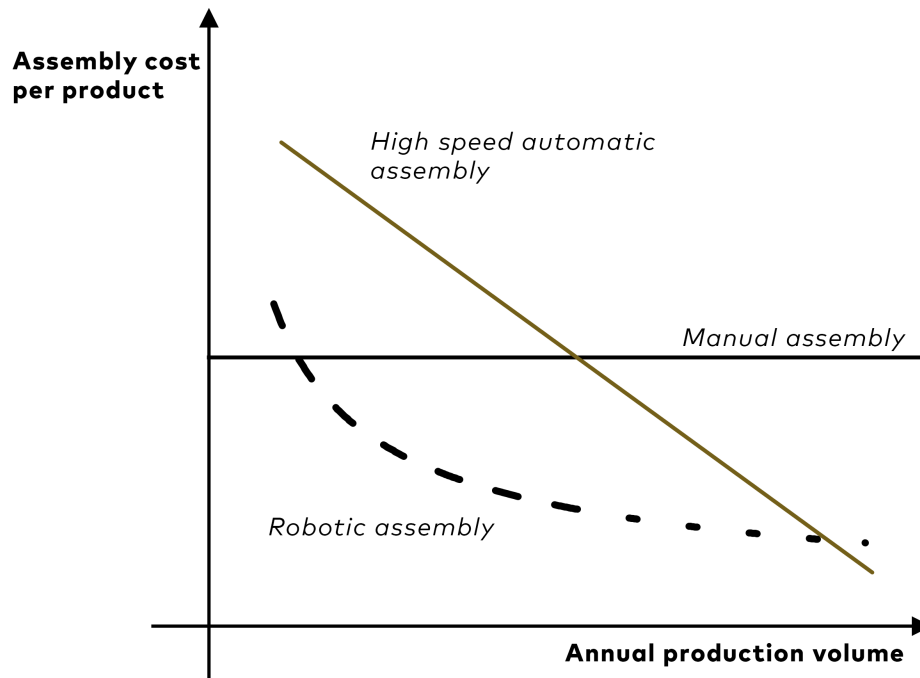


Figure 4-3. Visual comparison of the assembly cost of robotic assembly, high-speed assembly and manual assembly compared to the annual production volume¹⁵³.

The high-speed automatic assembly favours linear business models. Many companies have invested heavily in this assembly method to lower their cost; hence it may seem risky to convert to a more circular business model focussing less on sales. However, sustainability is becoming more important for all companies across all industries. Surveys have shown that 62 percent of executives consider a sustainability strategy necessary to be competitive today, and another 22 percent think it will be in the future¹⁵⁴.

Sustainability is a business approach to creating long-term value by considering how a given organization operates within the three Ps (People, Planet and Prosperity). Sustainability is built on the assumption that developing such strategies foster company longevity. Without a focus on sustainability, it can be questioned how long the company can continue to operate as the expectations on corporate responsibility increases. Transparency becomes more prevalent, and more companies recognise the need to act on sustainability. Professional communications and good intentions are no longer enough as green claims are investigated, and greenwashing will hurt the reputation of the company.

The following manufacturers illustrate what sustainability initiatives could look like regarding batteries:

- Bang & Olufsen: Beosound Level is assembled modularly using standardised types of screws. Service partners have easy access to critical components that can be repaired or replaced if needed. Customers can also replace the battery

153. Mital, A. et al., 2014. Product Development, Elsevier. Available at: <http://www.sciencedirect.com/science/article/pii/B9780127999456000144>

154. <https://www.imd.org/research-knowledge/articles/why-all-businesses-should-embrace-sustainability/>

themselves. This ensures a long life with one customer and enables multiple loops with a series of different ownerships. Beosound Level will also – when it reaches its end-of-life point after many years of service – support a resource-efficient process because of ease of disassembly and use of high-quality materials, including recirculated polymer materials for structural components¹⁵⁵.

- Northvolt: Sourcing raw materials to batteries according to international standards and practices and even introducing some of their own standards to secure a supply chain free from corruption and reduce consumption of virgin through recycling¹⁵⁶.
- Fortum: Participates in the BATCircle research programme, a circular ecosystem of battery metals consortium based in Finland. Fortum Recycling & Waste has an existing industrial-scale pilot facility in Harjavalta, Finland, producing sustainable metals from secondary, i.e. recycled resources. In addition, there are laid plans to build a large-scale commercial facility for recycling EV battery materials¹⁵⁷. Fortum operates inside an industrial park, in Harjavalta, where BASF is building a battery materials precursor plant and Nornickel is refining metal raw materials – creating a unique material cluster on a European scale.
- Volvo Cars: Planning to go full electric in all the cars by 2030 as many other car manufacturers focusing on electric cars. Jaguar is also reinventing themselves as an electric car brand from 2025, only selling electric cars¹⁵⁸.

Without a broad focus on sustainability, it may become increasingly difficult for companies to compete in the market. These considerations may increase the focus on the Nordics as a suitable place for production, as the green energy supply can help companies fulfil their sustainability goals and increase their market value.

155. https://assets.ctfassets.net/8cd2csgvqd3m/5w8T9zbtscFDyKMZrzt3Xj/8d05e97cddff5de9ea2771fe05c87871/CSR-Report_2020-21_final.pdf

156. <https://northvolt.com/environment/>

157. <https://www.fortum.com/media/2021/06/fortum-makes-new-harjavalta-recycling-plant-investment-expand-its-battery-recycling-capacity>

158. <https://www.gearpatrol.com/cars/g36321012/car-brands-going-electric/?slide=1>

5 Key barriers towards increased circularity today

As identified in the previous chapters, there are numerous possibilities and advantages to the circular economy. But one can ask, if circular economy is one of the promising solutions to our problems, why have we not implemented it yet? Many studies have tried to identify the main barriers against circular economy; one of them has been carried out by Utrecht University and Deloitte¹⁵⁹, who suggest that a major obstacle is the cultural challenges including shifting from a well-established linear economy, changing the mindset of consumers, involving full-life-cycle collaboration, and changing mindsets within companies. The findings are illustrated in Figure 5-1.

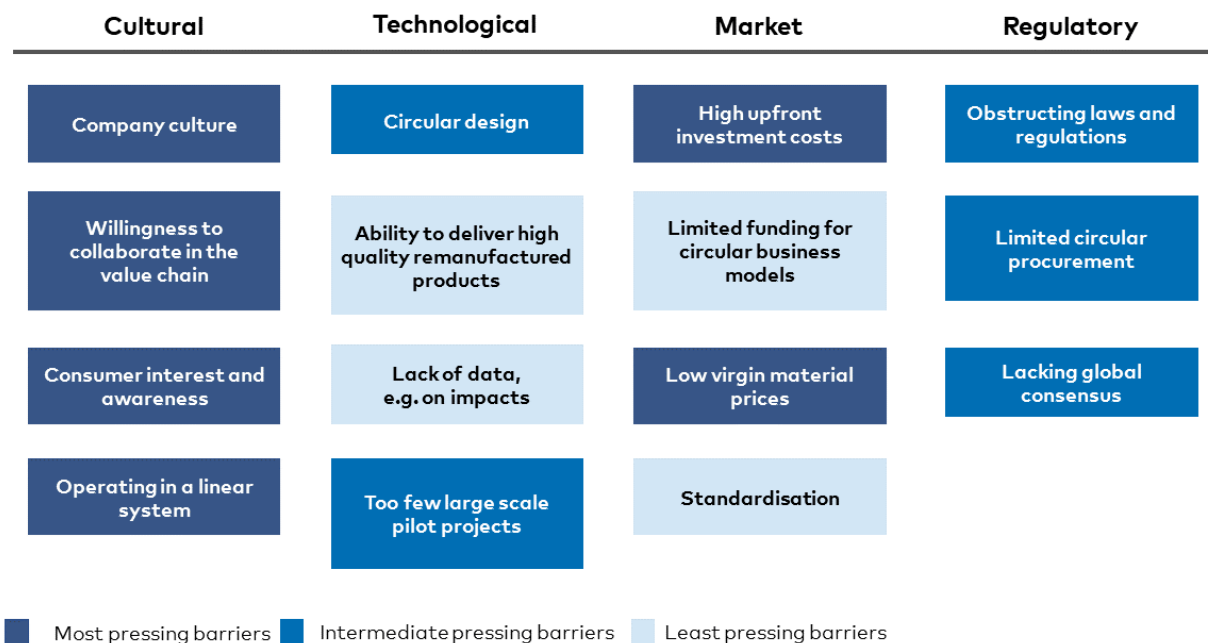


Figure 5-1. General barriers against the circular economy. Source: Breaking the Barriers to the Circular Economy. Julian Kirchherr, Marko Hekkert, Ruben Bour, Anne Huijbrechtse-Truijens, Erica Kostense-Smit, Jennifer Muller. October 2017.

159. https://circulareconomy.europa.eu/platform/sites/default/files/171106_white_paper_breaking_the_barriers_to_the_circular_economy_white_paper_vweb-14021.pdf

5.1 Company culture

The previous chapters presented innovative CE business models that often prove more profitable than business-as-usual models, but nevertheless the old business models are so well-established that they are challenging to transform. This is due to a rooted traditional *company culture* and the big change of mindset required to transition to circular economy. Consequently, young, or new businesses have an easier time transitioning compared to more settled companies.

The Swedish company Nortical, identifies in a research project Adding Transparency to Circular Flow of Batteries by Blockchain Technology several hurdles to overcome achieving second-life and better recycling of batteries. They identify them in the fields of strategical, organisational and technological barriers. Information flows are limited between actors, which points to the need of a data sharing network. A pilot will be made for such a network together with a proposed business model for circularity. The results will be used for supporting EU with developing strategies.¹⁶⁰

5.2 Lack of circular design

The lack of *circular design* is generally problematic in the circular economy, but even greater in electronics and batteries as the complexity of the small components makes dismantling tricky for the recyclers or refurbishers. There is a demand for yet smaller and sturdy electronic products, which is conflicting with the need for modular and separable components. The problem calls for value chain collaboration between designers and waste management experts. Also, as batteries all have varying dimensions, forms, and compositions of chemicals and metals, it is challenging to establish an efficient standardized system for battery recycling¹⁶³. Especially this would likely require manual labor for removal of battery, dismantling, module removal and cell separation, which is too costly in many countries compared to disposing the batteries at EoL. The number of lithium batteries that are recyclable is projected by the European Commission to multiply by a factor 700 in 2040¹⁶¹, thus, to reach this projection batteries and electronic products must be redesigned for reuse/recycling.

Most car companies, but not all, increase the integration of the battery into the car in order to optimise volume vs energy content and by that increase the range. However, this makes it more difficult to replace the battery.

5.3 Legislation

A study that compares Finland and Chile, that respectively recycle about 50% and 0% of their imported or produced portable batteries¹⁶², has shown that *lack of legislation* is a main barrier for promoting circular economy of batteries in Chile. Here, Finland is highlighted for increasing recycling rates through regulation. As seen in this report, the recycling markets and regulations are very similar between the Nordic countries, and we should continue to harvest the advantages of effective

160. Pavel Calderon, presentation at CMC April 2021

161. https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_2311

162. "Science for Environment Policy": European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, Bristol.

legislation, which was identified as the best way of shaping business models and making battery recycling economically feasible.

5.4 Lack of consumer awareness

The absence of *consumer interest and awareness* in some customer segments is greatly inhibiting the circular economy¹⁵⁹. Some consumers simply like new items before their old ones are worn out, which is particular for trend-based, hi-tech and fast-paced products, such as mobile phones or clothing¹⁵⁹. This market demand discourages manufacturers from making robust and more expensive products, as there is less market demand for such product for some product segments. Designers should be aware of this by clearly communicating the benefits of durability and repairability as further described in Section 6.2.5, which could prolong the lifetime of electronic devices, and lowering pressure on recycling systems and demand for new batteries.

Furthermore, consumers should be aware of the environmental advantages of recycling systems. The study comparing recycling in Finland and Chile has also found that due to the mandatory campaigns the consumers are exposed to in Finland (and other Nordic countries), they are much better at sorting their batteries for recycling.

5.5 Virgin vs recycled materials

The fluctuating price of raw materials, like plastics or metals, hinders the economic incentive for purchasing recycled materials, when there are *low raw material prices*. This further discourages investments in improving the current recycling systems which could help reducing the prices of regenerated resources.

The cost and availability of reuse or recycling systems for batteries does not outweigh the cheaper but less sustainable means of disposal¹⁶³. Furthermore, some primary raw materials are subject to subsidies¹⁶⁴ making the market price of recycled materials even more unfavourable. To tackle this, the European Commission has implemented specific goals for recycled materials in battery production – starting with labelling of recycled content on all batteries from 2027 and introducing a minimum requirement for recycled content by 2030 and increasing these targets in 2035¹⁶⁵. But improving recycling rates are not enough to cover the future need for batteries, that is expected to multiply by a factor 700 by 2040. This will furthermore necessitate a significant rise in raw material extraction for new battery production. The Commission has forecasted the demand for lithium to multiply almost 60 times by 2050¹⁶⁶ compared to today.

Current recycling systems for most materials, including batteries, will most often downcycle the resources to a lower quality than the original virgin grade. Thus, recycling of batteries does not close the loop and displace the need for virgin lithium, cobalt, etc.¹⁶⁷ Due to the inefficient recycling systems, recycled lithium prices are

163. <https://www.nrel.gov/docs/fy21osti/77035.pdf>

164. https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705

165. <https://www.gearpatrol.com/cars/g36321012/car-brands-going-electric/?slide=1>

166. <https://ec.europa.eu/docsroom/documents/42881>

167. InnovÉE, McGill University & CETEES (2020), "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials"

often three times higher than virgin¹⁶⁸, which is greatly inhibiting the circular economy of batteries.

Lastly, emissions from collecting, sorting, reprocessing of batteries for recycling, sometimes outweigh the environmental benefits of recycling, as much electrical and thermal energy is needed to recycle the materials¹⁶⁵. Also, there is still no way of recycling the electrode, but researchers are working on developing such solutions¹⁶⁹.

5.6 The black battery markets and illegal exports

5.6.1 Automotive

Between 30 and 40 percent of the EVs are exported before the end of their lives but the degree of illegal export is unknown¹⁷⁰. This leads to some circularity challenges that include the batteries ending up for recycling in other parts of the world. This results in increased emissions for transportation, less efficient recycling facilities thus lower output quality, and lastly a reduced amount of recycled materials for the Nordic battery production industry.

Nearly 40% of vehicles in Europe had an unknown EoL fate in 2014. The lack of traceability suggests that there is a large extent of illegal exports¹⁷¹. See Figure 5-2 below.

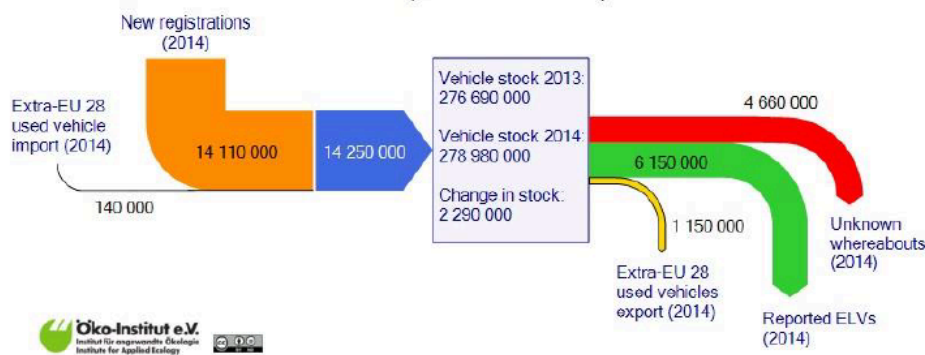


Figure 5-2. EU-28 balance for registration of new and import of used vehicles, the change in the vehicle stock and the whereabouts of the vehicles.¹⁷²

It is assumed that a lot of the black mass from recycling is being sold outside of the Nordics. Based on an interview with Norsk Hydro, it is suggested that the black mass is exported to other countries e.g. Asia, Canada, or companies, e.g. Clencore and Umicore.¹⁷³

168. "Science for Environment Policy": European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, Bristol.

169. Dr. Athanasios Karakatsanis, Sunlight Recycling Production Director in Recycling Magazine, June 2021.

170. Circular Energy Storage (2021) The lithium-ion battery life cycle report

171. EU report Mehlhart et al. (2017). Ökoinstitut

172. EU report Mehlhart et al. (2017). Ökoinstitut

173. Norsk Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

5.6.2 WEEE

Data on illegal export of WEEE is minimal. One of the most current data sources found at the EU level is published by Interpol Europe in 2015, where the estimates of waste flows generated in 2012 is presented in Figure 5-3. The 33% of WEEE (representing over 3 million tonnes) is estimated to be illegally exported to non-OECD countries. The typical destination regions are Africa and India. The report further anticipates that given that reuse and repair are the main economic drivers for such shipments, it is estimated that only 30% of the shipments are e-waste, while others are used equipment and products. Smartphones are often exported to China many times via Hong Kong where they are refurbished or remanufactured. Some of them are exported back to Europe¹⁷⁴. The same circularity problems are valid for them as described above for batteries from EVs.

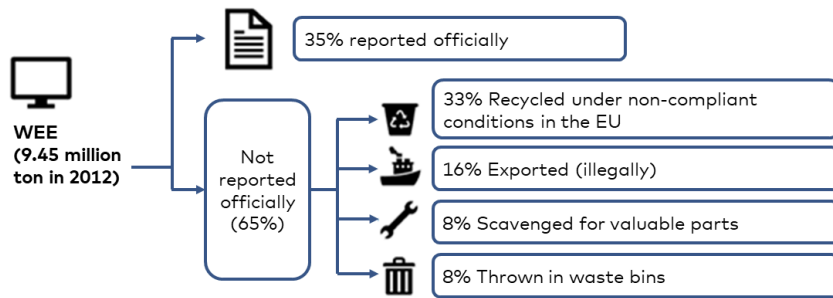


Figure 5-3. Estimates from Interpol Europe on what happens to WEEE produced in 2012. There is a big gap between the amount of EEE produced and WEEE collected.¹⁷⁵

174. Circular Energy Storage (2021) The lithium-ion battery life cycle report.

175. Drawn based on data from Huisman, et. al, 2015

6 Best practice and design for increased circularity – handbooks

6.1 Introduction

This section contains the content for the handbooks of best practice and design for businesses and consumers. Together with next section on policy recommendations, it constitutes Part 2 of the study.

The section is divided into two subsections, one for businesses and one for consumers. Some content is provided both for businesses and for consumers because it is relevant for both target groups.

6.2 Handbook of best practice for business

6.2.1 Introduction

Many businesses are currently exploring the countless possibilities of working with circularity of batteries and battery-driven products through new business models and improved ways of using the batteries more efficiently. To unlock these innovative business potentials in your company, new practices are needed both in your procurement, design and production departments. This circular way of thinking should be applied throughout the entire life cycle design of the batteries, spanning from how the materials are sourced, how the batteries are produced, through how consumers effectively use them, and to how the batteries are treated at their end-of-life.

In the following, we describe the principles behind circular design to better understand the following best practice recommendations.

Afterwards, to help inspiring you, we have gathered some examples of how other companies have implemented circularity in the business models and products. Not only does the circular approaches include a number of recycling activities, but there are other more sustainable and profitable ways of interacting with the circular economy, such as extending the lifetime of products or reusing components.

6.2.2 Principles for circular design

One source of inspiration for circular design is the principles established by the Ellen MacArthur Foundation shown in Figure 6-1. This model has been praised for being the foundation for commercialising and promoting the circular economy in the previous decade. Following this model, batteries belong to the righthand side due to their technical origin. According to this model, technical products should be shared, maintained, reused, refurbished, and recycled, to maximise economic extraction and minimise environmental impact.

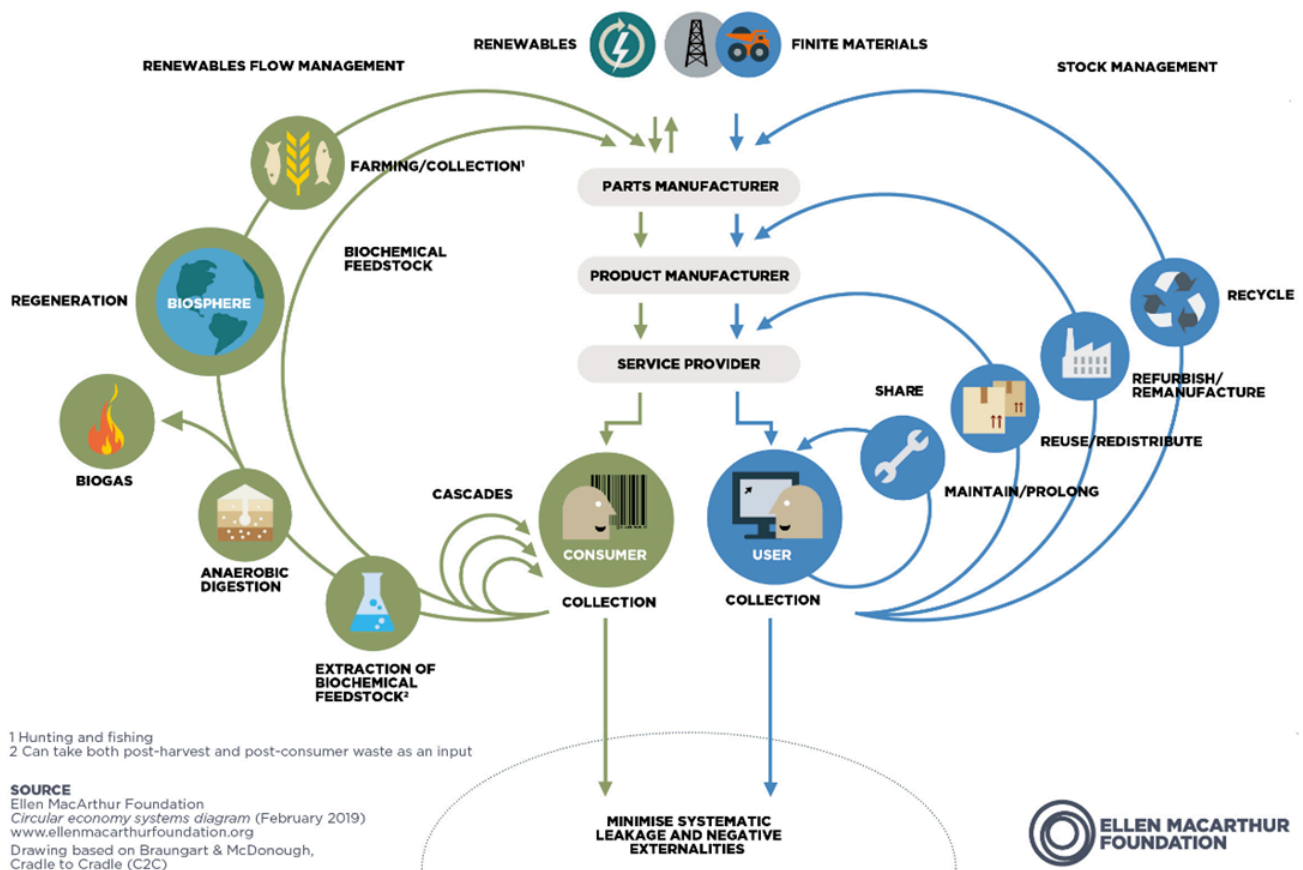


Figure 6-1. Principles of circular economy according to Ellen MacArthur Foundation

Source: <https://www.ellenmacarthurfoundation.org/circular-economy/concept/infographic>

Recycling is undoubtedly the strategy that receives the most attention, however, it is considered the least sustainable action of the four – because recycling often diminishes the economic value and the energy that has been put into processing the products – and leaves just the materials. The quality of the output depends greatly on the recycling process and the amount of impurities; can components be recycled, are materials downgraded or do they keep their original quality.

In order to harvest more value and decrease the climate impact, designers should aim for the smallest loop in the model. This should inspire designers to produce fewer products by sharing the amenities we already have or extending the lifetime of the goods. A lot of energy goes into the production of a battery e.g. the greenhouse gas emissions of producing a battery to an electric car is about the same as the rest of the car itself. Therefore, it is important to utilise the battery as much as possible to get the lowest emission per used kWh.

At the same time, it is also important to mention that mobile devices and battery driven electric vehicles has also driven the development towards energy efficiency in the use phase because it helps extending the periods between charging the batteries.

The strategy of maintaining and prolonging the batteries' lifetime focuses on

keeping them out of any recycling activities in the first place. The lifespan of a product is only as long as the lifespan of the weakest component unless it is repaired. Thus, it is essential to design the product for maintenance and repair so that the broken parts can be repaired or replaced and the product's lifetime can be prolonged.

Design for reuse and redistribution is a strategy, where the battery can be used in a different system or by another user when the user no longer needs the services from the battery. The circular design practice also enables products to be refurbished or remanufactured in their end-of-life and allowing them to reincarnate into a new product life.

There are numerous models on circular economy, many of which have been developed over the past decade, and most of them have their origin from The Ellen MacArthur Foundation's model. We have decided to use in this study an evolution of the Ellen MacArthur Foundation's model, where the focus on business models is stronger, thus making the model more applicable and practical for this study and useful for the intended audience of the report. This model is developed by Accenture Strategy¹⁷⁶ and as depicted in Figure 6-2. It uses life cycle thinking to consider all stages of a product from the upstream supply chain until the end-of-life treatment.

Business Models

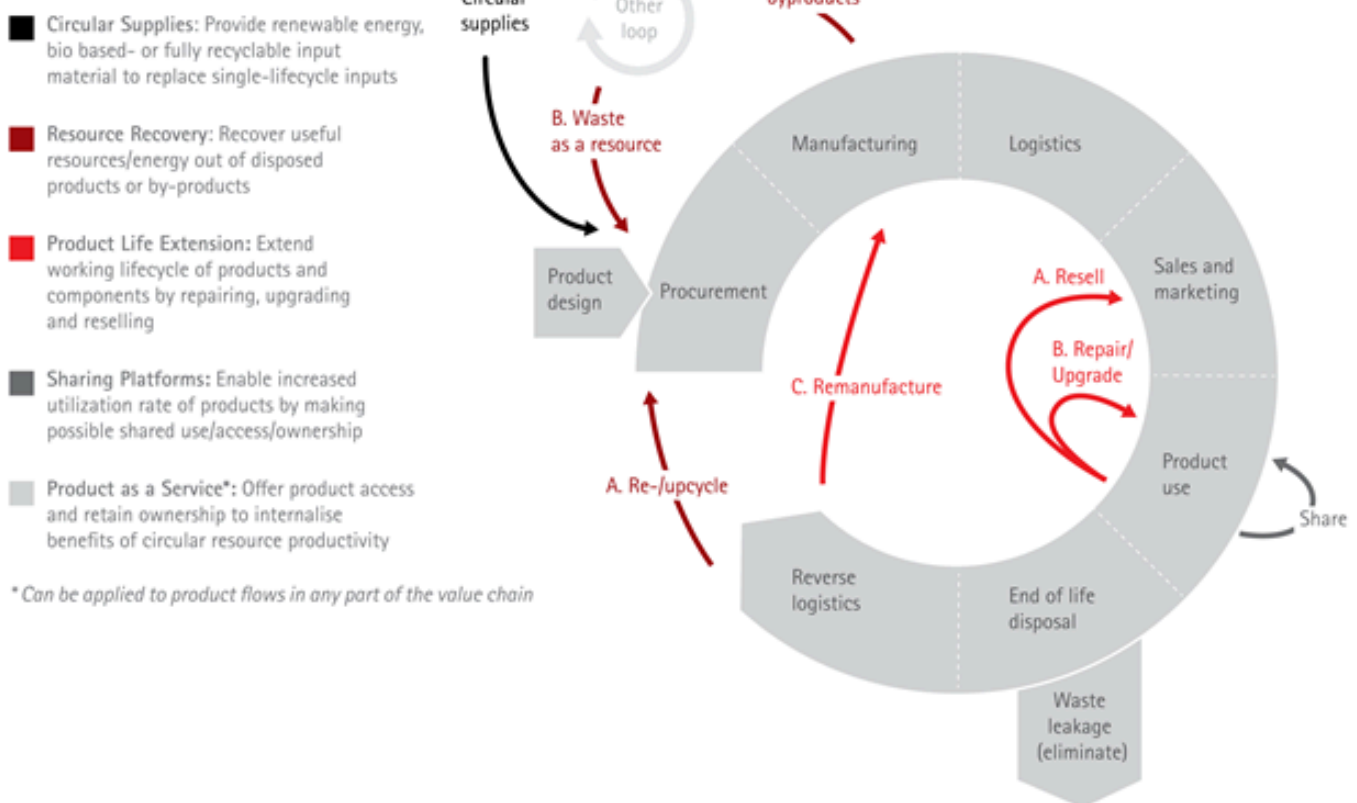


Figure 6-2. The Five Circular Business Models by Accenture.¹⁷⁷

176. Accenture Strategy, 2014, Circular Advantage, https://www.accenture.com/t20150523T053139_w_us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Strategy_6/Accenture-Circular-Advantage-Innovative-Business-Models-Technologies-Value-Growth.pdf

177. EU report Mehlhart et al. (2017). Ökoinstitut

In the following sections, we will explore each of the five business model types and provide case examples of companies that have adopted these approaches and initiatives that businesses can apply to support the circular economy of batteries.

The five sections cover:

- **Circular supplies** that describe to support sustainability and circular economy looking upstream in the value chain and demanding sustainable materials.
- **Resource recovery** that describes actions that can ensure reuse and recycling by applying actions downstream in the value chain.
- **Product life extension** that includes all the actions consumers and manufacturers can apply to increase the lifespan of products and components during the use phase.
- **Sharing platforms** that help to decrease the need for products by effectively sharing fewer amenities among more users.
- **Products as a service** where product ownership is never transferred to the consumer thus supporting maintenance, product life extension, and resource recovery.

Before we go into details with the five circular business models, it is needed to mention possible rebound effects, which can be a significant factor to be aware of when engaging with circular economy. Because many circular strategies increase profitability, decrease investment costs, and in general enhance convenience, they might even increase our resource dependency. For instance the invention of LED lights that reduced energy consumption significantly also led to just more lighting being put up. Or many car sharing services promote that they reduce the total production of cars. But most of their customers would not have been driving a car before the introduction of the sharing platforms. And battery swapping technologies increases convenience of driving EVs and thus increases the adoption of EVs, however this system requires many extra batteries for the infrastructure to work.

A more general rebound effect may take place, when we reduce product costs through sharing, reusing, and recycling, what happens to the money the consumers save? Many studies suggest that the money will be used elsewhere, increasing our consumerism and carbon footprint¹⁷⁸. A study from the Technical University of Denmark¹⁷⁹ concludes that full life cycle perspectives must be applied to ensure that economic growth and value creation in service systems still create a net resource reduction. In the following, we will just briefly mention a few rebound effects without going into more details.

6.2.3 Circular supplies

Circular supply is a business strategy where a company's scarce or non-renewable resource supply is replaced with circular alternatives, such as biobased, recycled, recyclable and biodegradable materials. The business model is especially sustainable and applicable in productions where scarce materials are used. Thus, the strategy could include using recovered lithium, cobalt, or nickel in the production of new batteries or replacing synthetic glue with a biobased material.

178. <https://doi.org/10.1016/j.rcrx.2019.100028>

179. https://backend.orbit.dtu.dk/ws/portalfiles/portal/162055145/Kj_r_et_al_2018_POSTPRINT_PSS_circular_economy.pdf

The best available techniques include battery companies that are researching or implementing ways of closing the loop of batteries. An important step in closing this loop, is to ensure that worn-out batteries in fact, become new ones through recycling or reuse schemes. After source separation, collection and efficient recycling, a new batch of battery-grade metals reenter the market.

Closing the loop for batteries will decouple our economy's dependency for mining virgin materials that often are scarce, polluting and include grave social challenges such as health hazards and child labour¹⁸¹. Over the years we have become more and more reliant on batteries for our many connected devices, e-mobility and to store renewable energy. This trend is expected to continue to grow, so in order to meet the future market demand, manufacturers must begin to source their materials more sustainably.

The current trend today for EV batteries in Europe is to increase the nickel content and to decrease cobalt which is on EU's Critical Raw Materials list¹⁸⁰. Since batteries containing cobalt relies on the market price of cobalt that may increase due to supply risk, risk for child labour in mining and safety issues compared to lithium iron phosphate (LFP) chemistry, old chemistries such as LMO and LFP have become in focus again especially for cheaper car models with lower range. VW is one player that has announced to have this type of differentiation. Also, in near future we may see new types of chemistries which will be better, and less environmentally impacting such as solid state or sodium batteries. Volvo is taking an additional approach and has started collaborating with NorthVolt in acquiring recycled batteries for their EVs.

Companies that manage to procure recycled materials, are not only helping to decrease the price and increase the quality of it. Participating in the circular economy, is a great way of improving the CSR (Corporate Social Responsibility) and company image. A source reports that 55% of consumers express that they are less willing to buy an electronic device if the company is not taking their environmental responsibility seriously. And not only do they want recycled and recyclable products, but also demand specific information on a product's percentage of recycled content and to what degree the product is recyclable at end-of-life¹⁸¹. The communication of circular supplies is often a driver for buying sustainable upstream supplies in the first place, thus it should obviously be clearly communicated on the product or its packaging.

The importance of communicating the circular supply information to the consumers, is mentioned in a study on consumer perspectives in circular business models; "companies following sustainable business strategies should engage consumers through awareness-raising communication campaigns and education on the consumption of circular goods, providing consumers with adequate information about recycled products and their characteristics"¹⁸².

NorthVolt Revolt is an example that have created their whole branding on their circular supply chain. Their batteries are produced from 97% recycled metals and 50% of the cells are reused. They team up with local recycling centers to source old batteries that are processed into new batteries.

180. https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

181. https://ec.europa.eu/info/sites/default/files/ec_circular_economy_final_report_0.pdf

182. Calvo-Porral & Lévy-Mangin, 2020, The Circular Economy Business Model: Examining Consumers' Acceptance of Recycled Goods



Figure 6-3. NorthVolt using their circular supply as a competitive advantage in branding.¹⁸³

In order to support the circular economy – and keep the recycling companies in business – manufacturing companies must demand and source recycled materials for their production. This growing market demand along with the concerns of resource scarcity is driving the adoption of recycling systems,¹⁸⁴ which eventually will decrease prices and increase quality of recycled battery-grade resources.¹⁸⁵

6.2.4 Resource recovery

Resource recovery promotes the recycling and reuse of end-of-life products through up- and recycling processes, so that the products, components, or materials can enter new product cycles. In contrast to business-as-usual recycling, this model deals with innovative systems or technologies to enable the circulation and require some product redesign to improve resource recovery through design principles such as modularisation and material homogeneity. Where the previous business model focused on upstream supply chain, this one is focused on the downstream treatment of resources.

Battery companies are currently attempting to close the loop of their resources. Apart from the need for adoption and market demand for recycled materials, another crucial focus is to enable resource recovery through various activities such as implementing modular design, design for separation, design for upgrade and so forth, so that the batteries, their materials and components can be efficiently recovered and reenter the circulation.

183. <https://northvolt.com/articles/a-binary-choice/>

184. European Union, 2016 Sustainable supply of raw materials

185. <https://everledger.io/closing-the-loop-on-portable-lithium-ion-battery-recycling/>

EU has set a goal to reach a 90% recovery target of cobalt and nickel in 2025, but that is calculated on the basis of batteries that are actually sorted. Evidently, making sure that consumers sort their batteries for recycling is crucial and that worn-out batteries are not accumulating in the consumers' homes. Figure 6-4 show batteries from smartphones collected for recycling.



Figure 6-4. Batteries from smartphones collected for recycling.¹⁸⁶

In order for manufacturers to recover their products and components to reuse and recycle them, thoughts must be put into the design phase. Products must be designed to effectively disassemble malfunctioning parts or separate the products in its diverse material fractions.

Nilfisk has for example designed their products to be disassembled by a screwdriver; this means that the battery can easily be taken out for waste separation at the end-of-life. The designers are following the standards developed by Joint Technical Committee 10 (JTC 10), which are supporting the EU's transition to a circular economy through requirements on durability, reparability, and recyclability of products. When all possible utilisation of the product has been harvested, the last thing is to extract the materials for new production through recycling.

Furthermore, if the battery can easily be disassembled, it not only supports efficient recycling, but also allows for simple change of battery by the user, which extends the lifetime of the device it is powering. The old battery can then be sent to companies like NorthVolt, Fortum, Stena or others, and the materials can effectively become new batteries.

Labelling of cells with the chemistry is very rare, but would simplify sorting before the hydrometallurgical recycling. The batteries used by Electrolux are for example marked with 'Li-ion', but not with the specific chemistry like NCM, NCA, LiFePO₄, LMO/LMNO, etc. Generally, this speaks into the traceability throughout the value chain so that composition and processing data can be accessed. This is an area of possible improvement for enhancing possibilities for recycling. Other materials such

186. <https://www.simslifecycle.com/2019/05/23/guide-how-to-responsibly-dispose-of-lithium-ion-batteries/>

as plastics should also be marked to indicate the polymer composition.

Resources are more attainable through partnerships in the value chain. There is an increase in cooperation between battery producing and battery recycling companies¹⁸⁷. E.g. Northvolt have partnered with Norsk Hydro to establish HydroVolt. This creates a win-win situation, because NorthVolt can design the batteries in order that Hydrovolt effectively can disassemble and recycle the batteries, which generate cheaper raw materials for NorthVolt's production. This is supporting Northvolt's goal to use 50% recycled (pre- and post-consumer) materials in their cell production by year 2030¹⁸⁸.

There will be a volume advantage of doing hydrometallurgical recycling in scale, i.e. centralized. But at the same time the benefit of more local disassembly of batteries is that there would be fewer hazards and regulation of transporting batteries across national and/or regional borders. Lithium-ion batteries are expensive to transport due to the legislation of hazardous goods.

One solution is to create more local collection and recycling points, where batteries are crushed and milled down for black mass, as transport of black mass is no problem. Black mass is classified as waste currently and looking over how it is classified could potentially increase the volumes available for the Nordics to recycle since there is a fight to get a hold of black mass for hydrometallurgical recyclers.

The implementation of more assembly points could therefore be a solution as suggested by a Norwegian project called LIBRES (Lithium-Ion Battery Recycling Project).¹⁸⁹

6.2.5 Product life extension

Product life extension is a business model where companies or users seek to prolong the lifetime of products through maintaining, repairing, upgrading and remanufacturing, thus, keeping the products or components intact for as long as possible, rather than recycling them down into their material fractions. This approach is not only environmentally viable, but from a business model perspective, the companies that master product life extension can also generate additional revenue due to extended usage of the product and consumers can save money because they only pay for the service that the product provides¹⁹⁰. The concept is often found in combination with the use of sensors and data to improve life through predictive maintenance or software upgrades. Battery management systems (BMS) is widely used to extend the lifetime of batteries through digital control of the batteries.

Recycling of batteries is much in focus, but how can we make sure batteries never become waste in the first place? Luckily, there are many ways of extending the lifetime of batteries and keeping them in our economy for as long as possible.

Around 63% of Europeans are repairing their products if they break which also correlates with a user segment that have knowledge about how to return or self-

187. Interview with Frida Vullum-Brøer from SINTEF

188. <https://northvolt.com/loop>

189. <https://www.standard.no/Global/PDF/Arendalsuka%202019/Sirkul%C3%A6r%20%C3%B8konomi/20190815%20-%20Rosenkilde%20Arendalsuka%20-%20Norsk%20Hydro.pdf>

190. https://www.accenture.com/t20150523T053139_w_us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Strategy_6/Accenture-Circular-Advantage-Innovative-Business-Models-Technologies-Value-Growth.pdf, accessed 16/03/2021

repair their products¹⁹¹. The remaining users are unaware of how to get their products repaired or even if it is possible. Additionally, it is shown that consumers are willing to pay more for durable and repairable products if the information is provided. Therefore, designers and manufacturers should focus on how to ensure and support of extending the lifetime of their products and communicate this information to attract the customers.



Figure 6-5. Electrolux have in collaboration with Stena Recycling made a reused vacuum cleaner from 100% recycled and reused materials.¹⁹²

Using LCAs to pinpoint the hotspots for intervention is useful for prioritising a company's environmental efforts by the actual impacts. This can help in identifying which phase extension the strategy should enable, such as repair for the initial customer, refurbishment to a new customer or second life with a completely new use case. Electrolux has used LCAs to analyse the most important aspects of their products and the results has taken them towards repairability, refurbishment and recyclability in general. They have also had a project on designing with re-use where a vacuum cleaner was equipped with a used electric motor.¹⁹³ They have since initiated three similar projects and they carry the symbol seen on Figure 6-5.

Some of the circular interventions to implement to increase lifetime are;

- Design robustness and digital robustness
- Modularity and upgradability
- Repair
- Refurbishing
- Second life in a new use case

Depending on whether the device or its battery is the limiting factor for the lifetime, some of the above mentioned strategies are more and less fitting. This will be elaborated further in the coming sections. But in general it is important to design all components and lifetime-determining factors such as the battery or the software, so that it corresponds to the lifetime of the overall device. If batteries are expected to wear out during the lifetime of the device, they should be easily replaceable, or the battery capacity could be larger so it runs fewer cycles and takes longer before it reaches its 70-80% capacity. Lastly, some battery technologies enable more cycles which could extend the lifetime.

191. https://ec.europa.eu/info/sites/default/files/ec_circular_economy_final_report_0.pdf

192. <https://www.stenarecycling.dk/nyheder/electrolux-presents-vacuum-cleaner-made-of-100-recycled-and-reused-materials2/>

193. <https://kunskapsrummet.com/artiklar/cirkularitet-aterbruk-och-smart-design/>

6.2.5.1 Robustness and Design

The BMS (Battery Management System), that controls how the battery is charged and discharged, can be designed to a usage profile with reduced voltage and current for better protection of the battery. This approach has enabled batteries used in Nilfisk products to have 1500 full charge cycles before the battery capacity is down to 70%. In comparison, the industry standard is about 600 cycles before the same capacity reduction¹⁹⁴. Nilfisk has also made an option that enables 3000 full cycles; however, this option will limit the module's initial available capacity because the cell is charged at a lower voltage. 3000 cycles are several times longer than the lifetime of an average consumer product, but this technology is useful for products that are leased or shared and therefore has more hours in use during the lifetime of the product compared to single user products. See a Nilfisk battery in Figure 6-6.



Figure 6-6. One of the batteries used in Nilfisk's products

Another approach, which e.g. can be seen in iPhones, is that the user is able to see the battery health in the phone's settings and turn on optimised battery charging, as shown in the screenshot on Figure 6-7. This ensures that the battery is only charged to 80% at night, and gives the final 20% power boost just before you wake up. This is useful, because batteries deteriorate when they are fully charged, so it should be avoided to stay too long in this phase. This feature does not exist for Android smartphones, and thirdparty apps cannot control and stop the charging. However, there are apps that notify Android users to manually unplug the charging cable at e.g. 80%.

194. Stated by Nilfisk



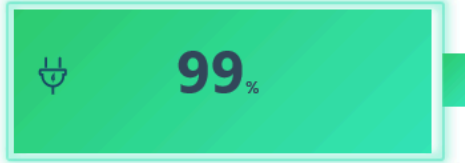
Figure 6-7. A screenshot from the battery health section in an iPhone

Few computer manufacturers like Lenovo and Asus, come with built in battery management software that allows users to set a charging limit, so that for daily work situations where they have their charger or even docked, the battery is not exceeding the 80%. For example, Lenovo offers a digital solution¹⁹⁵, where the charging is set to stop at 80%, as wear on lithium-ion batteries is highest when the battery is charged and used above 80% or below 5%. By only charging the battery to 80%, the battery is spared from unnecessary wear. Of course, when the users need full battery capacity, e.g. while travelling, they can still take advantage of all 100%, but it needs to be actively turned on. A similar tool is built in MacBooks, and similar to the iPhone technology, it analyses your daily routines and optimises charging for that.

On a Windows computer you can get a printed battery performance report by opening Windows PowerShell, and type `powercfg /batteryreport /output "C:\battery-report.html"` into the window and press Enter to run the command. Your computer has now generated a report and placed it on the C: drive. It gives you info like the current capacity, health of the battery and cycles count.

Some computers have also in the battery management software a possibility to see the battery health, see Figure 6-8.

¹⁹⁵. <https://support.lenovo.com/us/en/solutions/ht069687-easy-ways-to-extend-your-battery-life-ideapadlenovothinkpad-laptops>



Status	Ingen aktivitet	Strømforbrug	4.89 W	Stregkode	L3NX0CS00ZA
Resterende procent	99%	Temperatur	31 °C	FRU-partnummer	5B10W13905
Tæller for cyklus	17	Batteritype	Li-Polymer	Resterende kapacitet	51.07 Wh
Producent	LGC	Oprindelig kapacitet	50.5 Wh	Kapacitet ved fuld opladning	51.48 Wh
Fremstillingsdato	12/25/2020	Oprindelig spænding	11.55 V	Spænding	12.96 V
Dato for første anvendelse	04/14/2021			Firmwareversion	0001-00b7-0102-209c

Figure 6-8. A screenshot from Lenovo's battery health info

Lifetime of batteries can be prolonged by avoiding operating in extreme temperatures. Many BMS for mobile devices, such as laptops, tablets and smartphones switch the devices off automatically if the device is overheated. This safety action could be implemented more widely to protect batteries.

Ensuring high safety and uniformity of batteries and their BMS by following the new standard IEC 60335-1 is important, and done by many Nordic manufacturers as well. The certification sets requirements for correctly charging, and that no overload of the battery will occur. Furthermore, it ensures that individual cells are not overloaded, which leads to a prolonged lifetime of the battery because the cells are not put under unnecessary stress. Other standards include IEC 60086 that relate to the standardisation of dimensions and voltage, IEC 62840 which is underway and describes safety requirements for swappable EV batteries, and IEC 61429:1995 that dictates when secondary batteries can carry the Mobius recycling symbol.

6.2.5.2 Modularity and upgrade

Batteries that are easily separated from their devices, are not only beneficial for efficient sorting and recycling. Easy separation also allows for simple replacing and upgrading of batteries, thus the lifetime of the device can be prolonged if its lifetime is longer than the first battery's lifetime. If the battery has the longest lifetime, then the battery can be placed in a new product. However, the risk is also that modularity and upgradability of batteries might lead to batteries being replaced too often instead of using them until their capacity is completely worn out.

The JTC-10 standards are developed to support EU's transition towards a circular economy and ensure that the products are designed for repair, refurbishment and dismantling. Thus, they increase material efficiency through requirements on durability, reparability, and recyclability of products. Nilfisk has therefore designed all

of their products to be disassembled by a screwdriver; this means that the battery can easily be taken out for repair, replacement, or recycling in the end-of-life by the user.

Electrolux's claims that their new stick type vacuum cleaners have dismantlable batteries (see Figure 6-9), in contrast to previous designs. The advantage is that proper recycling of the battery can be done and that easy replacement of batteries allow for product life extension as well. The disadvantage is a somewhat clumsier design, and that one extra printed circuit board is needed which contains critical and scarce metals, of which only some will have a chance to be properly recycled.



Figure 6-9. The new line of Electrolux vacuum cleaners.

Sometimes, the separability of batteries is a trade-off with other functionalities, some of which also affect the lifetime. For instance, more and more manufacturers move away from accessible batteries, because they want their devices waterproof, which is also extending the lifetime through durability against vapour and particle wear and protection against water damages. In cases where batteries cannot be easily swapped, manufacturers should aim to match battery lifetime with device lifetime, through either overdimensioning the battery or build it with increased cycles. Often, it is possible to replace internal batteries in notebooks using widely available tools such as screwdrivers, while in mobile phones the battery would be more difficult to replace for the typical user.

Many of the examples above use modularity to make battery sharing possible between tools from the same brand. In contrast, the Cordless Alliance System (CAS) consist of a group of power tool producers, that have decided to use standard batteries that are compatible with 230 machines in the 18 V class as seen in Figure 6-10.



Figure 6-10. Some of the brands that have applied the CAS battery standard.¹⁹⁶

6.2.5.3 Repair and spare parts

A Danish study¹⁹⁷ has investigated the smartphone repair shops that has been emerging the past decade, and which seems to be a success both for the shops and their customers. However, some identified barriers faced by these shops include difficulties in attaining original spare parts, and that non-original spare parts are often low quality, and the legal right to two years warranty might be impeded using used components in smartphone repair.

A current movement called "Right to Repair"¹⁹⁸ is gaining attention from policymakers to allow consumers to repair their own products without losing warranty rights, thus putting pressure on manufacturers to implement modularity and repairability in their products and providing sufficient information on these matters. The slogan behind is shown below in Figure 6-11.



Figure 6-11. The EU campaign as part of the Right To Repair movement.

196. <https://www.cordless-alliance-system.com/>

197. https://vbn.aau.dk/ws/portalfiles/portal/266388717/309_607_1_SM.pdf

198. <https://repair.eu/>

In a survey made by The Ellen MacArthur Foundation among users of iFixit, a platform for DIY repair guides and spare part shop, 17% respondents were not able to find the spare parts they needed, and 18% found them too expensive, especially when looking for original parts. Generally, manufacturers of low-end products do not sell spare parts, and for high-end products, the spare parts are very expensive compared to the price of a new product.

Thus, some recommendations for increasing repairability include; extract and resell functional batteries from refurbished or waste products; sell spare parts such as batteries at a reasonable price including shipping costs; provide repair guides and offer spare parts on a website or collaborate with existing repair forums and phase out the use of glue and non-reversible snap locks to fasten batteries. If possible, batteries should be swappable without the need for any special tools.

There is potential for a market in second-hand electronics if followed by a guarantee, which is the case when the product is sold by a commercial trader¹⁹⁹. E.g. in a Swedish survey by Statistiska Centralbyrån, over almost 60% of Swedes answer that they have bought second-hand electronics. The correspondents answered that the main reason for why more people do not buy electrical products and electronics is that they are unsure of how long they are going to last, and the second reason is that they want a guarantee that they will last. An example of company that have made a business out of refurbishment is Fonebank (UK), and Blue City (DK, SE) , that buys up old phones and refurbish them, so they look as good as new, and sell them at a lower price than a new phone. This requires the phone to be designed for refurbishment such as the ability to change battery and outer cover.

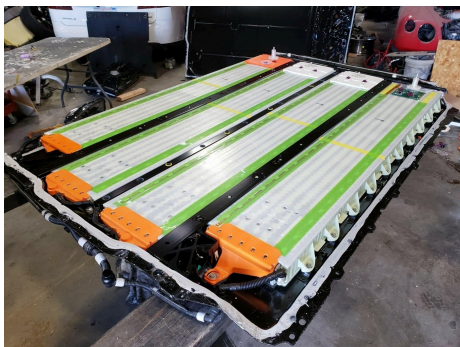


Figure 6-12. Tesla Model 3 battery modules.²⁰⁰

Repair of batteries on an individual cell level is not feasible today if the cells are placed in modules which is usually the case. After switching of modules the battery then needs to be recertified. If the refurbish or repair company wants to increase the capacity of the battery, they replace or add a battery module, because this process does not require recertification of the battery. However, Tesla have redesigned their modules for the newer Model 3 to enable individual cell replacement, which they plan to do at their Tesla mechanic service points. This might be a future trend that can spread to other industries.

199. https://europa.eu/youreurope/citizens/consumers/shopping/shopping-consumer-rights/index_en.htm#from-trader-1

200. <https://www.currentautomotive.com/how-much-does-a-tesla-model-3-battery-replacement-cost/>

6.2.5.4 Modularity / second life EV

Many electric and electronic products have a sound market for second life through reselling used devices or vehicles. However, when those products are worn out, there might still be options for a second life of the battery in another use context.

EV design in Europe is mainly moving towards integration of the battery into the car chassis and, by doing so, reducing the use of material around the cells. A reason for the integration is that the batteries are expected to be used for the entire lifetime of the car. However, this makes upgrading challenging in the future, e.g. if battery technology improves significantly or for second life of batteries in stationary energy storage. Therefore, it is seen as not being the best practice because of difficult battery replacement, though it is beneficial for reducing material consumption and energy consumption during use due to the lower weight.

Currently, car manufactures design the batteries physically for the first life purpose and this makes it almost impossible to automate disassembly of batteries, and they require expensive manual labour. In China, many EV manufacturers allow for battery swapping: a quick replacement of the battery to a charged one as alternative to traditional charging of the battery. This means that they are very easy to remove, upgrade and recycle. The negative side of swapping is that there is need for more batteries for the system to work, more materials are used, and users are less prone to take good care of the battery.

Heavy duty batteries for buses and trucks are relatively easy to replace in contrary to most passenger EVs, since they are expected to drive as much as possible and the batteries may be changed during the heavy vehicle's lifetime. These heavy duty EVs are relatively new on the market, thus the designs are not yet fully optimised for remanufacturing or second-life. Moreover, the battery chemistry is evolving at a very high pace which may counteract the design for long service-life. Nevertheless, second-life is a very hot topic, which becomes reality, since it is a way to reduce the end-of-life costs and impacts by sharing them with the company who uses the batteries in their second-life. One example is the collaboration between Volvo Group and Stena Recycling announced in 2020.²⁰¹

When lithium battery reaches a capacity of 70–80%, it reaches the end-of-life phase in applications such as cars and ferries. Some of the batteries can be refurbished for a second life in stationary storage systems, either in buildings or as grid support.

In Norway, several ferries have switched to battery driven technologies, however, the ferries are often used to transport people between smaller cities at the fjords. The energy system in the smaller cities is not built to powering both the city and charging an electric ferry in a short time. Therefore, energy storage systems have been developed to charge the ferry when it is docking, and stationary storage is a suitable situation for worn-out batteries from EVs for instance.

An example is Renault, that take back their EV batteries when they have decreased to 70% of their original capacity and are therefore not suitable for transportation anymore. The used batteries are instead used for general energy storage, where a weight and capacity are not as important design factors²⁰², which is shown in Figure 6-13.

201. <https://www.volvogroup.com/en/news-and-media/news/2020/sep/news-3766485.html>

202. <https://www.electrive.com/2018/09/26/renault-to-install-europes-largest-2nd-life-battery-storage/>



Figure 6-13. Batteries from Renault EVs are reused for stationary purposes.²⁰³

Several barriers complicate the process in giving vehicle and ferry batteries a second life. First of all, car manufactures use a closed-loop system, where the battery and its BMS is optimised for the best performance of that car. For safety reasons, the battery and BMS are inoperable for other actors. As a result, companies like ECO-STOR²⁰⁴, that repurpose EV batteries to give them second life, cannot just use any car battery. To solve this challenge, ECO-STOR partners up with a handful of car manufacturers e.g. Nissan, which provide them access to the BMS system, so ECO-STOR can modify the battery to perform as an energy storage battery.

6.2.6 Sharing platforms

A sharing platform is an efficient circular business model where products are shared between multiple users. The model requires a platform to control, manage and rent out all the products in order to maximise operation time and utilisation of the products, thus minimizing the needed amount of products. However, many examples of today's sharing systems are run by companies that share third party products, which are not specifically designed for sharing. In order to harvest the full potential of such business model and increase the lifespan of the overused product, they must be optimised for sharing, like improved robustness, increased traceability and monitoring through sensors and data logging.

Value benefits for end users include improved geographical access at cheaper prices for short term uses e.g., renting an e-scooter rather than buying one, and having 24-hour access to the service from every corner in the city. Some sharing platforms have evolved to include "sharing of sharing platforms", such as carpooling in Uber and Lyft, where not only idle time of cars are improved but also maximization of seat capacity in the vehicles.

Many devices are only used by the consumers for a very little part of its lifetime.

²⁰³. <https://www.electrive.com/2020/10/21/renault-presents-two-second-life-battery-projects/>

²⁰⁴. <https://www.eco-stor.com/>

Power tools are often tucked away in the garage. Electric cars are parked most of the time apart from those 2 hours a day when they are taking their owner to and from work. There is a great potential to reduce the amount of products and batteries you produce, while reaching the same amount of customers.

Examples of sharing of batteries between product lines within a brand are becoming more popular and is a great way of keeping your customers within your brand's products. Both Husqvarna, Nilfisk and to some extent Electrolux has done so and designed batteries that are exchangeable across their own products. As a result, batteries from one product can be used in another without problems. This makes it easier to obtain a spare part battery from e.g. Nilfisk, because they only produce few types of batteries that works across most of their products. Also, if you have a spare part battery from one product that breaks down, it is possible to use that battery in another product where the battery is worn out. However, Electrolux claims that a disadvantage is that the batteries has to be dimensioned for their most energy demanding vacuum cleaner. As a result, the less demanding products come with overengineered batteries, which might have a higher environmental impact and higher price tag.

Examples of platforms or hubs that enable many users of accessing a pool of products are for instance seen in Husqvarna's digital tool shed, where customers can rent professional equipment, through an app. Husqvarna sees this as a strategy towards higher utilisation of their products. In their view, customers prefer to rent and use high quality products compared to owning cheap products that they only use few times anyways. Husqvarna sees availability and ease of renting as important parameters towards more renting of equipment instead of buying. That is why they try to locate the digital shed close to the customers and making the tools available 24/7. They also think some consumers still prefer to buy the products instead of renting them, because petrol versions can be very cheap. As a regulatory tool that improve sharing of battery driven products, they see VAT reduction for renting as useful.



Figure 6-14. Husqvarna's digital shed.²⁰⁵

205. <https://www.husqvarna.com/se/support/tools-for-you/#location>

6.2.7 Product as a service

Product as a service is a model that seeks to improve the efficiency and shift the motivation for resource efficiency by delivering the value as a service rather than selling the asset to the customer. The model requires a deep understanding of the customers' needs and shifting to a contract-based service delivery.

An example outside the battery topic but still a relevant illustrative example is "pay-per-lux" from Philips that sell access to lighting in office buildings, but they do not sell the actual bulbs. The customer agrees to buy "lighting within work hours in a 3000 m2 office building" and pay a specified price for that service. Philips installs their LED bulbs, and take over the energy bill for lighting. Philips now have an economic incentive to improve energy efficiency as much as possible, maintaining the bulbs, and if the customer ends the contract for any reason, Philips can re-install their bulbs in other customers' office buildings. These kind of models are however only aiming at a narrow, financial benefit.

The business models can vary in the product-to-service ratio, meaning that one business model can be either full service with little or no product ownership, like in the pay-per-lux example, or involve mainly product ownership with a small service add-on including guarantee, support agreements, upgrade agreements or monitoring software.

As a manufacturing company, if you decide to move into delivering your products as a service, you will get access to all new user segments that both involve a more green segment, but also users that would normally not make the upfront investment of owning the products. Another obvious benefit for companies that manufacture high quality products, is that they earn more money the longer their products last, by taking advantage of the long lifespan and a subscription based revenue model. The robustness and reparability is often improved because the motivation is now on the manufacturers side, and it is in their interest to make products last longer than the normal two-year warranty period.

The acquisition cost of battery driven products is generally more expensive than petrol driven products (sometimes up to a factor 2), so some customers will rather purchase the petrol driven versions, such as lawn mowers, cars, scooters, hedge trimmers etc. However, Husqvarna experienced that the total life cycle cost is typically lower for battery driven equipment, thus a great potential for selling it as a service so the user is paying less for what they actually need, and the capacity of the battery is fully optimised during its lifetime.

High-quality products, with long lifetime often comes with a higher price tag. According to Nilfisk, their customers are willing to pay for the higher price, as their segment is demanding resilient, robust, and durable products, so that they have as little downtime as possible. This is also enforced as many customers are retailers that rent out the equipment. The company is using Li-ion batteries even though they are more expensive. Still, because of the Li-ion battery's properties, the self-autonomous cleaning machines can run for a longer time and cover a larger area, which is economically beneficial for the customer.

Similar to the pay per lux model, Electrolux has developed a pay per square metre business model, where a robot vacuum cleaner sweeps the area paid for instead of the customer owns the robot.

Selling mobility as a service is nothing new. It has been normalised through services such as taxis, leasing or car rental. But new concepts for electric vehicles are emerging to prolong the lifetime of batteries and maximise the use time of those. Volvo Trucks and Polestar are currently investigating such options in order to increase profit per vehicle and decrease GHG impact per kilometre, and battery exchange is a central topic because of its relatively high contribution to GHG emissions for the vehicle production. The project, financed by Swedish Vinnova, is run by the project leader research institute RISE and IVL Swedish Environmental Research Institute and is Future Adaptable Design Electrical Vehicle by Circular Business models, FAD-EV²⁰⁶.

The battery is for many customers used for a limited number of cycles in some products like gardening tools and to increase that utilization Husqvarna tries to promote renting and leasing of their products. A part of that strategy is digitalization, where the company is able to track the products, see when it needs service and how many cycles the battery has been used for. This is useful for predictive maintenance, as products are not cared for to the same extent as if it was owned by the user.

There are many advantages to the circular economy design principles. Emerging business models increase availability through shared access on platforms, decrease total cost of ownership through improved repairability and prolonged lifetime, and reduce material cost through promotion of recycled resources. However, designers should also be aware of potential rebound effects, where shifts in culture and economy might lead to unwanted effects. An example is the car-sharing systems that are intended to decrease the need for cars through utilizing fewer vehicles to more users. However, the accessible sharing systems might appeal to consumers that would normally use public transportation and might not appeal to users that have a relatively stable need for a car. The result is increased car transport and decreased biking or public transport. Also, in many sharing systems, the products have very short lifetime, because the users do not care for the products as they would if they owned them. As a result, e-scooters as an example only have an expected lifetime of 3 months according to a study by Boston Consulting Group in 2019.²⁰⁷

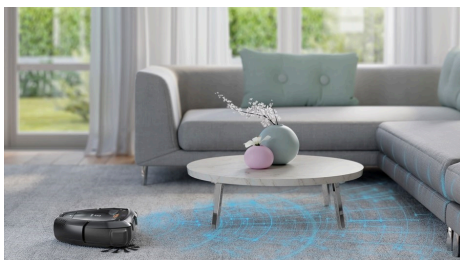


Figure 6-15. Electrolux is currently testing vacuum-as-a-service.²⁰⁸

206. <https://www.ri.se/en/what-we-do/projects/future-adaptable-design-electrical-vehicle-by-circular-business-models-fad-ev>

207. <https://www.bcg.com/publications/2019/promise-pitfalls-e-scooter-sharing>

208. <https://www.electroluxgroup.com/en/vacuum-as-a-service-electrolux-trials-new-subscription-based-business-models-29880/>

6.3 Handbook of best practice for consumers

6.3.1 Introduction

Many businesses are currently exploring the countless possibilities of working with circularity of batteries and battery-driven products through new business models and improved ways of using the batteries more efficiently. Consumers can support this development via their purchases and at the same time achieve economic benefits for themselves and help protecting the environment.

In the following, we describe the principles behind circular design to better understand the following best practice recommendations.

Afterwards, we describe what you as consumer can do via your action at the purchase situation and during use of the purchased products.

6.3.2 How design can improve circularity and sustainability of products

Recycling is undoubtedly the strategy that receives the most attention, however, it is considered one of the least sustainable actions within the principles of circular economy – because recycling often diminishes the economic value and the energy that has been put into processing the products – and leaves just the materials. The quality of the output depends greatly on the recycling process and the amount of impurities; can components be recycled, are materials downgraded or do they keep their original quality.

In order to harvest more value and decrease the climate impact, we should aim for smaller "loops"; like using fewer products by sharing the amenities we already have, e.g. sharing batteries between different products in your home or sharing the products with other people. A lot of energy goes into the production of a battery e.g. the greenhouse gas emissions of producing a battery to an electric car is about the same as the rest of the car itself. Therefore, it is important to utilise the battery as much as possible to get the lowest emission per used kWh.

Maintaining and prolonging the lifetime of batteries' keeps them out of any recycling activities in the first place. The lifespan of a product is only as long as the lifespan of the weakest component unless it is repaired. Thus, it is essential to buy products that are designed for maintenance and repair in mind, so that the broken parts can be repaired or replaced and the product's overall lifetime can be prolonged.

Design for reuse and redistribution is a concept, where the battery can be used in a different system or by another user when you no longer need the services from the battery. This also enables products to be refurbished or remanufactured in their end-of-life and allowing them to reincarnate into a new product life.

In the following sections, we will explore some circular ways to buying, using and disposing batteries and provide case examples of companies that have adopted circular initiatives.

The five sections cover:

- **Circular supplies** that describe circularity in the materials that go into the products.
- **Resource recovery** that describes actions that can ensure reuse and recycling of

batteries.

- **Product life extension** that includes all the actions that can increase the lifespan of your battery products and components during the use phase.
- **Sharing platforms** that help to decrease the need for products by effectively sharing fewer amenities among more users.
- **Products as a service** where product ownership is never transferred to you thus supporting maintenance, product life extension, and resource recovery.

Before we go into details with the five sections, it is necessary to mention possible rebound effects, which can be a significant factor to be aware of when engaging with circular economy. Because many circular strategies increase profitability, decrease investment costs, and in general enhance convenience, they might even increase our resource dependency. For instance the invention of LED lights that reduced energy consumption significantly also led to just more lighting being put up. Or many car sharing services promote that they reduce the total production of cars. But most consumer would not have been driving a car before the introduction of the sharing platforms. And battery swapping technologies increases convenience of driving EVs and thus increases the adoption of EVs, however this system requires many extra batteries for the infrastructure to work.

A more general rebound effect may take place, when we reduce product costs through sharing, reusing, and recycling, what happens to the money we save? Many studies suggest that the money will be used elsewhere, increasing our consumerism and carbon footprint.²⁰⁹

6.3.3 Circular supplies

If a product's scarce or non-renewable resource supply are replaced with circular alternatives, such as biobased, recycled, re-cyclable and biodegradable materials, we could improve the sustainability performance significantly. In the case of batteries this could include using recovered lithium, cobalt, or nickel in the production of new batteries or replacing synthetic glue with a biobased material.

Consumers can help the transition towards circular economy and close the loop for batteries. This will not only decrease the environmental burden of products, but also reduce the price over time and decouple the need for mining, which is hazardous for miners and often rely on child labour. Thus, the higher content of recycled materials in a battery, the less dependent is it on unsustainable sourcing and the lower climate impact.

To demand circular supplies and to push the development, consumers should look for labels and certificates on products.²¹⁰ This includes the rate of recycled material in the product; the recyclability of the product and its packaging; worker ethics labelling; energy efficiency labels; and biobased and plastic free production labels. An example is the industry label Eco Rating which evaluates the environmental impact of the entire process of production, transportation, use and disposal of mobile phones and provides a score from 1 to 100.

However, the amount of labels can often be overwhelming and lack of

209. <https://doi.org/10.1016/j.rcrx.2019.100028>

210. https://circulareconomy.europa.eu/platform/sites/default/files/carta_consumo_circolare_eng.pdf

standardisation makes transparency challenging. So sometimes you might need to look up a certificate while in the store, to see what the labels actually entail. Figure 6-16 gives an overview of a few relevant labels to look for when buying battery equipped devices. In relation to the complexity of labels, consumers should demand standardised labelling systems for circular and sustainable performance of products.



Figure 6-16. Labels from left; (1) Mobius Loop, (2) The Green Dot, (3) WEEE, (4) Nordic Swan, (5) IRMA, (6) SCS Recycled Content.²¹¹

With few words the labels are described as the following:

1. Mobius Loop shows that a given product is able to be recycled at its end-of-life. However, this does not say anything about whether the product is made from recycled material.
2. The Green Dot is a European symbol, that shows that the producer of a given product has financially contributed to the collection and recycling of such products. It does not necessarily mean that their product is recyclable or made from recycled content.
3. WEEE is a European label that should remind consumers not to put the waste electronic in the general waste bin but go to recycling through the local recycling stations or dedicated bins.
4. The Nordic Swan looks at the entire life cycle of a product and indicates that this product is a better alternative over other products in terms of use of environmental performance and human health.
5. IRMA sets a set of rules and standards for sustainable leadership in mines, the focus is mostly on social sustainability, so it is not necessarily an indication of environmental friendly mineral extraction.
6. SCS Recycled Content certifies that a company can claim a certain content of recycled material in their products.

Not only the sourcing of materials for production is important when discussing circular supplies of batteries. In the use phase of mobile devices and EVs, electricity consumption is an environmental hotspot. However, batteries are drivers of the green energy transition as they allow for more flexible consumption patterns of electricity. Using batteries, we can store energy when there is a green surplus and spend it when renewable sources are not producing enough electricity.

211. <https://www.recyclenow.com/recycling-knowledge/packaging-symbols-explained>



Figure 6-17. Batteries can help driving the transition to green energy.²¹²

As more and more households invest in EVs, the energy consumption of those households is expected to heavily increase. Also, the need for batteries are expected to grow greatly. The EV battery will often be fully charged at home at night, while smaller recharges during drives might be necessary. Aligning the recharging with availability of green and cheap energy is possible through a variety of different models.

Managed charging is where consumers subscribe to charging infrastructure, but agrees to delay the charging up to e.g. one hour²¹³, which enables the energy provider to align with the grids needs and thus increase the share of green energy. Discount programmes allows for differentiated charging based on the availability of green energy. This can be controlled through internet connected apps, where your phone will receive information on current energy prices and green share while controlling the charging of your EV. Another option to purchase a stationary battery that recharges when energy is green and cheap. The battery then releases the energy to the EV whenever the customer needs it.²¹⁴

6.3.4 Resource recovery

Resource recovery promotes the recycling and reuse of end-of-life products through up- and recycling processes, so that the products, components, or materials can enter new product cycles. In contrast to normal recycling, this concept deals with innovative systems or technologies to enable the circulation and require some product redesign to improve resource recovery through design principles such as modularisation and material homogeneity.

A chain is only as strong as its weakest link, and in order for resources to effectively circulate, consumers are one of the links that connect the whole value chain and have a great responsibility to help reducing the environmental footprint and improve social challenges in mining regions.

212. <https://orsted.com/en/media/newsroom/news/2019/12/945369984118407>

213. <https://www.wri.org/insights/4-emerging-ways-pair-electric-vehicles-and-renewable-energy>

214. https://www.tesla.com/da_dk/powerwall

To ensure the recycling and circular supplies for battery production, consumers must participate in their local sorting schemes. These are slightly different between the Nordic countries, but generally batteries should be separated from the device, taped at the poles and source separated individually. In some cases, the battery can be disposed within the electronic waste, if the battery cannot easily be removed.



Figure 6-18. Most consumers have old LiBs stowed away²¹⁵

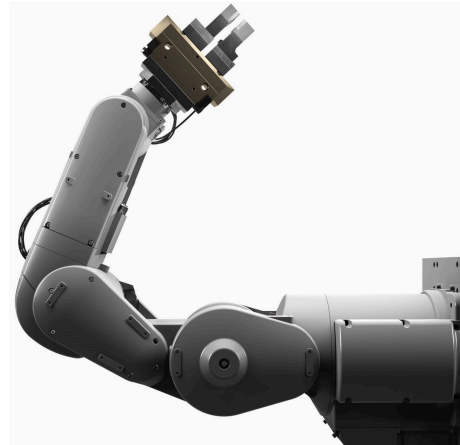


Figure 6-19. Apple's special robot for disassembling their old products.²¹⁶

Even though lifetime extension is the most preferred circular action, batteries are still expected to degrade over time. Thus, recycling is inevitable at some point but in order to allow this, sorting and recycling efficiencies must be improved. According to the US Department of Energy, around 95% of LiBs on the American market, will never be recycled.²¹⁷ This is due to lack of motivation and action of consumers and policymakers, and lack of manufacturing companies designing their products for recycling.

Sorting your batteries for recycling is crucial and you should ask yourself, how many batteries you have hidden away in your drawers. Most people have around 10 LiBs tucked away, that accumulate instead of reincarnating into new products.²¹⁸ So it might be of good intention that you store your used batteries in a jar – just remember to send them to recycling frequently.

If possible for large batteries and electronics, prioritise to deliver the product and battery back to the producer if they offer the service instead of the municipal WEEE scheme, as the manufacturer knows exactly how to dismantle their old products. Furthermore, some manufacturers even promote the recovery of their products and their valuable materials by providing a purchasing credit for consumers that hand in old products when buying a new one. Apple is doing this on many of their devices such as iPhones and MacBooks, where functioning products and components are refurbished and re-sold, while older or broken models are disassembled using automated robots for precious metal recycling.²¹⁹ There are many different recovery programmes similar to the one provided by Apple.

215. <https://www.mirror.co.uk/news/uk-news/unused-old-gadgets-you-sitting-13741767>

216. <https://www.apple.com/shop/trade-in>

217. <https://everledger.io/closing-the-loop-on-portable-lithium-ion-battery-recycling/>

218. <https://everledger.io/closing-the-loop-on-portable-lithium-ion-battery-recycling/>

219. <https://www.apple.com/shop/trade-in>

6.3.5 Product life extension

Product life extension is a business model where companies or users seek to prolong the lifetime of products through maintaining, repairing, upgrading and remanufacturing, thus, keeping the products or components intact for as long as possible, rather than recycling them down into their material fractions. This approach is not only environmentally viable, but from a business model perspective, the companies that master product life extension can also generate additional revenue due to extended usage of the product and consumers can save money because they only pay for the service that the product provides.²²⁰ The concept is often found in combination with the use of sensors and data to improve life through predictive maintenance or software upgrades. Battery management systems (BMS) is widely used to extend the lifetime of batteries through digital control of the batteries.

Recycling of batteries is much in focus, but how can you make sure batteries never become waste in the first place? Luckily, there are many ways of extending the lifetime of your devices and batteries to save money and the environment. Some of the recommendations that will be elaborated in the following section include:

- Buy longlasting, robust products
- Maintain and repair your products – also digitally
- Look for modularity, upgradability and repairability in new products
- Buy refurbished products and resell them when you do not need them
- Give your devices a second life in a new use case

6.3.5.1 Modularity, upgradability

Design for simple exchange of components is promoted by multiple companies already. For many mobile devices, batteries are the weakest component with the shortest lifetime due to their reduced capacity over time. In some smartphones the battery can be easily swapped without any tools when it has been worn out, as old mobile phones used to before the development of smartphones. A few manufacturers, e.g. FairPhone²²¹ however have implemented this ability, which enable users to easily extend the lifetime of their phones without having to pay repair shops to do the work and risk of losing the phone's warranty. See Figure 6-20.

220. https://www.accenture.com/t20150523T053139__w__/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Strategy_6/Accenture-Circular-Advantage-Innovative-Business-Models-Technologies-Value-Growth.pdf, accessed 16/03/2021

221. <https://support.fairphone.com/hc/en-us/articles/115001041206-Find-fix-an-issue-yourself>



Figure 6-20. FairPhone's website gives you guides for self repair of most common issues.²²²

6.3.5.2 Maintain

Lifetime of batteries can be prolonged by avoiding operating in extreme temperatures (0 to 35°C) and only be stored with in cool environments, around 10–15°C. For long time storing of battery-driven devices, the battery should be half-charged and powered off. Many battery management systems, a part of the device's software for mobile devices, such as laptops, tablets and smartphones, switch the devices off automatically if the device is overheated. It is recommended to not place your devices directly in the sun, and turn them off if temperatures go above or below the recommended temperature threshold.

Another approach for consumers to prolong the lifetime of batteries can be done digitally through software interventions. In iPhones, users can see the battery health in the phone's settings and turn on optimised battery charging, as shown in the screenshot on Figure 6-20. This ensures that the battery is only charged to 80% at night, and gives the final 20% power boost just before you wake up. This is useful, because batteries deteriorate when they are fully charged, so it should be avoided to stay too long in this phase. This feature does not exist for Android smartphones, and thirdparty apps cannot control and stop the charging. However, there are apps that notify Android users to manually unplug the charging cable at e.g. 80%.

222. <https://support.fairphone.com/hc/en-us/articles/115001041206-Find-fix-an-issue-yourself>

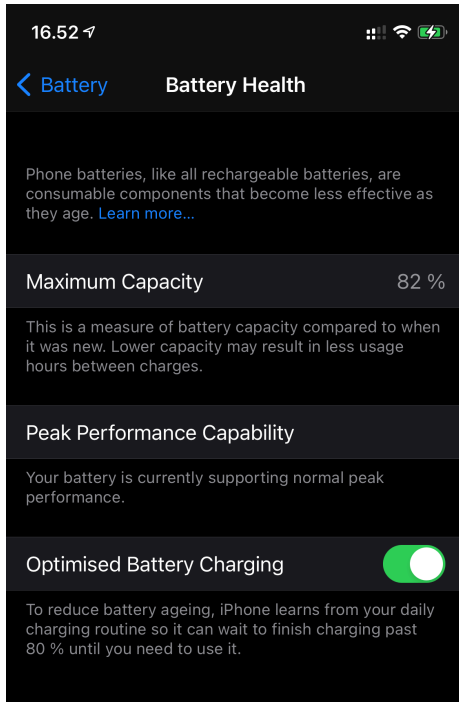


Figure 6-20. A screenshot from the battery health section in an iPhone

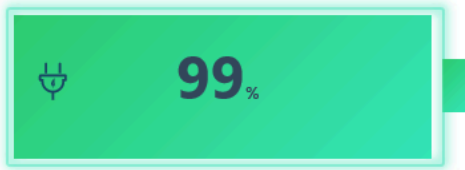
These digital solutions can be used to extend the lifetime of batteries and can be worth for users to explore both when purchasing their products but also as downloadable addons after purchase. Products come with built in Battery Management Software, which primary purpose is to protect the cells from operating outside its safe operating conditions.²²³ But, some BMS' does also have properties that can affect the lifetime of the battery, by monitoring the condition of the battery and limiting the charging pressure. For example, Lenovo offers a digital solution²²⁴, where the charging is set to stop at 80%, as wear on lithium-ion batteries is highest when the battery is charged and used above 80% or below 5%. By only charging the battery to 80%, the battery is spared from unnecessary wear. Of course, when the users need full battery capacity, e.g. while travelling, they can still take advantage of all 100%, but it needs to be actively turned on. A similar tool is built in MacBooks, and similar to the iPhone technology, it analyses your daily routines and optimises charging for that.

On your Windows computer you can get a printed battery performance report by opening Windows PowerShell, and type `powercfg /batteryreport /output "C:\battery-report.html"` into the window and press Enter to run the command. Your computer has now generated a report and placed it on the C: drive. It gives you info like the current capacity, health of the battery and cycles count.

Some computers have also in the battery management software a possibility to see the battery health, see Figure 6-21.

223. <https://news.inventuspower.com/blog/what-is-a-battery-management-system-bms> , accessed 16/03/201

224. <https://support.lenovo.com/us/en/solutions/ht069687-easy-ways-to-extend-your-battery-life-ideapadlenovothinkpad-laptops>



Status	Ingen aktivitet	Strømforbrug	4.89 W	Stregkode	L3NX0CS00ZA
Resterende procent	99%	Temperatur	31 °C	FRU-partnummer	5B10W13905
Tæller for cyklus	17	Batteritype	Li-Polymer	Resterende kapacitet	51.07 Wh
Producent	LGC	Oprindelig kapacitet	50.5 Wh	Kapacitet ved fuld opladning	51.48 Wh
Fremstillingsdato	12/25/2020	Oprindelig spænding	11.55 V	Spænding	12.96 V
Dato for første anvendelse	04/14/2021			Firmwareversion	0001-00b7-0102-209c

Figure 6-21. A screenshot from Lenovo's battery health info.

For your EV it is recommended to mostly use the AC charging instead of the super chargers, that charge the LiB slower and often over night. Furthermore, it is recommended to use the battery between 20–90%, and only fully charging it when you need that extra distance.

6.3.6 Sharing platforms

A sharing platform is an efficient circular business model, where products are shared between multiple users. The model requires a platform to control, manage and rent out all the products in order to maximise operation time and utilisation of the products, thus minimizing the needed amount of products. However, many examples of today's sharing systems are run by companies that share third party products, which are not specifically designed for sharing. In order to harvest the full potential of such business model and increase the lifespan of the overused product, they must be optimised for sharing, like improved robustness, increased traceability and monitoring through sensors and data logging.

Value benefits for end users include improved geographical access at cheaper prices for short term uses e.g., renting an e-scooter rather than buying one, and having 24-hour access to the service from every corner in the city. Some sharing platforms have evolved to include "sharing of sharing platforms", such as carpooling in Uber and Lyft, where not only idle time of cars are improved but also maximization of seat capacity in the vehicles.

Another way of reducing the climate impact of our devices is by sharing products between multiple users so that fewer products are needed to satisfy the same amount of people. This removes the upfront purchasing cost and limits the total production of batteries. An additional advantage is the effective use justifies always having the battery fully charged.

This concept is especially great for amenities that you only use occasionally, such as

drilling machines, hedge trimmers or lawn mowers. For city residents cars and e-scooters can be accessed the same way in case you do not want to own one full time.

Husqvarna's digital tool shed, allows customers to rent professional equipment, through an app. The shed is placed at different locations that are accessible 24/7. Similarly, in Copenhagen a concept called Naboskab allows neighbours to share things like power tools in smart lockers. The concept has been evaluated by the Danish EPA as a solution to reduce resource consumption²²⁵, and is intended for local communities such as an apartment block.



Figure 6-22. Naboskab, a locker to share amenities between neighbours.

There are a variety of mobility sharing platforms such as Donkey Republic, Lime, ShareNow, Green Mobility, and KINTO. One thing to be aware of when using sharing platforms, is to consider potential rebound effects. Often sharing platforms will brand themselves as sustainable because they reduce resource consumption. However, sometimes they create a need that was not there before. Such as the availability of e-scooters that is currently competing with normal bikes, that most Scandinavians own anyway. Also, consider if the environmental cost of the sharing platforms' infrastructure is more impacting than the alternative, i.e., what about the energy and resource consumption for the digital sheds?

6.3.7 Product as a service

Product as a service is a model that seeks to improve the efficiency and shift the motivation for resource efficiency by delivering the value as a service rather than selling the asset to the customer. The model requires a deep understanding of the customers' needs and shifting to a contract-based service delivery.

An example outside the battery topic but still a relevant illustrative example is "pay-per-lux" from Philips that sell access to lighting in office buildings, but they do not sell the actual bulbs. The customer agrees to buy "lighting within work hours in a 3000 m2 office building" and pay a specified price for that service. Philips installs their LED bulbs, and take over the energy bill for lighting. Philips now have an

225. <https://naboskab.dk/mst/>

economic incentive to improve energy efficiency as much as possible, maintaining the bulbs, and if the customer ends the contract for any reason, Philips can re-install their bulbs in other customers' office buildings.

The business models can vary in the product-to-service ratio, meaning that one business model can be either full service with little or no product ownership, like in the pay-per-lux example, or involve mainly product ownership with a small service add-on including guarantee, support agreements, upgrade agreements or monitoring software.

For many products, leasing is a convenient, economic and environmentally better performing option. The ownership and responsibility for repair is placed at the manufacturer or reseller and you, as a consumer, does not need to worry about unexpected bills or big upfront costs. Because the responsibility is placed at the manufacturer, you will often find that parts are better quality, the product is easier maintained thus fewer breakdowns compared to if you own a product.

When leasing a product, you support many circular strategies such as improved reuse, refurbishing and recycling of products and product life extension, thus reduced resource consumption. Acquisition costs of battery driven products are sometimes up to double as high compared to petrol or cabled options. As leasing diminishes the up front costs, you can often get access to electric and mobile options without having to find a lot of money to begin with.

There are many examples of products as a service in the battery driven industry. In Denmark, Volt is leasing out mobile batteries, mainly for festival guests, where you continuously can swap a drained battery for another one that functions. In this way, you can easily recharge your devices on the go.²²⁶ See Figure 6-23.



Figure 6-23. Volt Batteries on a Danish festival.²²⁷

226. <https://www.getvolt.dk/>

227. <https://www.roskilde-festival.dk/da/years/2020/news/volt/>

However, it is important to note that product as a service is not necessarily a more sustainable option, as they sometimes require more require more resources to function, or might even increase our resource demand as customers now have easier access to new products without the upfront investment.

7 Recommended policy options – policy brief

Pressures on the environment have been high in recent years both in the Nordics and globally. While technological development within batteries and the increased use of batteries are likely to reduce some of these pressures, others will increase, sometimes significantly, as more raw materials are needed and the energy consumption to produce batteries are high. To help the Nordics address this problem and promote the Nordics as a forerunner within lithium-ion batteries and circular economy, a policy brief with recommendations to help the Nordics fulfil this ambition are presented in this section.

There is a clear need for action, as climate change is a global problem that brings multiple different changes in different regions. These include changes to wetness and dryness, to winds, snow and ice, coastal areas and oceans. For example²²⁸:

- *“Climate change is intensifying the water cycle. This brings more intense rainfall and associated flooding, as well as more intense drought in many regions.*
- *Climate change is affecting rainfall patterns. In high latitudes, precipitation is likely to increase, while it is projected to decrease over large parts of the subtropics. Changes to monsoon precipitation are expected, which will vary by region.*
- *Coastal areas will see continued sea level rise throughout the 21st century, contributing to more frequent and severe coastal flooding in low-lying areas and coastal erosion. Extreme sea level events that previously occurred once in 100 years could happen every year by the end of this century.*
- *Further warming will amplify permafrost thawing, and the loss of seasonal snow cover, melting of glaciers and ice sheets, and loss of summer Arctic sea ice.*
- *Changes to the ocean, including warming, more frequent marine heatwaves, ocean acidification, and reduced oxygen levels have been clearly linked to human influence. These changes affect both ocean ecosystems and the people that rely on them, and they will continue throughout at least the rest of this century.*
- *For cities, some aspects of climate change may be amplified, including heat (since urban areas are usually warmer than their surroundings), flooding from heavy precipitation events and sea level rise in coastal cities.”*

A recent IPCC report suggests that climate change occurs faster than expected and states that unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5°C or even 2°C will be beyond reach. In light of the new findings of the IPCC report and considering the history of global agreements on reductions on greenhouse gasses and recent

228. <https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/>

improvements, it seems unlikely that 2°C scenario can be reached. The OECD countries need to reach significant reductions in their emissions. The non-OECD countries need to decouple their financial growth from increased emissions, which is still difficult for many OECD countries.

However, it is still essential to reduce the emission of greenhouse gases, and previously astonishing environmental goals have been reached, e.g. the reduction/ban on ozone-depleting substances, giving hope that the climate crisis can be solved. With significant reductions, the temperature rise can be minimized as much as possible to limit the impacts and to reduce the time it takes nature to restore.

A cornerstone in green transition is to move away from fossil fuels, which are a good energy carrier due to their high energy density. They can be stored and transformed into energy whenever there is a need. Batteries can help reduce the dependency on fossil fuels by allowing more renewable can be produced and utilized when needed, as batteries can help balance the energy grid.

The greenhouse gas emission in the transport sector historically has been challenging to reduce, but with recent development in both battery technology and the efficiency of electric cars, electric cars are today a viable alternative to conventional cars, which will impose significant savings in the emission of greenhouse gases. Also, within other sectors, batteries are used to displace petrol-fuelled products, e.g. within gardening products.

Batteries are important and needed benefits to reduce the emission of greenhouse gases, but the batteries come at both environmental and social costs. The production of batteries is very energy-intensive, increasing energy consumption, and some of the needed resources are mined under poor conditions.

A possible solution to overcome some of these challenges with batteries are found in the circular economy, where the key message is to reduce the need for new batteries.

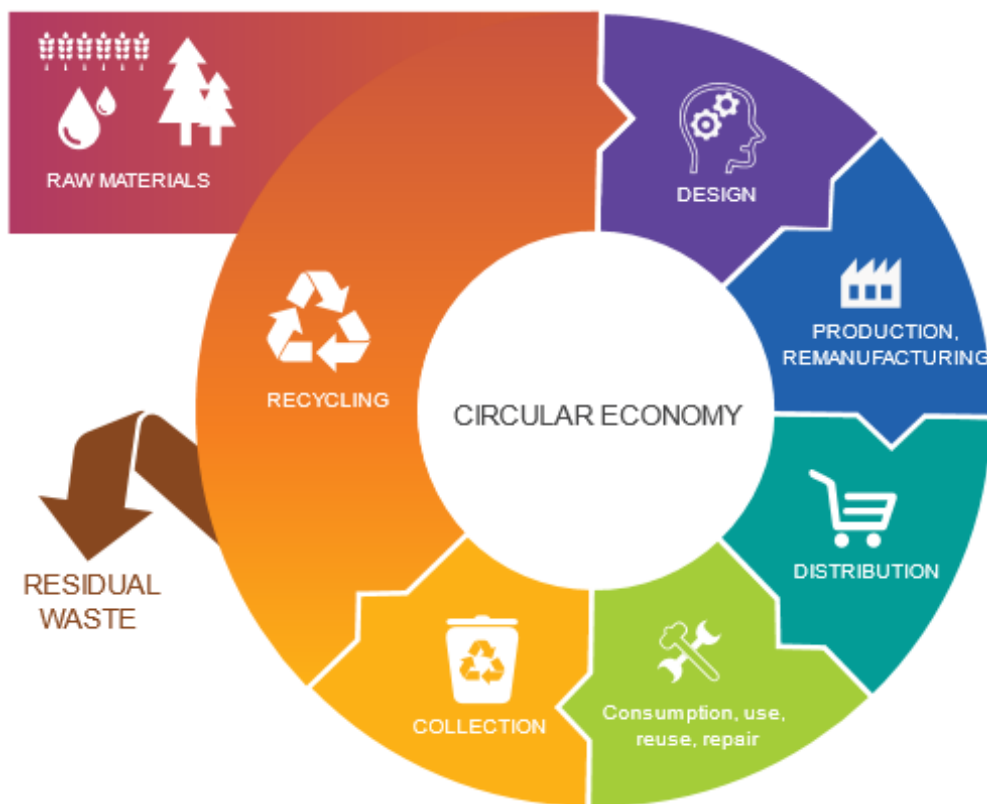


Figure 7-1. Conceptual visualisation of the circular economy.

The policy brief is divided into two sections, where the first section focuses on existing and known technologies, including batteries, while second section focuses on recommendations on what the Nordic countries can do to contribute to creating the right framework conditions for the Nordic countries to be centrally placed in an innovative, sustainable and competitive battery ecosystem in Europe.

7.1 Policy recommendations for the Nordic countries to improve circularity of batteries and equipment

7.1.1 Background for the recommendations

The policy recommendations for the Nordic countries in this section will focus on existing and known technologies of batteries and products using batteries. The aim is to improve the circularity, which means that better batteries that can be removed, repaired, and effectively recycled need to be promoted by an ambitious regulatory framework. Below are the different recommendations presented and briefly discussed,

To frame the policy recommendations, first we present brief summaries of interview with relevant stakeholders:

The importance of legislative push was emphasised in the interview with Fortum. They expressed their view that regulations are critical to sustain the circularity of batteries. Legislative push is important in the recycling industry in particular because

virgin materials are always cheaper to procure, and because the low recycling capacity for battery materials cannot be incentivised to grow without regulations (Fortum).

They added that without legislative push, the market will see the “cherry picking” of materials where recyclers will focus only on the very valuable and easy to access materials, while other materials that require more effort or investment may not remain in Europe. This may lead to the legal or illegal leakage of materials outside European borders, in which case legislation related to waste shipment and categorisation is also relevant (Fortum).

While one recycler (Fortum) stressed the importance of regulation to push the LIB market towards circularity, others also argue that neither increased or more restrictive policy is the solution. Rather, it is the market that needs to develop.

One recycler (who wished to remain confidential) indicated that because black mass recycling in Europe is not at large scale, the biggest recyclers that do recycle black mass are not stable and regular buyers on the EU market. Rather, they tend to enter and exit the market irregularly. This creates instability on the EU buyers' market for black mass characterized by an unstable and constant shift of movement of material, which incentivises a black market. This recycler stresses that over-restrictive regulation can push market players to go “underground” rather than foster an open marketplace. They argue that big European recyclers need to be supported to build capacity and develop to be competitive in the EU and align with global market and pricing.

A similar sentiment was expressed by Teknikföretagen (Association of Swedish Engineering Industries), who in their view indicated that regulation should not end up being a barrier to market development. That is, it should not slow the development of novel technologies and chemistries and should not be too rigid regarding battery chemistry and performance (Teknikföretagen interview).

If the proposal comes as a regulation it will also bring an interesting effect to the batteries, since the other producer responsibility products would be regulated with the Finnish Waste Act that would give the main requirements and then their corresponding Government Decrees would give the specific requirements. However, with batteries it might be that the instead of the Finnish Waste Act the requirements would come directly from the Batteries regulation. This might bring some cases where the interpretation of the legislations might differ between the Finnish Waste Act and the Batteries Regulations. (Pirkanmaa Ely interview)

The requirements in the proposed battery directive for producers to use secondary raw materials limits mean that it will create a market for recyclers, but it might also restrict where the metals could be used because they might be needed to be used for other applications. (Pirkanmaa Ely interview)

A fast transition towards battery production and recycling in the Nordic countries is key if the Nordic countries needs to be a forerunner region. The lithium-ion market is booming and the demand is high, many countries and entrepreneurs around the world does therefore see great business opportunities. Being a first mover is important to land deals with e.g. car manufacturers. However, Fride says that the regulatory system in Norway is an obstacle, because it can take years to get a permission to build a factory. Furthermore, creating a battery manufacturing and recycling industry requires a substantial amount of skilled employees, not just of Phd. Level, but also on bachelor and master level. Certain competences are missing

in both the European and Norwegian market, particularly with regards to battery cell production. But candidates are being educated with battery knowledge, particularly materials and electrochemistry knowledge. Currently, the challenge is that the demand is much higher than what the educational institutions are able to deliver, thus there is a need for new study programs and also more student places on existing programs. (SINTEF interview)

The policy recommendations cover the following areas which we believe should be included in a comprehensive policy package:

- Adopt the measures from the working documents for smartphones regarding relevant measures for batteries across all product groups containing batteries that fall under the Ecodesign Directive
- Create a new metric regarding battery performance, allowing manufacturers a higher degree of freedom to develop the best-suited batteries for the specific application
- Ensure interoperable batteries across product groups with batteries that have many similarities
- Support the battery proposal
- Use Green Public procurement to increase the demand for sustainable batteries
- Support a far-reaching review of the EcoDesign directive and push for inclusion of the transport sector

7.1.2 Adopt the measures from the working documents for smartphones regarding relevant measures for batteries across all product groups containing batteries that fall under the Ecodesign Directive

With regard to policy measures for products and equipment, the EU Ecodesign Directive constitutes a very efficient policy framework for energy-related products using lithium-ion batteries. The Ecodesign framework is closely linked to the circular economy plan, and new studies and implementing measures have increased focus on circular aspects. One of the most comprehensive sets of measures relevant for products containing batteries is found in the working documents for smartphones, where both Ecodesign requirements and energy label are proposed. The relevant requirements for batteries are:

- Design for repair and reuse, ensuring that batteries are available as spare parts with a maximum delivery time and price of the spare parts. Also, access to repair, maintenance and disassembly information needs to be available. Finally, disassembly requirements and requirements for preparation for reuse.
- Design for reliability: ensuring that batteries have a reasonable endurance in cycles and battery management systems and charging systems that can help the consumers increase the lifetime of their batteries.
- Recyclability requirements: Making available, on a free-access website, the dismantling information needed to access the battery or batteries, sequence of

dismantling steps, tools or technologies needed to access the battery or batteries.

- Information requirements: Making information available on how the components of the products are produced, amount of critical raw materials, recyclability rate, content on recycled materials in the product, minimum battery endurance in number of cycles, minimum battery endurance in cycles under conditions of fast charging (if applicable) to inform consumers on these important aspects and create competition between manufactures to perform better. If fast charging is relevant and available, the consumers need to be warned about the impact on the battery life.
- Energy label: Ensure that products that contain batteries will have an Energy label that provides information on the, e.g. cycles or expected life.

The above-mentioned recommended measures could easily have been highlighted as individual initiatives to improve the circularity of batteries, but the strength of the proposed measures in the working documents is the combination of the proposed requirements.

7.1.3 Create a new metric regarding battery performance, allowing manufacturers a higher degree of freedom to develop the best-suited batteries for the specific application

Build-in batteries are more widespread today in a range of applications such as smartphones. Instead of setting requirements on cycles, it could be relevant to develop a metric that calculates the lifetime of the battery, which needs to fit the expected life of the product.

This approach is considered to allow manufactures a higher degree of freedom to include the best design strategy for their products, as the battery life can be improved by different approaches, e.g. using a bigger battery to ensure that the consumers will need to charge less times which will reduce the number of cycles, or to use more durable batteries than can perform more cycles without significant drops in the capacity.

The metric should also take into account the energy consumption of the device, so the product and battery fits perfectly together and the manufactures still are committed to improve the efficiency of the product.

Creation of such metric could take place as a technical study under the European product and battery policies involving the Member States and stakeholder.

7.1.4 Ensure interoperable batteries across product groups with batteries that have many similarities

Interoperable batteries were considered both in the proposal for a battery regulation and the Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020–2024, but both studies did not include these requirements in the final recommendations leaving out a potential saving which can reduce the number of

batteries needed for the different appliances.

Interoperable batteries make most sense within product groups where there often are periods of time with no use e.g. power tools, cordless vacuum cleaners, gardening tools and lawnmowers. All these products use detachable rechargeable batteries that are very similar or identical, which however due to customised connectors, recharge docks, form factors and lack of data interoperability (i.e. because of non-standardised battery management circuitry and protocols), in most cases are not interchangeable between brands or even between different product series within the same brand. However, examples of cross-brand interoperability exist, demonstrating the concept that interoperability would be possible, if suitable requirements would be set.

The conclusion from the Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020–2024 showed that the savings achieved for the battery production are approximately 18–45 PJ in primary energy consumption, 950–2300 CO₂eq kt in GHG emissions and 6,500–15,000 mill. EUR in consumer expenditure by applying interoperable batteries for this product group. Also, savings within the number of needed resources are important to mention as the dependency on conflicted minerals will decrease.

The Nordics may use the current study to provide these recommendations to the European Commission.

7.1.5 Support the battery proposal

The proposed Battery Regulation is quite comprehensive and covering many relevant areas. In the current policy process, the Nordics may discuss internally and with other Member States if common positions can be reached and how it can be supported.

7.1.6 Use Green Public Procurement to increase the demand for sustainable batteries

Public authorities are major consumers in Europe spending approximately 1.8 trillion EUR annually, representing around 14% of the EU's gross domestic product.²²⁹ This enormous purchasing power can be used to increase the demand for sustainable batteries.

One policy measure for Green Public Procurement is the development of EU GPP criteria.²³⁰ The Nordics can suggest the European Commission and the GPP Advisory Group²³¹ to include batteries in a technical study aiming at setting GPP criteria for batteries.

229. https://ec.europa.eu/environment/gpp/what_en.htm

230. https://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm

231. https://ec.europa.eu/environment/gpp/expert_meeting_en.htm

7.1.7 Support a far-reaching review of the Ecodesign directive and push for inclusion of the transport sector

The current Ecodesign Directive is not applicable for means of transports (Article 1 point 3 of the Directive). Therefore, batteries in cars, bicycles and other means of transports cannot benefit from eco-design requirements. The Nordics should push to remove the exemption for means of transport from the Ecodesign Directive - or at least that the exemption should not apply to batteries for means of transport. This can be fed into the current process of Sustainable Products Initiative amending or replacing the current Ecodesign Directive.

The potential within the transport sector is huge. Some potential measures within Ecodesign regulations may overlap with the battery proposal, but there is still room for both regulations to have an effect on the same appliance. No labelling is suggested regarding the battery proposal. The energy label could pose to be an effective tool informing the customer of relevant information on both the performance of the car but also the battery itself.

7.2 Policy recommendations for the Nordic countries to contribute to creating needed framework conditions

7.2.1 Background for the recommendations

Below, we have outlined policy recommendation that may contribute to creating the right framework conditions for the Nordic countries to be centrally placed in an innovative, sustainable and competitive battery ecosystem in Europe.

The policy recommendations cover the following areas which we believe should be included in a comprehensive policy package:

- Positioning the Nordic countries to benefit from sustainability requirements in the new EU Regulatory Framework for Batteries.
- Preparing Nordic project developers for participation in the available financial support for European projects demonstrating and scaling up innovative sustainable battery technologies and business models.
- Facilitating Nordic research project participation in the improved European research and innovation funding opportunities for battery technology.
- Working with TSOs and national energy market regulators to ensure that the necessary regulatory framework and pricing mechanisms allow for sustainable battery technology demonstration and scaleup.

The policy recommendations include revision of national legislation, active cooperation on the development of EU legislation, support for voluntary sector initiatives and direct support for innovation and roll out of innovative technologies, products and business models for sustainable battery value chains. These are discussed further below.

To frame the policy recommendations we also present three related citations from interviewed stakeholders active in sustainability and recycling of LIBs in the Nordics:

- *The Nordics are in a very good position to become a good recycler of EOL LIBs. One reason is because we have green energy right. Another reason is because of the access to plentiful sources of key metals (Co, Ni, Cu, Al). Today there is already a large concentration of the nickel & cobalt part of the value chain already exists through investments and infrastructure (i.e. Finland in the hub, in Norway Glencore in Norway as one of the largest nickel refineries, and Northvolt is refining and also doing recycling and hydrometallurgical recycling, and a strong copper industry with Boliden). There is nothing preventing the Nordics from taking care of all battery recycling. There are still several other continental recyclers and refiners, however Europe currently does not have enough recycling capacity. (Norsk Hydro interview)*
- *It is likely that all European Member States will see increased volumes of EoL EV batteries in the future, but not all Member States will have the same high level of quality for battery recycling. So regulations are needed to support investment in high quality recycling, control shipment of waste to keep the waste batteries within the EU, and ensure supply of scarce materials and metals, which would make the materials more attractive (Fortum interview).*
- *Car manufacturers are seeing batteries as the "new engine" to differentiate themselves. They see trend moving in this direction. They are skeptical for design for recycling legislation and hope that it will be a market-driven force instead of driven by legislature. Making recycling as efficient as possible is important for Europe, which would mean a higher cost to recycle benefit with more efficient batteries. (Norsk Hydro interview).*

7.2.2 Positioning the Nordic countries to benefit from sustainability requirements in the new EU Regulatory Framework for Batteries

The EU Strategic Action Plan for Batteries foresees supporting a sustainable battery value chain that will be well-integrated into the circular economy and drive the competitiveness of European products. This will be reflected in the Commission proposal for a New Regulatory Framework for Batteries (adoption expected 2022).

The Nordic countries should position themselves to support and subsequently benefit from the expected (i) rules on recycled content; (ii) measures to improve the collection and recycling rates of all batteries; (iii) progressively phasing out non-rechargeable batteries; and (iv) sustainability and transparency requirements for batteries (carbon footprint, ethical sourcing of raw materials, security of supply, and facilitating reuse, repurposing and recycling).

Against this background we recommend:

- A vision of making the Nordics a substantial player in sustainable recycling of Li-ion batteries from other EU countries based on access to renewable energy sources and a conducive national framework for sustainability.
- Active engagement in consultation processes related to the proposed EC regulatory framework on batteries prior to proposed adoption (expected 2022) with a view to ensure that the legal environment supports Nordic industrial players in contributing to the above vision.

- A strategy for reskilling and upskilling to ensure that the Nordic battery industry in general and the recycling and reuse part of the value chain in particular has access to a labour force to match the ambitions.
- Consultations with industrial players on the developing policy framework.

7.2.3 Preparing Nordic project developers for participation in the available financial support for European projects demonstrating and scaling up innovative sustainable battery technologies and business models

The Strategic Action Plan for Batteries furthermore foresees working closely with interested Member States to support European projects covering different segments of the battery value chain. This will include making public funding or financing for battery cells manufacturing projects available in order to incentivise, leverage and 'de-risk' private sector investment through Horizon Europe, Invest EU, LIFE and the Innovation Fund in support of innovative battery-related deployment projects.

The Nordic countries should position their battery industry to take advantage of these funding options for projects covering different segments of the battery value chain.

Against this background we recommend:

- Informing Nordic stakeholders in industry and research institutions about the EU funding opportunities and in particular the opportunities under Horizon Europe (through the Batteries Partnership and the IPCEI projects) and the Innovation Fund.
- Encouraging Nordic stakeholders in industry and research institutions to participate actively in the European Batteries Alliance and the Batteries Partnership under Horizon Europe (through BATT4EU).
- Considering Nordic Energy Research calls dedicated to LI-ion sustainability and recycling (e.g. under the Green Transport Focus Area).
- Considering following up the 2020 Nordregio report "Skills Policies - Building Capacities for Innovative and Resilient Nordic Regions" with dedicated work on reskilling and upskilling workers for a sustainable batteries value chain.

7.2.4 Facilitating Nordic research project participation in the improved European research and innovation funding opportunities for battery technology

The Strategic Action Plan also foresees collaboration with Member States on stepped-up EU research and innovation support covering the full value chain (including also recycling and second-use). This will include making available, research and innovation funds (Horizon Europe) for battery-related innovation projects and - in the longer term - the launch of a large-scale Future Emerging Technologies Flagship research initiative, which could support long-term research in advanced

battery technologies for the 2025+ timeframe.

The Nordic countries should be prepared to participate in these improved research and innovation funding opportunities for battery technology.

Against this background we recommend:

- Engage with Nordic stakeholders in industry and research institutions on identification of key areas for Nordic technology strength in a sustainable batteries value chain.
- Define Nordic research initiatives in sustainable batteries.

7.2.5 Working with TSOs and national energy market regulators to ensure that the necessary regulatory framework and pricing mechanisms allow for sustainable battery technology demonstration and scaleup

New technologies and business models, which currently are not on the market will often meet obstacles in the form of current market practises and lack of an adequate regulatory framework for its introduction. This is, e.g. the case for battery technology for decentral storage of intermittent renewable energy, which is on one side essential for the electrification of large parts of the Nordic economies and meeting climate goals by 2030 and 2050, and on the other side provides a range of services which is not currently priced in the market (frequency response, reactive power, provision of inertia).

The Nordic countries should work with TSOs (Transmission System Operator) and national energy market regulators to ensure that the necessary regulatory framework and pricing mechanisms for making Nordic power markets viable for sustainable battery technology demonstration and scaleup are in place.

Against this background we recommend:

- Assess the opportunities for and costs and benefits of repurposing of Li-ion batteries for decentral energy storage as a EOL extension, and identification of related regulatory and market barriers. This could be Nordic Energy Research project.
- Engage with industry and national TSOs on a pilot project for assessment of potential power market services that could be provided by repurposed Li-ion batteries for decentral energy storage.

ANNEX A: Interviewees and organisations referenced

Manufacturing industry

Husqvarna

Husqvarna is a Swedish manufacturer of machine equipment used for forestry maintenance, lawn moving and the building industry. For the last 8 years they have been on a transition from fossil fuel driven products to electrical (mainly battery driven) products. Some of their newer products are born battery driven, e.g. the robot lawn movers. Some of the products which have been in their product range for many years now comes in both petrol version (the old version) and a new battery driven version e.g. chainsaw, leave blowers and hedgetrimmers. While other products, especially in the building industry is still only provided in a petrol driven version, because batteries cannot supply power enough or the product is use at site, where there is no possibility of charging the battery (e.g. a forest). The goal is to have a product fleet that is 100% electrical driven and lithium-ion batteries is key to achieve that.

Nilfisk

Nilfisk produces vacuum cleaners, cleaning machines and high-pressure products. Nilfisk main markets are Europe and USA, but they do also experience increasing sales in Asia. The high-pressure products are powered by a cord or a generated, 90 percent of their vacuum cleaners are connected by cord and 90 percent of their floorcare products are powered by batteries. Nilfisk sees a trend in battery-driven vacuum cleaners used in households, because they are only run for a limited period each day, and it does not have to cover a huge area. The cord type still dominates professional vacuum cleaners because they have to run for many hours during the day. The cleaning machines are dominated by batteries, because they cover large areas, where it is not possible to drag a cord. Nilfisk is a large company with approximately 5,000 employees and have a whole department that work exclusively with the newest standards and constantly tries to keep up or ahead of the game.

Electrolux

Electrolux is a global producer of appliances with about 48,000 employees around the world. Its headquarters are in Stockholm, Sweden. The product range includes refrigerators, freezers, ovens, cookers, hobs, hoods, microwave ovens, dishwashers, washing machines, tumble dryers, vacuum cleaners, air conditioners, air purifiers and small domestic appliances. In terms of batteries, only some of the vacuum cleaners are designed for [or produced with] batteries, with the majority of these designed for lithium-ion batteries.

Looking forward, the company's target for 2030 is to be a leader in product

efficiency in key product categories and markets and continue to develop products with good overall environmental performance, while simultaneously integrating sustainability into the Group's brands and driving the market for efficient products through awareness-raising consumer campaigns. Electrolux will contribute to the circular economy by integrating recycled materials into product platforms, promoting recyclability, using more sustainable packaging solutions, increasing the availability of spare parts to facilitate product repair, and developing circular business solutions.

Recycling industry

Akkuser

Akkuser was founded in 2005. Its main business is in recycling spent portable batteries. Two main business lines: 1) Receiving, sorting and recycling of spent portable batteries collected by Finnish PRO, and 2) li-ion battery processing to produce black mass. They specialise in the treatment of mainly high-Co content batteries from LCO chemistries from electronic devices and lower-Co content batteries from e-bikes and power tools (typically NMC).

Akkuser is a pre-processing facility using mechanical processes called Dry Technology – this involves pure mechanical shredding followed by magnetic and mechanical separation. The resulting metal content rates are based on the input materials. The Co obtained from high Co batteries is the most valuable. Akkuser has a capacity of 700–800 tonnes of li-ion batteries treated per year, 650 tonnes of which are LCO.

Akkuser's customers of Co and Cu are 100% to Finnish refineries. Fe is sent to companies that combine with other materials, which could then be sent to other countries.²³²

Fortum

In Fortum, battery recycling is a relatively new business area on top of other business areas including recycling of other waste streams. Fortum operates two facilities for lithium-ion battery recycling (mainly EV batteries). The first is a mechanical treatment plant in Ikkalinen, Finland that produces black mass currently with a capacity of treating 3,000 tonnes per year (equivalent to 10,000 vehicles). The black mass is treated in the second plant (a hydrometallurgical plant) in Harjavalta, Finland to produce recycled raw materials. The plant has recently received a 24 million Euro investment.²³³

At the mechanical plant, batteries are discharged and batteries that are suitable for second life are separated and sent for second life applications. Then, the packs are dismantled and plastic and metal scrap are separated and recycled or recovered. The black mass is separated in the mechanical processing and sent to further treatment in Harjavalta. At the hydrometallurgical plant, the black mass is treated to recover nickel, cobalt and manganese. Lithium recycling is at the patent application stage.

232. Akkuser interview with Tommi Karjalainen conducted by Alexandra Wu and Erik Emilsson. Q3 2021

233. <https://www.fortum.com/media/2021/06/fortum-makes-new-harjavalta-recycling-plant-investment-expand-its-battery-recycling-capacity>

Stena

Stena began recycling batteries 10 years ago. Stena main processes regarding li-ion battery management are 1) Reuse via the BatteryLoop project to reuse LFP bus batteries, and 2) Recycling via a) Dismantling and b) Shredding and separating. Stena does not currently recycle black mass. Does not have the hydrometallurgical processes for this. Recycling is mostly of LFP EV batteries, and to lesser extent LCO batteries from electronics.

To process battery (or other waste streams), recyclers like Stena bid for regional contracts from PROs like Elkretsen in Sweden where contracts last for 3 years. Then the winner of the contract becomes responsible for treating 100% of that waste stream in the region.

Stena partly owns Akkuser. Clients of their secondlife batteries are mainly the real estate sector which use the batteries for solar or wind energy storage on rooftops of buildings. The biggest competitors in Sweden are Veolia and Fortum.²³⁴

URecycle

In the UK, URecycle had a processing plant in the south of England that was developing an EV and hybrid battery program, for take-back and recycling from the perspective of production scrap from manufacturing. This factory intended to take production scrap (mainly from the stage before addition of electrolyte) for processing to recover Al, Cu, graphite and black mass (containing Co and Ni). At the moment of the interview, black mass was sold to a refiner in the US which was a preferable buyer because the EU buyer market was less attractive from a financial perspective. This may have to do with having fewer buyers on the market and lower purchasing price.²³⁵ URecycle was dissolved on 6 July 2021.²³⁶

Norsk Hydro (Aluminium recycler)

Hydro (Norsk Hydro) is one of the oldest Norwegian companies which began in the hydropower industry. Hydro has a 115-year-old history and has done many things from fertilizer, gas, aluminium, fish farming etc. In the last four years back, Hydro has started working with batteries. Today, Hydro and Northvolt are part of the joint venture Hydrovolt, in which EOL EV LIBs black mass is recycled by Northvolt while crushed aluminium is recycled by Hydro. The capacity will be over 8000 tonnes of batteries per year. For Hydrovolt, Hydro has received a 100miljon NOK investment with support from the Norwegian research scheme. Hydro Volt plant will start this year (2021). Hydro is strengthening its business with low carbon aluminium with its investments in wind, solar, and battery investments. They are also exploring a giga-type cell production plant with Panasonic and Equinor and looking into possibly exploring mining in the future. For Hydro Volt, AS BatteriRetur collects EV batteries

234. Stena Metall Interview with Christer Forsgren conducted by Alexandra Wu and Erik Emilsson. Q1 2021.

235. Urecycle interview conducted by Alexandra Wu. Q1 2021.

236. <https://find-and-update.company-information.service.gov.uk/company/11013167>

and does a deep discharge in Sandefjord and disassemble the packs to module level.²³⁷

Miscellaneous

SINTEF

SINTEF is a Norwegian non-profit research organization that performs research covering large parts of the battery value chain. They have an energy lab department that performs research covering large parts of the battery value chain, including development of Li-ion technology, materials for new battery chemistries, battery cell design and prototypes, sensor technology, cooling and control systems (BMS) for battery cells and packs, as well as evaluation of performance and lifetime of prototype and commercial batteries and battery systems for a variety of applications.

Belmont-Trading

Belmont-Trading is a company that receives, manages, recycles and trades in electronic products and batteries, including mobile phones.

Inrego (collector, refurbisher)

Inrego's main business is in taking in used electronics (mostly mobile phones and laptop computers) and refurbishing and reselling them. Their biggest consumers are businesses but private consumers are also a growing segment.²³⁸

Pirkanmaa Ely (EPR authority)

In Finland (except Åland), Pirkanmaa Ely is operating as the competent authority for extended producer responsibility, for all batteries in all sectors. The main work is to monitor the producers of batteries, so they fulfill the legislative requirements. They do not specifically monitor the waste operators, but they do ensure that the producers use permitted waste operators that reach the recycling targets set out in the legislation. They also currently report waste battery statistics to the EU commission.²³⁹

Teknikföretagen (Association of Swedish Engineering Industries)

The Association of Swedish Engineering Industries is the main representative of Swedish industry covering 4,200 member companies which account for a third of

237. Norks Hydro Interview with Christian Rosenkilde conducted by Alexandra Wu and Erik Emilsson. Q3 2021.

238. Inrego interview with Sebastian Holmström conducted by Johan Holmqvist & Alexandra Wu. Q2 2021.

239. Pirkanmaa Ely Interview with Matti Lenkkeri conducted by Erik Emilsson. Q2 2021.

Sweden's exports. In relation to li-ion batteries, the interviewees work focus on the new battery regulation, circular economy action plan and proactively looking for sustainable business models. They are also involved in projects and product legislature connected to Ecodesign and sustainable design, as well as how to regulate policies for batteries with regard to the environment.²⁴⁰

240. Teknikföretagen Interview with Elinor Kruse and Emilia Käck conducted by Johan Holmqvist & Erik Emilsson.
Q2 2021

ANNEX B: Preferred options IA

Commission, E. (2020). Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020. D. Environment. Brussels.

Commission, E. (n.d.). "Batteries and accumulators." Retrieved June 22, 2021, from https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en#ecl-inpage-388.

Preferred options presented in the proposed EU Battery Regulation and adapted from the new EU Battery Regulation proposal (Commission 2020). The green cells indicate the preferred option; light green indicates the preferred option pending a revision clause.

Measures	Option 2 - medium level of ambition	Option 3 - high level of ambition	Option 4 – very high level of ambition
1. Classification and definition	New category for EV batteries Weight limit of 5 kg to differentiate portable from industrial batteries	New calculation methodology for collection rates of portable batteries based on batteries available for collection	/
2. Second-life of industrial batteries	At the end of the first life, used batteries are considered waste (except for reuse). Repurposing is considered a waste treatment operation. Repurposed (second life) batteries are considered as new products which have to comply with the product requirements when they are placed on the market	At the end of the first life, used batteries are not waste. Repurposed (second life) batteries are considered as new products which have to comply with the product requirements when they are placed on the market.	Mandatory second life readiness
3. Collection rate for portable batteries	65% collection target in 2025	70% collection target in 2030	75% collection target in 2025
4. Collection rate for automotive and industrial batteries	New reporting system for automotive, EV and industrial batteries	Collection target for batteries powering light transport vehicles.	Explicit collection target for industrial, EV and automotive batteries
5. Recycling efficiencies and recovery of materials	Lithium-ion batteries and Co, Ni, Li, Cu: Recycling efficiency lithium-ion batteries: 65% by 2025 Material recovery rates for Co, Ni, Li, Cu: resp. 90%, 90%, 35% and 90% in 2025 Lead-acid batteries and lead: Recycling efficiency lead-acid batteries: 75% by 2025 Material recovery for lead: 90% in 2025	Lithium-ion batteries and Co, Ni, Li, Cu: Recycling efficiency lithium-ion batteries: 70% by 2030 Material recovery rates for Co, Ni, Li, Cu: resp. 95%, 95%, 70% and 95% in 2030 Lead-acid batteries and lead: Recycling efficiency lead-acid batteries: 80% by 2030 Material recovery for lead: 95% by 2030	/

6. Carbon footprint for industrial and EV batteries	Mandatory carbon footprint declaration	Carbon footprint performance classes and maximum carbon thresholds for batteries as a condition for placement on the market	/
7. Performance and durability of rechargeable industrial and EV batteries	Information requirements on performance and durability	Minimum performance and durability requirements for industrial batteries as a condition for placement on the market	/
8. Non-rechargeable portable batteries	Technical parameters for performance and durability of portable primary batteries	Phase out of portable primary batteries of general use	Total phase out of primary batteries
9. Recycled content in industrial, EV and automotive batteries	Mandatory declaration of levels of recycled content, in 2025	Mandatory levels of recycled content, in 2030 and 2035	/
10. Extended producer responsibility	Clear specifications for extended producer responsibility obligations for industrial batteries Minimum standards for PROs	/	/
11. Design requirements for portable batteries	Strengthened obligation on removability	New obligation on replaceability	Requirement on interoperability KURSIV
12. Provision of information	Provision of basic information (as labels, technical documentation or online) Provision of more specific information to end-users and economic operators (with selective access)	Setting up an electronic information exchange system for batteries and a passport scheme (for industrial and electric vehicle batteries only)	/
13. Supply-chain due diligence for raw materials in industrial and EV batteries	Voluntary supply-chain due diligence	Mandatory supply chain due diligence	/

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