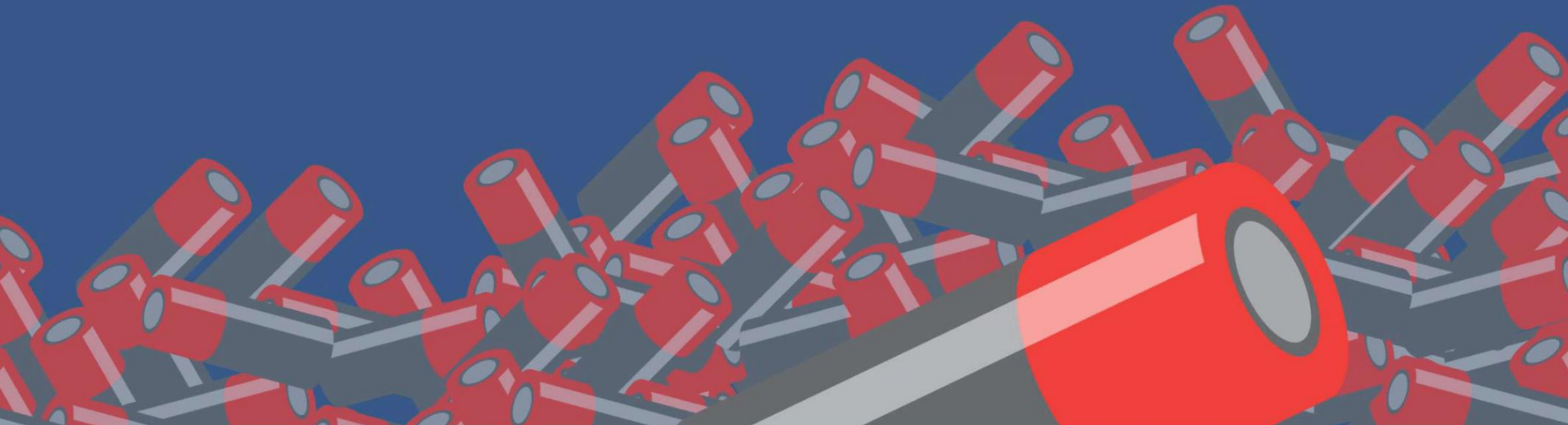




Nordic Council
of Ministers

Circularity of Batteries

Inspiration book 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 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 several 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.

Principles for Circular Design

One source of inspiration for circular design is the principles established by the Ellen MacArthur Foundation¹. 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.

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.

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

¹ <https://www.ellenmacarthurfoundation.org/circular-economy/concept/infographic>

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 Strategy². It uses life cycle thinking to consider all stages of a product from the upstream supply chain until the end-of-life treatment.

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 consumers 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 footprint³. A study from the Technical University of Denmark⁴ 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.

²Accenture Strategy, 2014, Circular Advantage

³ <https://doi.org/10.1016/j.rcrx.2019.100028>

⁴ https://backend.orbit.dtu.dk/ws/portalfiles/portal/162055145/Kj_r_et_al_2018_POSTPRINT_PSS_circular_economy.pdf

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.

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 re-enter 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 labour¹⁰. 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 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 list⁵. 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 seriously⁶. 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-life⁷. 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"⁸.

⁵ https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

⁶ <https://www.ingwb.com/media/3076131/ing-circular-economy-survey-2020-learning-from-consumers.pdf>

⁷ https://ec.europa.eu/info/sites/default/files/ec_circular_economy_final_report_o.pdf

⁸ Calvo-Porrà & Lévy-Mangin, 2020, The Circular Economy Business Model: Examining Consumers' Acceptance of Recycled Goods

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.

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,⁹ which eventually will decrease prices and increase quality of recycled battery-grade resources¹⁰.



Figure 1: NorthVolt using their circular supply as a competitive advantage in branding¹¹

⁹ European Union, 2016 Sustainable supply of raw materials

¹⁰ <https://everledger.io/closing-the-loop-on-portable-lithium-ion-battery-recycling/>

¹¹ <https://northvolt.com/articles/a-binary-choice/>

(JTC 10),¹⁴ 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 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 companies¹⁵. 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 2030¹⁶.

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)¹⁷.

¹⁴ https://www.cencenelec.eu/news/brief_news/pages/tn-2018-034.aspx

¹⁵ Interview with Fride Vullum-Bruer from SINTEF

¹⁶ <https://northvolt.com/loop>

¹⁷ <https://www.standard.no/Global/PDF/Arendalsuka%202019/Sirkul%C3>

[%A6r%20%C3%B8konomi/20190815%20-%20Rosenkilde%20Arendalsuka%20-%20Norsk%20Hydro.pdf](#)

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 provides¹⁸. 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.



Figure 3: Electrolux have in collaboration with Stena Recycling made a reused vacuum cleaner from 100% recycled and reused materials¹⁹.

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-repair their products²⁰. 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.

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

¹⁸ 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

¹⁹ <https://www.stenarecycling.dk/nyheder/electrolux-presents-vacuum-cleaner-made-of-100-recycled-and-reused-materials2/>

²⁰

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

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 motor²¹. They have since initiated three similar projects and they carry the symbol seen on Figure 3.

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.

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 reduction²². 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 4.



Figure 4: 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 5. 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 third-party 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%.

²¹ <https://kunskapsrummet.com/artiklar/cirkularitet-aterbruk-och-smart-design/>

²² Stated by Nilfisk

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 solution²³, 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 like 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.

²³ <https://support.lenovo.com/us/en/solutions/hto6g687-easy-ways-to-extend-your-battery-life-ideapadlenovothinkpad-laptops>



Figure 5: A screenshot from the battery health section in an iPhone

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.

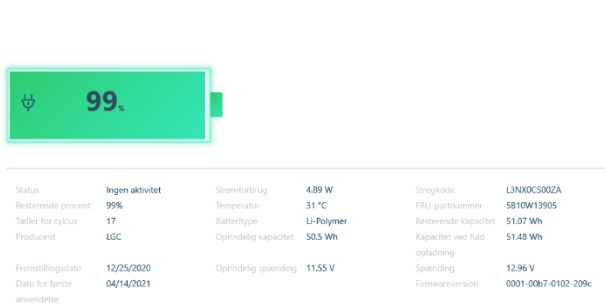


Figure 6: A screenshot from Lenovo's battery health info

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.

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 economy²⁴ 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 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 7), in contrast to previous designs. The advantage is that proper recycling of the



Figure 7: The new line of Electrolux vacuum cleaners

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.

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 over dimensioning 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 8.



Figure 8: Some of the brands that have applied the CAS battery standard²⁵

²⁴ https://www.cencenelec.eu/news/brief_news/pages/tn-2018-034.aspx, accessed 06/03/2021

²⁵ <https://www.cordless-alliance-system.com/>

Repair and spare parts

A Danish study²⁶ 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 those 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"²⁷ 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 9.

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



Figure 9: The EU campaign as part of the Right to Repair movement

parts they needed, and 18% found them too expensive²⁸, 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 tools²⁹.

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 trader³⁰. 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.³¹ 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.

²⁶

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

²⁷ <https://repair.eu/>

²⁸

<https://www.ellenmacarthurfoundation.org/assets/downloads/ce100/Empowering-Repair-Final-Public.pdf>

²⁹

<https://www.ellenmacarthurfoundation.org/assets/downloads/ce100/Empowering-Repair-Final-Public.pdf>

³⁰

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

³¹ <https://www.naturvardsverket.se/upload/stod-i-miljoarbetet/vagledning/avfall/producentansvar/attitydundersokning>



Figure 10: Tesla Model 3 battery modules³²

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.

Modularity / Second life of EVs

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.

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 EVs are 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 since it is a way to reduce the end-of-life costs and impacts. One example is the collaboration between Volvo Group and Stena Recycling announced in 2020³³.

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.

³² <https://www.currentautomotive.com/how-much-does-a-tesla-model-3-battery-replacement-cost/>

³³ <https://www.volvogroup.com/en/news-and-media/news/2020/sep/news-3766485.html>

In Norway, several ferries have switched to battery driven technologies, however, the ferries are often used to transport people between smaller cities. 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 factors³⁴, which is shown in Figure 11.

Several barriers complicate the process in giving vehicle and ferry batteries a second life. First, 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-STOR³⁵, 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,



Figure 11: Batteries from Renault EVs are reused for stationary purposes³⁶

which provide them access to the BMS system, so ECO-STOR can modify the battery to perform as an energy storage battery.

³⁴ <https://www.electrive.com/2018/09/26/renault-to-install-europes-largest-2nd-life-battery-storage/>

³⁵ <https://www.eco-stor.com/>

³⁶ <https://www.electrive.com/2020/10/21/renault-presents-two-second-life-battery-projects/>

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 to maximise operation time and utilisation of the products, thus minimizing the needed number 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. 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. 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 number of products and batteries you produce, while reaching the same number of customers.

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 must 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.

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



Figure 12: Husqvarna's digital shed³⁷

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.

³⁷ <https://www.husqvarna.com/se/support/tools-for-you/#location>

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 kinds 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 greener 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 repairability 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.

Like 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 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



Figure 13: Electrolux is currently testing vacuum-as-a-service³⁸

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-EV³⁸.

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 can 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 2019³⁹.

³⁸ <https://www.ri.se/en/what-we-do/projects/future-adaptable-design-electrical-vehicle-by-circular-business-models-fad-ev>

³⁹ <https://www.bcg.com/publications/2019/promise-pitfalls-e-scooter-sharing>

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