Netherlands

Circular Batteries Charging the Future

Collaborating for a Sustainable and Resilient Value Chain

Source: Unsplash

Content

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Circular Batteries: Powering a climate-neutral society

For the Netherlands, batteries represent an instrumental technology on the path to climate neutrality and achieving full circularity by 2050. To achieve our goals, we must first focus on minimising the current negative socio-environmental impact of batteries throughout their entire lifecycle.

Today, batteries are made with scarce and virgin raw materials, sourced far away from their final use destination, and difficult to disassemble, repair, refurbish, and even recycle. Tomorrow, batteries will be manufactured beginning from secondary raw materials, designed for being repaired and reused multiple times and in different applications. They will be easy to recycle at the end of their lifespan.

To get there, concerted actions from both the public and private sectors are necessary. Ahead of the newly adopted EU Battery Regulation, the Netherlands initiated a national strategic approach to batteries in 2020. The aim is to foster the sustainable and safe use of batteries via public-private partnerships and maximise the multiple economic opportunities the thriving battery sector offers.

With a rich history of entrepreneurship and circular innovation, The Netherlands has much to offer to international partners regarding solutions, technology, and know-how to enable the circular transition in the battery supply chain: from alternative materials and advanced battery chemistries to refurbishing methods and recycling technologies, and new circular business models and propositions.

Well aware of the catalysing power of collaborations, pioneering actors in the Dutch battery supply chain have started working in ecosystems, committing to expanding the Battery Competence Cluster. Supported by an extensive team across sectors, this ecosystem exemplifies the primary strength of the Dutch battery industry. The mission is clear: to work together and exchange knowledge to develop ground-breaking solutions that we can share with the world.

With this brochure on circular batteries, we wish to present our insights, lessons learned, and best practices from entrepreneurs, public authorities, and knowledge institutes. We encourage you to fully explore the many options available in this sector. This way, we inspire others around the globe and accelerate the circular transition in this crucial industry.

We believe that assessing and discussing the available avenues and making business opportunities visible are highly relevant to the continued development of new, innovative solutions in circular batteries. Even more importantly, we have identified countless promising opportunities for international partnerships on circular strategies for batteries. For us, advancing forward is the cornerstone of achieving long-term sustainability, economic resilience, and enhanced competitiveness.

> "Circularity is at the core of the long-term Dutch Battery Strategy, and we believe that we can play a pivotal role in the global value chain. For this, international cooperation is particularly crucial."

Rutger van Poppel

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Programme Manager, the Battery Competence Cluster - NL

Elevating Dutch circular battery innovations through international collaborations

Access to critical materials is essential to facilitate the energy transition, as they are the core of multiple technologies that either produce or store green energy, like solar panels, wind turbines and battery applications in mobility or consumer electronics. The Netherlands is in great need of these materials across several industries, but does not possess any local mining or refining industry. To secure a long-term material supply, the Dutch Battery Strategy was devised with a focus on enhancing sustainability and circularity.

The Dutch government and industry continue to heavily invest in the creation of a circular value chain for different battery products, from e-bike to consumer electronics and e-vehicles. Since the Netherlands was an early adopter of these products, among others through the bike culture, and early set up subsidies for e-vehicles and a good charging infrastructure, we see opportunities to become a frontrunner in circular battery technology, from designing circular cells and packs, to optimally using the local ‘urban mine’ for recycling.

To implement the strategy, multiple Dutch stakeholders joined forces in the Battery Competence Cluster – NL (BCC-NL) to develop an eight-year innovation programme: ‘Material Independence & Circular Batteries’. This will see the involvement of ~65 partners and an investment of €700 million - of which €300 million in subsidies - starting in 2024. Its core is an integral circular approach in which cell components and battery packs will be designed to be fit for second-life applications and become easier to disassemble and recycle, which will enhance recycling efficiency and bring down the Total Cost of Ownership.

Importantly, the goal of these activities is not necessarily to do everything within the Netherlands ourselves. The program is rather focused towards creating a differentiating and complementing position for our industry, through which we become a strategic partner in Europe. It is key for us to identify collaboration opportunities with complementary players to assure that the right competences and activities are developed as quickly as possible.

Circularity is thus at the core of the long-term Dutch battery strategy, and we believe that we can play a pivotal role in the international value chain. This brochure provides several key examples of how this is currently being put into practice, and proudly presents the potential of the future circular battery value chain in the Netherlands. It shows that we are committed to growing the sector sustainably to support EU objectives and attain an independent battery value chain through full circularity. For this, international cooperation is particularly crucial, and the Dutch are excited to become your strategic partner on this path.

Introduction and context

Batteries are the foundation of our modern society. From powering our phones and laptops, through starting the engine of our cars and trucks, to storing the energy we generate for later use, they enable our day-to-day lives. Although batteries have been around for decades, their strategic importance has recently experienced considerable growth. Simply put, a transition to a climate-neutral society with low-carbon electricity, transportation and logistics requires a ramp-up in battery capacity and production never seen before.

This unprecedented rise in the demand for batteries is fuelled in particular by the mobility sector, keen to decarbonise itself and meet the goals of the Paris Agreement. Increasing supply however comes with a multitude of environmental, socio-economic and geopolitical challenges. Batteries are mined, produced and moved across a truly global supply chain with significant negative impacts on ecosystems and local communities. Governments and businesses around the world are confronted with the need to do more with less, and to act fast and locally to ensure a resilient supply.

This creates a strong momentum for the circular economy in the sector. Circular strategies can deliver on most if not all objectives when it comes to resource efficiency and recovery, environmental protection, and even safety. In the EU, the Battery Regulation (2023) entered into force, recognising the fit of circularity for a resilient and thriving battery sector and finally including circular battery strategies in EU legislation.

With its innovative approach and technological advancements, the Netherlands has been directing considerable investments into circular batteries since 2020. A small country with the high ambition to be fully circular by 2050, the Netherlands experiences an increasing demand for batteries for electric vehicles, electronic devices and stationary energy storage systems. Notwithstanding, the availability of the needed raw materials nationally or at EU level is limited. In order to foster the competitiveness and resilience of its economy, the Netherlands will need to diversify its supply of batteries and their components by transitioning to circular business and procurement practices and enlarging collaborations with EU and international partners.

Today, it is clear and widely recognised why a circular economy for batteries is necessary and beneficial. Circularity truly represents a unique opportunity to future-proof our economy, society and environment, as the no-regret scenario for Europe. Now, we must move from the why to the how and transition collaboratively as fast as possible.

This brochure provides an account of the challenges (Chapter 1) and opportunities (Chapter 2) on the road to a circular value chain for batteries. We present the Netherlands as a country showing how circular strategies for batteries are already successful and can be scaled up further. These inspirational examples from the public, private and not-for-profit sectors are collected in Chapter 3.

Overall, (inter)national collaboration is key, as no one actor nor country can succeed on its own. Our publication thus concludes with a future outlook and joint reflections (Chapter 4) on what is needed next to accelerate the uptake of circular strategies in this crucial sector, both within and beyond the Netherlands.

Our aim as authors is to spur exchange of knowledge, best practices and ideas and stimulate a multi-stakeholder debate that can ultimately contribute to batteries that are circular and sustainable in the long-term.

E mobility ©Mark Kuipers

Chapter 1

Circular Batteries Challenges & Opportunities

It is hard today to imagine a world that is not powered by batteries. They are a key technology in the transition to a fossil-free energy system and to zero-emission mobility. However, they present significant sustainability challenges.

In recent years, the strategic importance of the battery sector has grown exponentially with the realisation that batteries are crucial for sustainable development and to meet the climate neutrality goals set by the Paris Agreement[1]. On the one hand, batteries will enable the decarbonisation of the transport sector. Only in 2022, electric vehicle (EV) usage accounted for a net reduction of ~80 Mt of GHG emissions[2], showing the crucial importance of scaling up electric mobility for a climate neutral future. Also, lifecycle assessments consistently show that EVS emit considerably less than traditional combustion vehicles[3].

On the other hand, batteries can safely store wind and solar energy, providing flexibility and stability to the intermittent production of renewable energy. As governments divest from fossil-fuels, the need for battery energy storage systems (BESS) in GWh in 2030 will equal the total GWh necessary to power all battery applications today[4]. Importantly, BESS can also provide affordable energy supply to remote communities with little or no access to lighting and electricity[5].

If we consider that batteries are also necessary to power our electronic and digital devices, it becomes evident how a present and future society without battery power is unthinkable. However, the current linear mode of production, use and disposal of batteries globally has a considerable negative impact on affected ecosystems, workers and communities[6]. Responsible material sourcing, circular design, the use of renewable energy and the development of more resource-efficient processes can all play a crucial role in abating these emissions, in line with circularity principles.


Source: NL branding toolkit

How are batteries classified?

The newly adopted EU Battery Regulation (2023) includes a revision of battery categories based on their design, use and application. The classification distinguishes between:

- EV batteries - those used for traction in road vehicles (4-wheeled) such as Lithium-ion batteries (LiBs);
- Light means of transport batteries - those in 2- or 3-wheeled EVs;
- Industrial batteries - now comprising those used in transport vehicles (water, air, rail) and off-road machinery for activities in industry, agriculture, electricity generation and distribution (including energy storage in private/domestic environments) and in communication infrastacture;
- Portable batteries - those used in consumer goods and electronic devices and weighting up to 5kg;
- Starting, lighting and ignition batteries used in vehicles or machineries.

Why focusing on lithium-ion batteries specifically?

Whilst other batteries are more widely collected and recycled in the EU, Lithium-ion Batteries (LiBs) are mostly treated as waste, landfilled and often exported outside the EU when their capacity decreases. Here their residual values and materials are lost, with subsequent safety and environmental hazards. Accurate data is currently difficult to retrieve. While China and South Korea have ramped up their activities significantly in recent years, EU, US and Australia are only now starting to follow suit, prompted by recent regulatory requirements. As the production of LiB for EVs rises and regulations around the world set ever higher ambitions for their collection, reuse, and recycling, we must strive to find circular solutions. For example, meeting material demand via secondary raw materials, implementing responsible sourcing and safe working conditions, focusing on reuse and remanufacturing to extend battery lifespans and avoid mounting waste, and more. This is why this brochure focuses on LiBs.

1. Today's Lithium-ion Batteries

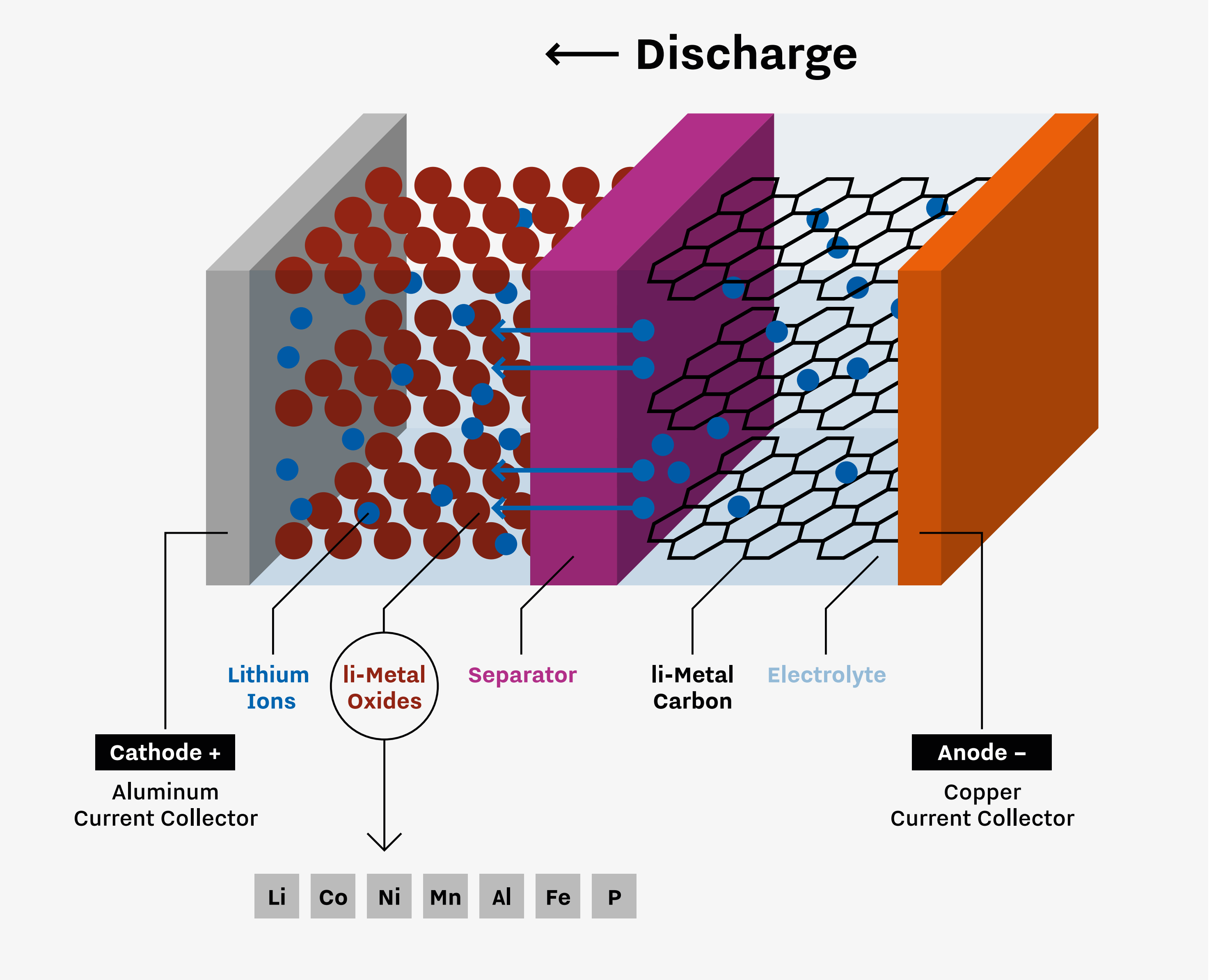
1.1 Structure and materials of LiBs

LiBs have been significantly improved over time, since the very first battery presenting a layered Lithium Cobalt Oxide (LCO) structure as cathode and graphite as anode. Today, battery cell geometries can differ significantly in their specific chemical composition depending on factors such as brand, type and year of manufacturing. Generally, a LiB cell consists of a cathode, anode, polymer separator and a supporting electrolyte.

The anode and cathode materials act as hosts to store Li at very different potentials, determining its energy storage capability. The energy density of a battery (gravimetric and volumetric) is determined by how much Lithium (Li) per gram per weight/volume can be stored in the electrodes and by the difference in the anode/cathode working potential (battery voltage).

LiBs typically employ a graphite anode aand a Li metal oxide cathode of various possible chemistries. Since the active materials are prepared in powder form, they are glued to thin metal foils that are used to collect the electric current. This whole basic structure is soaked in a liquid organic electrolyte containing Li salts and it is enclosed in a protective casing typically made of steel, aluminium (Al), or plastic.

Figure 1: Li-ion battery cell structure and materials



Source: TU Delft and Holland Circular Hotspot

1.2 Improving chemistries for enhanced performance and durability

Structural instabilities in LCO have led to the use of Nickel (Ni) and Manganese (Mn) as battery capacity booster and structure stabiliser respectively. In particular, the development of Ni-rich compositions[8] (such as NMC622, NMC811 and in the future ultimately $LiNiO_2$) was boosted by the need to reduce or completely replace Cobalt (Co) as a battery component due its limited geographical availability. However, the main challenge with these chemistries remains stabilising the Ni structure and surface to obtain a sufficiently long battery lifecycle. Protective Atomic Layer Diposition (ALD) coatings present a promising solution to these issues, as shown by several Dutch startups such as Powall (see page 50).

Figure 2: Common Lithium-ion Battery Compositions, properties and applications

Type chemistry	Properties	Applications
LCO Lithium-Cobalt Oxide Battery	Higher energy density Greater safety risks, especially when damaged Limited power Shorter lifespan	Portable electronic devices
LFP Lithium-Iron Phosphate Battery	Lower energy density Longer life Considerably reduced safety risk	EVs Stationary Application (grid stabilisation)
NMC Lithium Nickel Manganese Cobalt Oxide Battery	Higher energy density Longer life Higher capacity Reduced safety risk	EVs Electric bikes Medical devices
LMO Lithium-Manganese Oxide Battery	Good thermal stability/reduced safety risk Higher power Shorter life Lower capacity	Power tools Medical devices Electric bikes
NCA Lithium Nickel Cobalt Aluminum Oxide	Higher energy density Longer life Reduced safety risk Less thermally stable	EVs Medical devices
LTO Lithium-Titanate Battery	High power Lower energy density Longer life Reduced safety risk	EVs Energy storage

Source: ARUP, 2020, TU Delft, Holland Circular Hotspot

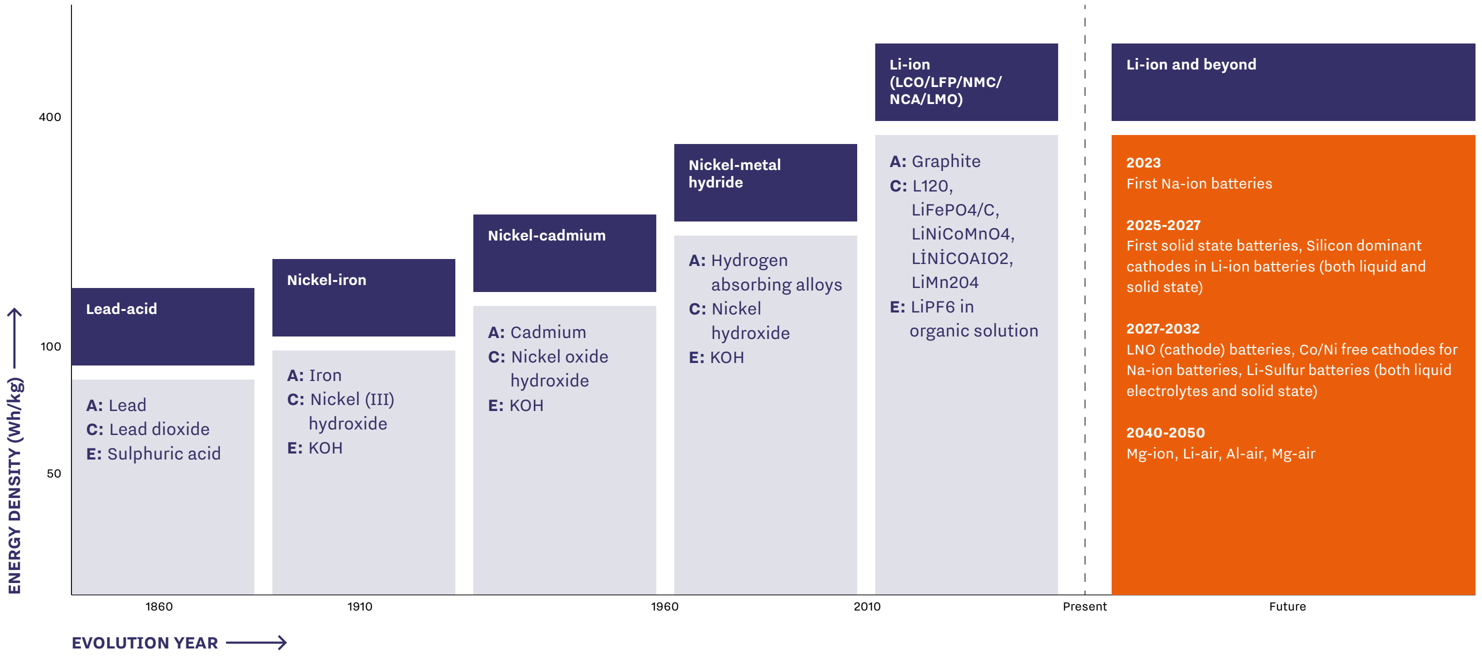
Several cathodes have also emerged over time, including polyanion $LiFePO_4$ (and recently $LiFe\frac{1}{2}Mn\frac{1}{2}PO_4$) which lowers the battery energy density. These provide improved safety and longer lifecycle, while relying on more abundant transition metal elements, preventing the use of Co and Ni.

Other cathodes so far introduced on a small scale or currently being developed include high-voltage spinel ($LiNi_{0.5}Mn_{1.5}O_2$), conversion materials (e.g. FeF_3), disordered rocksalt, antiperovskite electrodes, sulphide (Li_2S) and oxygen (Li_2O_2) electrodes. These aim at higher Li capacities (i.e. higher energy densities), lower costs and the use of more abundant and/or renewable raw materials.

Similarly, multiple anodes have been developed, despite being usually characterised by lower capacities and consequently lower voltages. Although this compromises energy density, it also presents some advantages. For example, the commercialised $Li_4Ti_5O_{12}$ bosts an extremely long life cycle. The ultimate anode with respect to energy density is Li-metal. However, decades of research demonstrated how it poses considerable safety hazards[9].

Ultimately, these attempts to enhance battery chemistries are geared towards extending battery lifecycle and thus improving its sustainability. This is achieved by increasing the ratio between the energy invested to manufacture the battery and that stored in the battery over its use, which lowers the battery footprint per stored unit of energy.

Figure 3: Timeline of battery technology development



Source: TU Delft, FutureBridge, 2021

2. Next Generation Batteries

2.1 Solid State Batteries: Challenges and Opportunities

A recent development receiving significant attention is represented by solid state batteries (SSBs). This technology utilises the same anodes and cathodes of Li-ion batteries but in combination with a solid instead of a liquid electrolyte, which is intrinsically less flammable and thus safer. Often solid state batteries are associated with energy densities beyond LiBs batteries. However, the safe use of Li-metal as anode remains a formidable challenge[10].

Despite the safety advantage, a number of challenges remain[11]. For instance, the difficulty to develop solid electrolytes that can fulfil all boundary conditions and to establish an intimate solid electrode - solid electrolyte interface during manufacturing (and maintaining these during cycling upon the volume changes of the electrodes). Similarly to liquid electrolytes, developing stable solid electrolytes that also provide a high Li-ion conductivity (the primary role of the electrolyte), poses an additional challenge.

Also for solid electrolytes many different chemistries are being developed, from sulfides and oxides to polymers and composites. Each has specific advantages with regards to conductivity, stability, mechanical properties, processability, etc. Overall, these chemistries require further R&D towards new manufacturing processes and machinery, which will challenge the manufacturing footprint[12].

Another notable issue is that SSBs based on inorganic solid electrolytes necessitate at least twice the amount of Li - currently a CRM - for the same energy stored[13]. These existing challenges delay the large-scale commercialisation of these electrolytes. Yet, announcements of their introduction continue to be released also by major car manufacturers (e.g. Toyota is on track for limited production by 2025).

2.2 Other Batteries on the Horizon

Other charge carriers replacing Li are also being considered, a.o. Sodium-ion (Na-ion), Potassium-ion (K-ion), Mg-ion, Al-ion. In parallel, new redox flow and salt water battery chemistries are emerging. The latter two are particularly suited for large-scale stationary applications. For instance, Mg-ion and Na-ion offer a relatively high energy density and as such can potentially replace Li-ion in the future.

While Mg-ion is in the research phase, Na-ion is being rapidly developed, with the first commercial productions taking place (CATL Unveils Its First Generation Sodium-ion Batteries). As Na is chemically very similar to Li, also the related battery materials (up to large-scale manufacturing processes) are very similar[14]. Na presents several sustainability advantages compared to Li, giving its large abundance around the globe and its lower mining footprint[15]. Additionally, using Na reduces the need for CRMs like Li, Co and Ni, with a small compromise in energy density and opportunities for high-power applications in comparison to Li-ion batteries.

Batteries for Stationary Energy Storage

Similarly to batteries for e-mobility, batteries in energy storage systems (BESS) play a vital role in achieving a cleaner, more sustainable, and resilient energy future[16][17]. The main electrochemical technologies used in grid applications include lithium-ion, sodium-sulfur, lead-acid and redox flow batteries. LiB are usually the preferred option, since they outperform the other technologies, offering higher power and energy density, efficiency, and low daily self-discharge[18]. Consequently, they have been the preferred choice by the industry. BESS are deployed for multiple purposes:

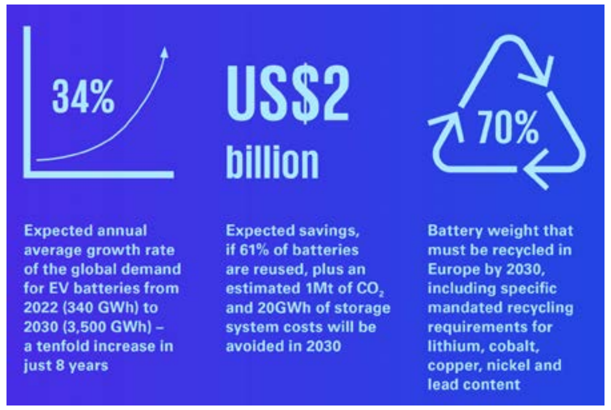
- **Renewables Integration:** Renewable energy generation fluctuates based on weather conditions. BESS can store excess energy during peak generation periods and discharge it when demand rises or production lowers. This helps to smooth out the intermittent nature of renewables, ensuring a stable and reliable power supply.
- **Grid Stabilisation & Flexibility:** BESS regulates frequency and voltage in the grid, offering fast response times compared to conventional power plants. They can rapidly inject or absorb power into the grid to address sudden fluctuations in supply or demand. Subsequently, grid reliability and efficiency are enhanced and the need for expensive and polluting fossil fuel-based back-up power plants reduced.
- **Peak Load Management:** BESS can help manage peak electricity demand. During times of high demand, such as hot summer afternoons when air conditioning usage is high, they can provide additional power to avoid overloading the grid. This can avoid the construction of costly new power plants and transmission infrastructure.
- **Distributed Energy Systems**: BESS allow for the development of distributed energy systems, where power generation and storage are located closer to the point of consumption. This reduces transmission losses and enhances grid resilience. Distributed BESS can also provide backup power during outages, improving grid reliability.
- **Vehicle-to-grid (V2G):** The integration of high-capacity EVs with BESSs can create a V2G infrastructure, where EV batteries can store excess electricity and discharge it back to the grid when needed. This supports the grid and promotes the use of clean transportation, reducing fossil-fuel reliance.

3. The Challenges of a Linear Battery Supply Chain

3.1 Demand for batteries is growing exponentially

Until 2030, the demand for LIBs is projected to increase by ~33% year on year[19], largely driven by the soaring demand for EVs[20]. Worldwide the three largest markets for EV are China (#1), Europe (#2) and the United States (#3). Global EV sales have increased steadily over the last few years and current projections show that around 18% of all cars sold in 2023 will be electric.

Figure 4: Key insights related to EV batteries and circular economy



Expected annual average growth rate of the global demand for EV batteries from 2022 (340 GWh) to 2030 (3,500 GWh) – a tenfold increase in just 8 years

Expected savings, if 61% of batteries are reused, plus an estimated 1Mt of CO_2 and 20GWh of storage system costs will be avoided in 2030

Battery weight that must be recycled in Europe by 2030, including specific mandated recycling requirements for lithium, cobalt, copper, nickel and lead content

Source: KPMG, 2023

This growth is attributed to financial incentives and targeted policies at national level - recently also in emerging economies - and to the energy crisis and fuel surcharges of 2022-2023. A positive trend encouraged also by the latest updates on battery manufacturing capacity, enough to meet estimated demand by 2030[21]. The acceleration in the electric shift also characterises other types of vehicles, from bikes, scooters and mopeds to light and heavy-duty vehicles[22].

3.2 Matching supply and demand for battery materials is increasingly difficult

Scaling up the production of LiBs poses a number of challenges. The EV sector alone is responsible for 60%, 30% and 10% of the global demand of Li, Co and Ni respectively, much of which is attributed to batteries[23]. Based on latest estimates, the mining and refining industries would need to enlarge their production of Ni, Neodymium (Nd), Co and Li by 300% in ten years to meet global EV demand. This calls for a much needed acceleration of the production, since a decade is often too short to bring a new mining site fully up to speed[24].

Silicon supply-demand balance is also an issue. Today, a small amount of silicon is mixed with graphite as a capacity booster in LiBs, providing for higher energy densities and longer-lasting batteries with multiple charge/discharge cycles. Although silicon is the second most abundant element on earth, currently it is considered a CRM because silica-rich quartz is mined predominantly in China[25] and its processing (also mainly in China) is energy intensive[26].

Worsening the issue, most EVs currently on the road in the three strongest markets are SUVs. These large cars contain batteries up to three times bigger than average, which furthers the need for limited raw materials and minerals, with consequent environmental and social impacts[27].

Securing a stable supply of battery materials is increasingly also a matter of geopolitics. In particular for countries like the EU who heavily rely on imports, since these materials are highly concentrated in a few geographic areas. Russia's war on Ukraine has further destabilised the price of metals needed for EV batteries such as Ni, as considerable reserves of these materials exist in both countries[28].

Today, it is still difficult to exactly predict whether there are even enough material supplies globally to sustain future needs. CRM demand can be significantly reduced by the uptake of new battery chemistries that are more material efficient and/or reliant on more naturally abundant raw materials, together with circular strategies enabling their reuse and recovery[29].

The European Commission regularly assesses the criticality of several non-energy and non-agricultural raw materials. Critical Raw Materials (CRM) are defined based on their economic importance for the EU industry and economy, and on the risks and uncertainty related to their individual supply. Most LiB materials are part of this list. Ni and copper (Cu) are instead considered Strategic Raw Materials, due to their highly diversified supply[33].

Key Materials in LiBs	Geolocation of Reservoirs*	Major Processing Countries
Lithium (Li)	Australia 46.9% Chile 30.0% China 14.6%	China 58.0% Chile 29.0% Argentina 10.0%
Cobalt (Co)	Democratic Republic of the Congo 70.0% Indonesia 5.4% Russian Federation 4.8%	China 70.0% Indonesia 18.0% Finland 11.0%
Manganese (Mn)	South Africa 35.8% Gabon 22.9% Australia 16.4%	China 93%
Nickel (Ni)	Indonesia 48.8% Philippines 10.1% Russian Federation 6.7%	Indonesia 39.8% China 23.9% Japan 5.0%
Copper (Cu)	Chile 23.6% Peru 10.0% Democratic Republic of the Congo 10.0%	China 42.3% Chile 8.1% Democratic Republic of the Congo 6.5%
Graphite (C)	China 64.6% Mozambique 12.9% Madagascar 8.4%	China 100%
Neodymium (Nd)	China 45.8% Australia 23.1% Greenland 8.2%	China 88.0% Malaysia 11.0% Estonia 1.0%

Source: IRENA, 2023.

* Figures relative to total estimated reservoirs worldwide. Only top 3 countries / geolocations shown.

3.3 Materials mining and processing negatively impacts ecosystems and communities

Extraction of battery materials is also often executed with little regard for workers' safety, health and human rights and multiple sites reportedly employ children[31]. This is the case of the Democratic Republic of Congo, where around half of all cobalt reserves can be found and forced and child labor involves hundreds of thousands. At the same time, cobalt mining is key to Congo's economy and to the survival of local communities[32].

Also in the so-called Lithium Triangle (Argentina, Bolivia, Chile), the prospects for a significant boost of the local economy and social conditions when tapping further into these reserves are promising. There is however little data available yet on the impact of such extraction activities on the local ecosystems, agriculture and human health[33].

Lithium mining has an especially high carbon and water footprints[34], requiring 700,000 litres of water per tonne of production. More than half of lithium is mined in areas where water supplies are already under pressure, as in the case of the Bolivian and Chilean salt flats. Risks of water and air contamination from unintentional lithium release persist, with consequent detrimental impacts for biodiversity and human health[35].

Overall, 40-to-60% of the GHGs emitted during EV production is attributable to batteries. This high carbon footprint is caused by the mining, refining and shipment of battery materials, and by the energy-intensive production of anodes and cathodes materials[36]. Focusing on responsible sourcing, sustainable mining and production processes and circularity can all help to lower the environmental and social impacts of batteries.

The environmental impact of certain extraction processes is not entirely clear yet. This is the case for deepsea mining, which could potentially provide a number of materials strategic for battery development but whose (in)direct impacts on ocean's biodiversity, temperature and carbon absorption are largely unknown and potentially irriversible[37]. In July 2023, these concerns led the International Seabed Authority to hold their final decision on large-scale industrial mining until 2024, following major global calls on a ban of such operations.

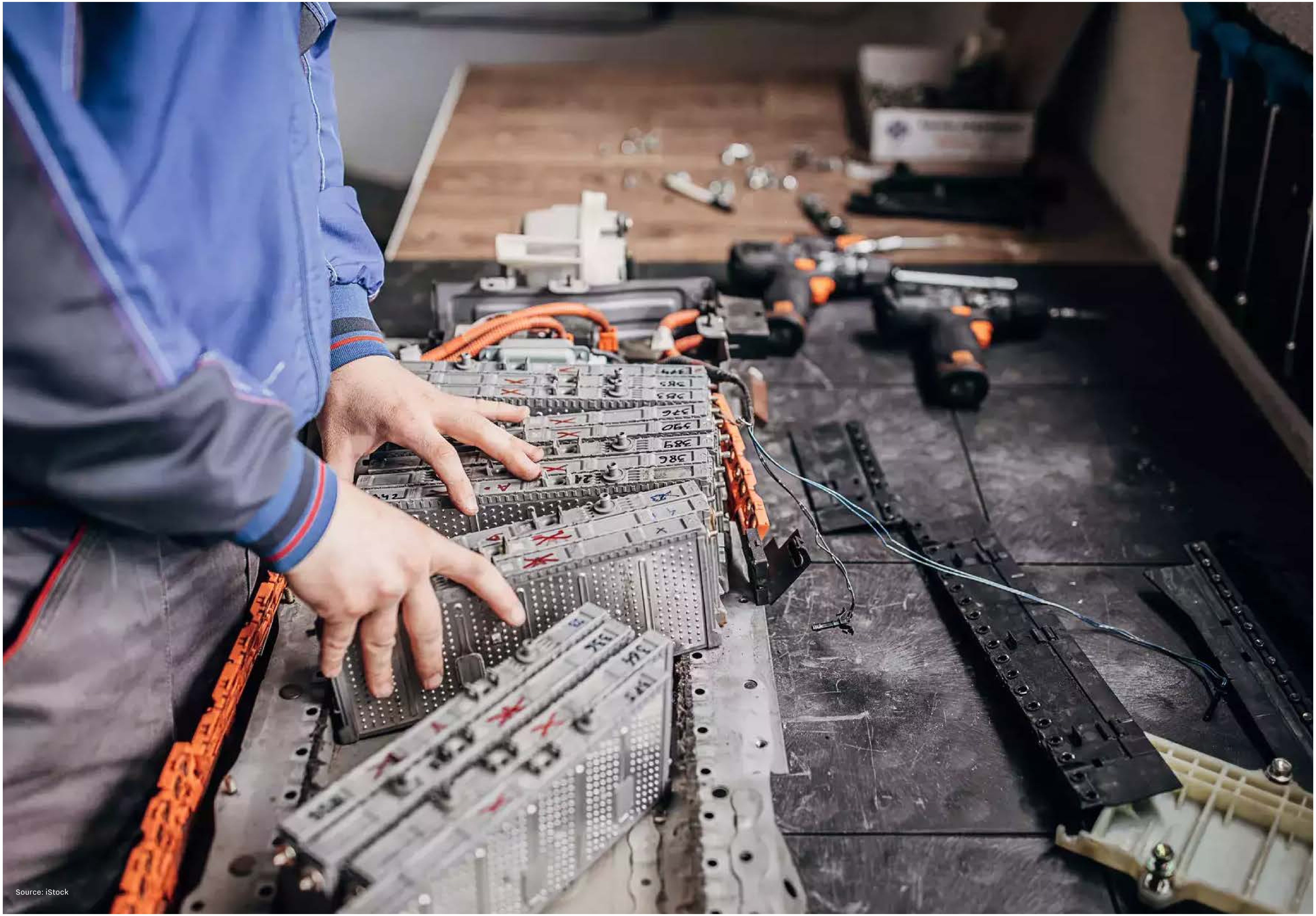
Risks in Transporting, Storing and Handling Batteries

There are several risks associated with storing and transporting batteries and accumulators. A thermal runaway is a chemical reaction involving heat and gas generation in the battery. When occuring, the pressure can become so great that gases escape and ignite other batteries, with a potential conflagration involved. A fire or exposure of lithium to oxygen can also cause an explosion. These all pose major risks to the surrounding people and areas, from the release of corrosive and toxic substances and severe burns and injuries to eyes and skin. Extinguishing batteries on fire can additionally create toxic firewater, posing a danger to firefighters, emergency workers, employees and nearby residents.

The causes of fire or explosion can be multiple: damages during falling (by far the most important cause), manufacturing fault, errors during loading process in storage, ageing during storage, short circuit due to water, etc. Specific requirements already apply to their transport due to the related safety risks. These are laid down in the ADR for road transport (LiBs fall under ADR class 9) and in the IATA-DGR regulations for air transport.

In 2024, the Dutch 'PGS37' will enter into force as a new guideline for safe handling of energy systems on site (PGS37-1) and storage of lithium-containing energy carriers by vendors, distribution centres, storage companies and collection and recycling companies PGS37-2). Measures deal with safety devices, storage height and temperature in the room, differ by type of company, activity and situation, and aim at achieving occupational and environmental safety, fire prevention and disaster relief.

Source: Johan Cruijff ArenA



Source: iStock

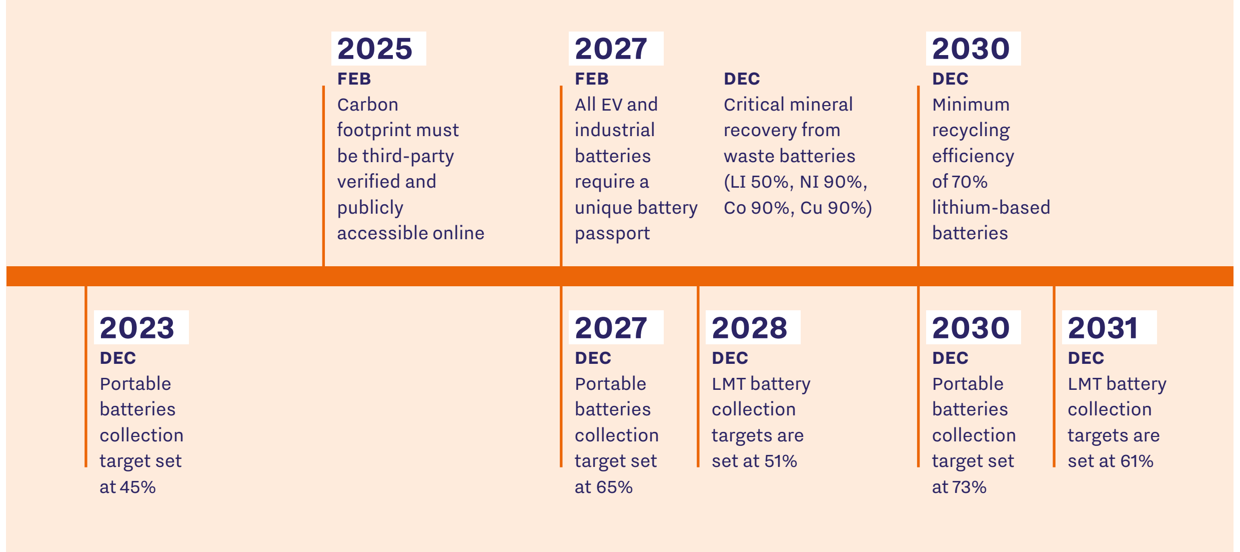
Source: Adobe Stock

Chapter 2

On the Road to a Circular Battery Value Chain

Making batteries circular requires multistakeholder efforts in R&D, investments and international collaborations. All circular strategies need to be taken into account, from refuse and rethink to reuse, and up until recycling.

Figure 5: EU Battery Regulation Timeline



Source: Circularise, 2023

A circular approach can significantly aid in balancing supply and demand for LIBs and their materials by strengthening resource efficiency and value chain resilience through innovation of processes, products, and business models. At the same time, a circular value chain can effectively deliver better social conditions, enhanced environmental protection and increasing financial profitability in the short and long term. The battery recycling value chain alone is in fact expected to yield yearly revenues above 95 billion dollars by 2040[38].

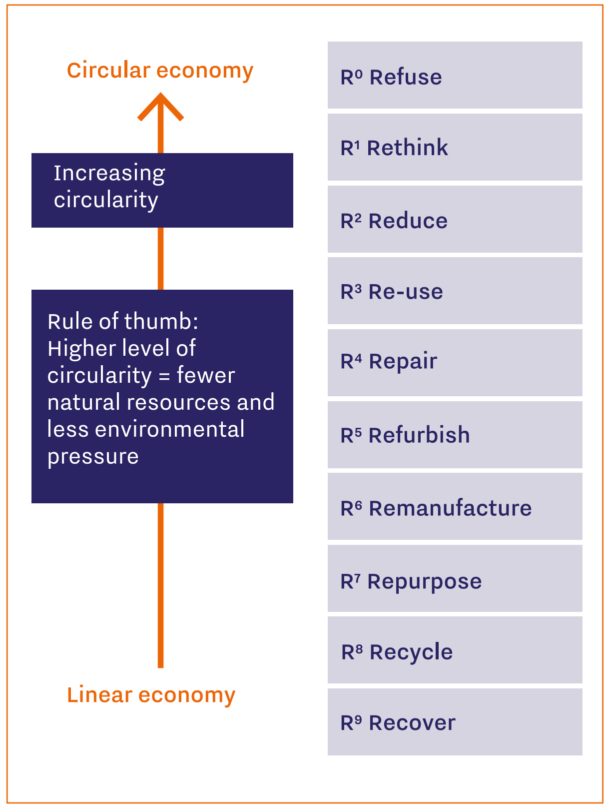
Aware of the existing challenges and opportunities ahead, the 2023 EU Battery Regulation has introduced specific requirements to a.o. increase supply chain due diligence, foster repair and reuse, mandate the use of secondary raw materials, and encourage standardisation and circular design.

However, making the battery value chain circular requires a true paradigm shift, enabled via concerted actions and joint efforts of all involved stakeholders and at both national and international levels. In particular, it is important to recognise that for a truly successful circular transition, all circular strategies and so-called R-practices[39] must be taken into account.

What characteristics does a circular battery have?

There are multiple definitions and interpretations of circular batteries and more broadly, of circularity. Here, we consider circular a battery that throughout its lifetime has a considerably lower (to minimal) socio-environmental impact compared to an average battery on the market today thanks to the simultaneous deployment of several circular practices and strategies. Overall, a circular battery should be safe, durable, easily repairable and/or reusable, and fully recyclable at end of life (i.e. once all reuse and repair options have been exploited and no more value than that of the inner materials remains). It should be manufactured with as little material and energy inputs, through environmentally-sound processes, without hazardous or pollutant processes involved, and with fair working conditions. Also, supply chains should be as local and short as possible to limit transport emissions and safety risks.

Figure 6: Levels of circularity



Refuse, Rethink and Reduce throughout the battery lifecycle

In the context of batteries and their value chains, these three circular strategies stand at the top of the 'R-ladder'[40].

Refuse and reduce go hand in hand and refer to whether we even need to produce more batteries and how we can achieve more with less. They particularly relate to the importance of reducing increased battery production (and thus battery materials extraction) wherever possible and to instead concentrate first on the development of more efficient batteries and battery use.

Concrete examples of these circular strategies include focusing on the development of ever smaller but yet powerful batteries and on business models preferring lease and sharing of batteries over owning. These would indeed help curb demand for new batteries, as much as possible through e.g. an increase in public transport accessibility and affordability.

Simultaneously, there is a clear necessity to rethink batteries and their materials, production and use phases altogether. Still in its infancy in this sector[41], circular design can enable from the outset to produce batteries that are easily disassembled for efficient reuse, repair and eventually recycling, and also made out of secondary raw materials and non-critical metals. This would also alleviate material dependency, supply insecurity and fluctuating prices for countries like within the EU.

Working towards battery standardisation would significantly enhance the feasibility of circular practices like reuse, repair and up until recycling. However, achieving standardisation is challenging given the increasing diversity in battery chemistries,fostered by the specific demands of different applications and issues of material criticality and sustainability.

Hence, developing sustainable battery technologies requires a comprehensive evaluation of the lifecycle impacts of each of the many possible chemistries, in conjunction with the respective battery performance potential. The remaining uncertainties also will need to be tackled in a collaborative way by experts across the entire battery value chain.

In today's Li-ion batteries, a Li-salt and several additives are dissolved in carbonate based solvents, providing a balance between stability, safety and high Li-ion conductivity. The challenge with next generation cathodes and anodes is that they typically promote electrolyte degradation reactions. Hence, a better understanding of these degradation reactions as well as strategies to prevent them - for instance through protective electrode coatings or improved electrolyte formulations - is paramount for the realization of next generation batteries. In the Netherlands, the BatterNL national NWA-NWO consortium is pursuing research into both these directions.

Material extraction and manufacturing processes can also be redesigned to minimise and wherever possible avoid, water and air pollution or safety hazards for workers and local communities. Shifting from organic to aqueous solvents in battery manufacturing, moving away from fluorinated electrolytes and binder components, and preventing the need of dry-rooms all present important opportunities[42]. These components and processes are indeed largely responsible for the high performance of Li-ion batteries today.

The footprint of materials transport and battery distribution across borders can also be significantly reduced by e.g. reshoring supply chains or reusing and recovering components locally.

Source: Unsplash

Reducing raw material consumption for batteries in electric cars

For a truly circular economy, we should rethink not just LiB batteries but also the vehicles containing them, particularly e-cars which do not emit while in use, but do have a high material and energy footprint during production.

Currently, only 3% of the 9 million cars in the Netherlands are electric. This share must increase rapidly to reach carbon neutrality by 2050. Considering that an average of 10 kg of lithium and 40 kg of nickel go into an e-car, this ramp up would require massive amounts of new raw materials. Researchers from Metabolic, Copper8 and Leiden University calculated that the Netherlands may consume ~4.5 % of the global metal supply by 2030, against a Dutch population representing only 0,2 % of the world population.

Using raw materials sparingly will help us minimise damage and prevent the unnecessary risks and detrimental consequences brought about by fossil fuels extraction in the last century. Think of earthquakes in Groningen, oil spills in the Gulf of Mexico and Nigeria, and pollution at coal mines worldwide. There is an opportunity for us not merely to replace the fossil car with an e-car 1:1, but also to rethink the car's place in our economy. How can we get there?

Government policies can influence mobility choices. Reducing battery demand starts with redesigning cities and towns so that fewer cars are needed. Today, 50 % of public space in cities is set aside for cars., with cars taking 70% more space than pedestrians. In rural areas, 64% of people say they have become increasingly dependent on cars, as facilities disappear and public transport scales down. And 1/3 Dutch people see the car not as a free choice but as a necessity.

The following measures can help change this unsustainable status quo and indirectly foster battery sustainability and circularity:

In Urban Areas: Reducing the number of parking spaces around homes, offices and shopping centres. Cities like Utrecht and Amsterdam show the positive effects of strict parking policies. Whereas car ownership increased in the rest of the country, it actually decreased in these cities. Choosing locations near public transport hubs in new housing, office and retail developments. Providing a wide range of shared (electric) cars and bicycles for both visitors and residents. Data shows that one shared car can replace as many as eight private cars. In Rural areas: Ensuring facilities are easily reachable and widespread. Providing more public transport, shared mobility and cycling infrastructure.

Through Public Policy: Setting price incentives and standards for smaller batteries. Smaller batteries require less raw materials and are therefore preferable to large batteries. Now we see that cars are getting bigger and heavier, for instance, by 2022 as many as 50% of new cars sold in the Netherlands were SUVs. Bigger cars also need bigger batteries. To promote the use of smaller batteries, different price incentives and standards can be applied. For example, taxing battery weight so that users think more consciously about the actual use of their car; aligning subsidies with car downsizing and attaching conditions or benefits to these subsidies.

At Company Level: Besides government policies, it is important that businesses also reduce resource use in mobility. They can promote hybrid working, offer cycling plans to encourage employees to use alternatives and provide a combination of shared cars and public transport in a well integrated company plan and transport system.

Reusing and Repairing to extend the battery lifespan

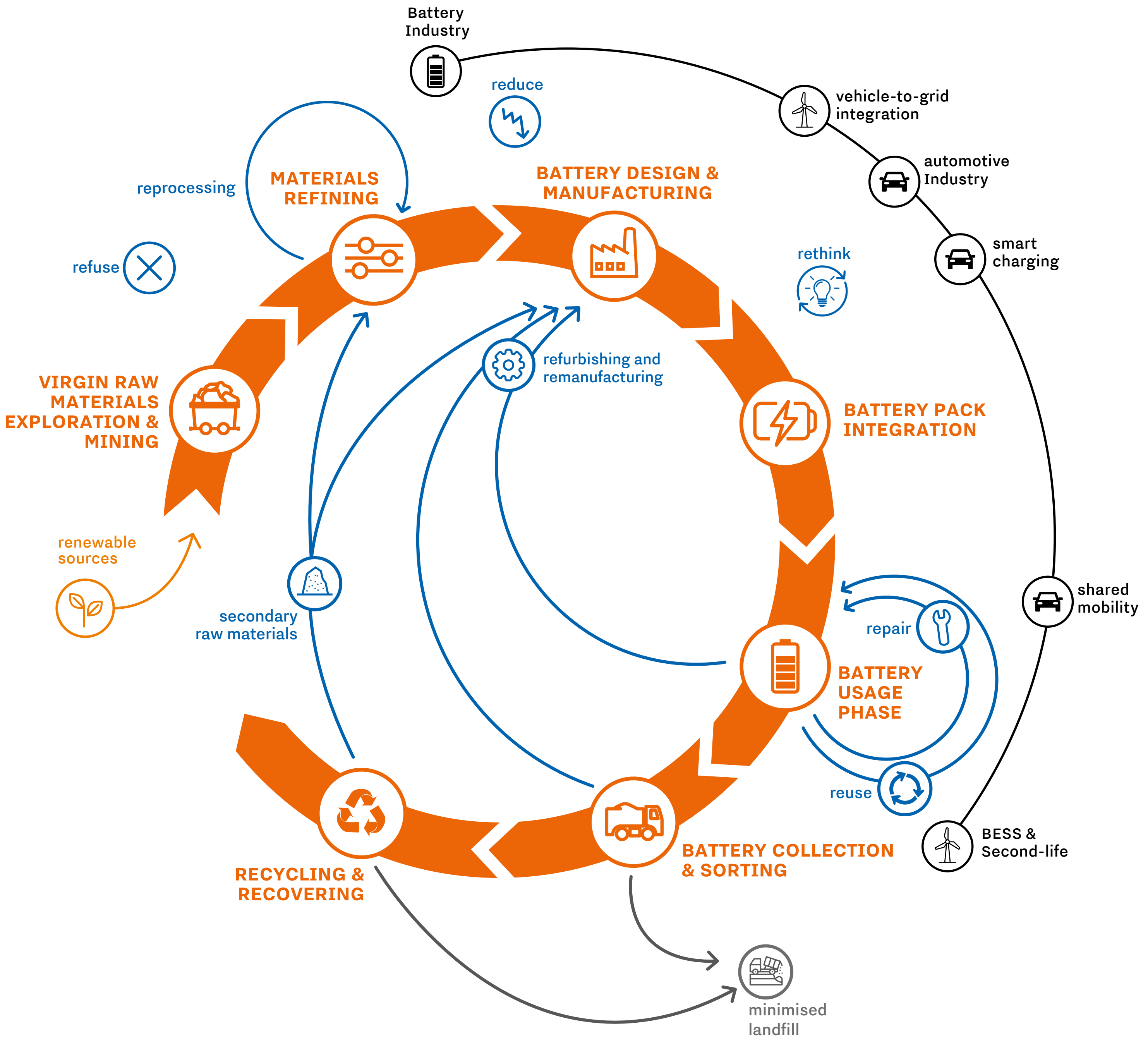
In order to keep materials in loop and avoid the need for new batteries and new raw materials, it is crucial to significantly invest in those R-strategies that can slow the loop on LiBs. From reuse and repair, to refurbishing, remanufacturing and repurposing.

All these processes require different new material and energy inputs in order to return the battery to its original power capacity or to prepare it for second-life. However, these inputs are still considerably lower than those needed for the manufacturing of a completely new battery.

A concrete example of how successful repurposing and second-life can be is that of spent EV batteries with reduced, yet sufficient capacity which can be refurbished for less demanding applications like stationary energy storage. A notable Dutch example is the BESS of the Johan Cruyff ArenA in Amsterdam (see page 52).

Enabling these circular strategies however requires precise labeling and the open provision of information on the battery pack and its state-of-health, as well as cooperation and legal agreements over ownerships. The new EU regulations have embraced such initiatives by introducing a ‘battery passport’ and requiring OEMs to make portable batteries in appliances and light means of transport such as e-bikes or e-scooters removable and replaceable by the end-user or an independent professional respectively and as of 2027.
The EU-funded CIRPASS Project is driving the digital product passport for batteries forward by preparing the ground for its piloting and roll-out.

Figure 7: A circular supply chain for batteries



Source: Developed for this brochure by Holland Circular Hotspot based on TU Delft expert research; KPMG, 2023; McKinsey & Company & Global Battery Alliance, 2023.

Preparing for the EU Battery Regulation & Battery Passport: The Experience of Circularise

The adoption of the EU Battery Regulation in August 2023 marked a milestone in the future of sustainable battery production and end-of-life recovery. A key aspect of the legislation is the battery passport which will be the primary mechanism for communicating critical information regarding a battery between the actors in its supply chain, as well as the consumer and end-of-life operators.

This means that any electric vehicle (EV), industrial battery, or light means of transport (LMT) with a battery capacity of over 2 kWh, regardless of origin, will require a battery passport in order to be sold in the European Market.

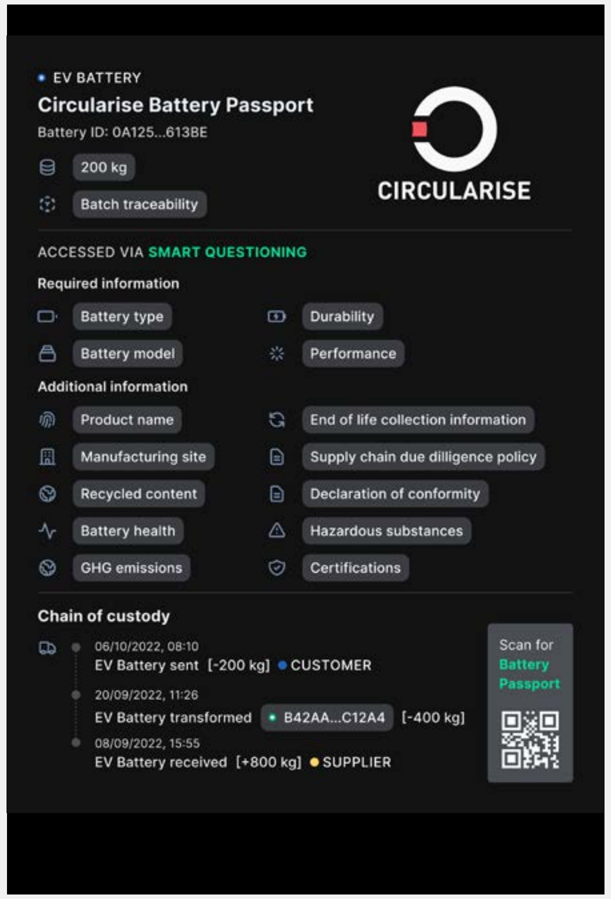
A blockchain platform founded in 2016, Circularise focuses on bringing end-to-end traceability and secure data exchange to complex supply chains through digital product passports. Through their services, companies can trace products and materials to verify their origins, certificates, CO2, and other data on their socio-environmental impacts. By doing so, Circularise aims at enabling a circular economy. Having worked across multiple industries including automotive, aviation, and plastics, today Circularise is part of key consortia such as Catena-x and the Global Battery Alliance. Since the battery passport will be the first digital product passport to be mandated by the European Union, the company is well-positioned to support the industry in the needed transition.

A battery passport will store relevant battery data throughout the entire battery lifecycle, containing detailed information about a battery's production, testing, and recycling. It is designed to ensure that batteries comply with the EU Battery Regulation, as well as to provide a record of the battery's history. This is especially important for batteries that are sold to consumers, as it provides them with the assurance that the batteries purchased are safe and compliant.

One of the major concerns with the adoption of digital product passports in the past has been the aspect of sensitive data protection with the sharing of information downstream. To address this concern Circularise's battery passport harnesses a patented 'Smart Questioning' technology. The latter uses zero-knowledge proofs (ZKPs) to enable actors across battery value chains to selectively share data at different disclosure levels depending on the type of stakeholder.

This technology unlocks access and visibility into more sensitive data (such as detailed chemical composition and reports required for due diligence) only to the actors who need to see them. Other data points can be made available to the public or other relevant parties within the value chain, and all without breach of privacy or confidentiality.

As with all other digital product passports, the battery passport by Circularise helps brands to get visibility into their Scope 3 emissions and other metrics, which is aligned with the regulatory push around Digital Product Passports, the SEC's proposed climate risk disclosure rules, and the Corporate Sustainability Reporting Directive.



● EV BATTERY

Circularise Battery Passport

Battery ID: 0A125...613BE

200 kg

Batch traceability

ACCESSED VIA SMART QUESTIONING

Required information

Battery type
Durability
Battery model
Performance

Additional information

Product name
End of life collection information
Manufacturing site
Supply chain due dilligence policy
Recycled content
Declaration of conformity
Battery health
Hazardous substances
GHG emissions
Certifications

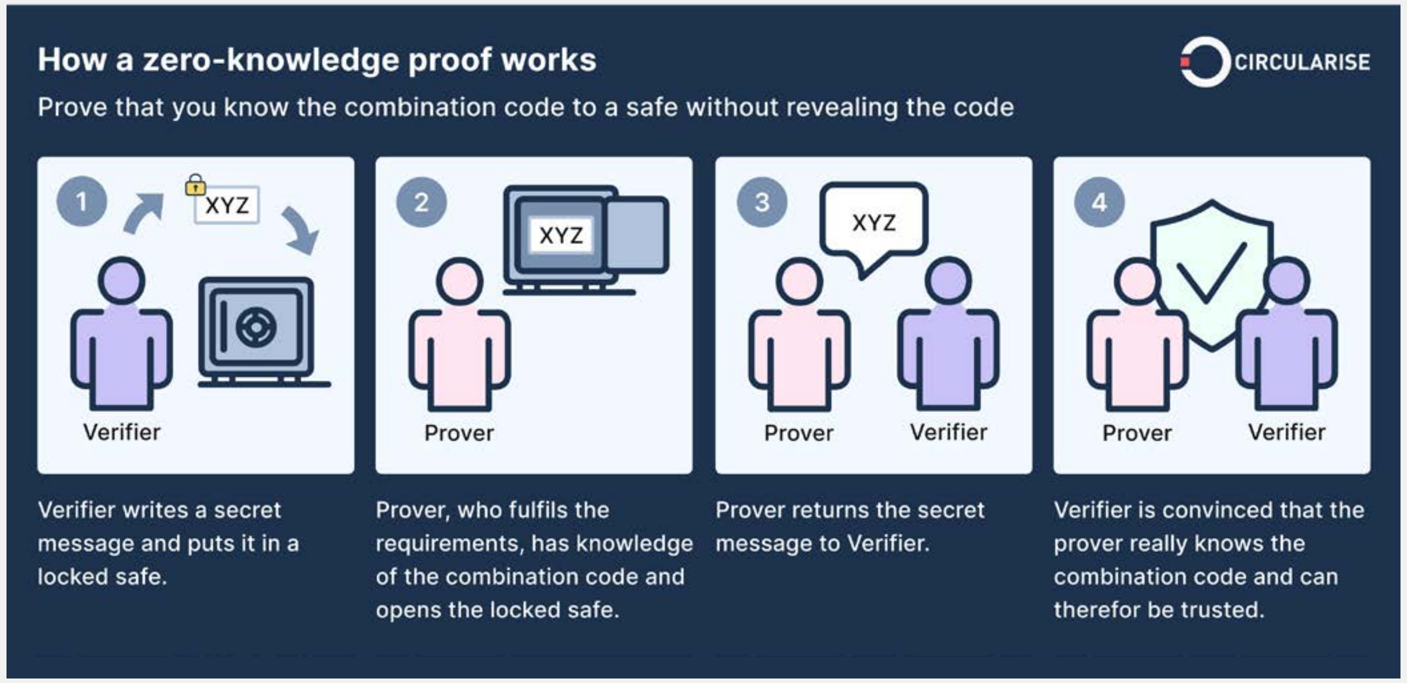
Chain of custody

06/10/2022, 08:10
EV Battery sent [-200 kg] ● CUSTOMER

20/09/2022, 11:26
EV Battery transformed ● B42AA...C12A4 [-400 kg]

08/09/2022, 15:55
EV Battery received [+800 kg] ● SUPPLIER

Scan for Battery Passport



How a zero-knowledge proof works

Prove that you know the combination code to a safe without revealing the code

1. Verifier writes a secret message and puts it in a locked safe.
2. Prover, who fulfils the requirements, has knowledge of the combination code and opens the locked safe.
3. Prover returns the secret message to Verifier.
4. Verifier is convinced that the prover really knows the combination code and can therefor be trusted.

Recycling EoL Batteries & Recovering Precious Materials

From an environmental standpoint, materials recycling is one of the last resorts for scrap and end-of-life (EoL) battery materials, since it requires large amounts of energy and/or reagents to recover raw materials and is always associated with a still considerable environmental footprint, in particular for water and energy use, and GHG emissions. From a circular perspective, it is thus desirable to utilise shorter - and hence more efficient - routes to first slow and only eventually close, the loops on batteries at the very end of their lifespan.

Notwithstanding, recycling LiBs is increasingly paramount as a crucial part of circular value chains for batteries[43]. Not only does inadequate disposal of LiBs pose severe safety and environmental risks, but EoL batteries also contain very valuable secondary resources that can be reclaimed through different processes. In fact, although recycling processes are still quite energy-intensive, the environmental footprint of the recycling of battery materials is still lower than that generated by the mining and refining of an equivalent amount.

Recycling Challenges and Opportunities

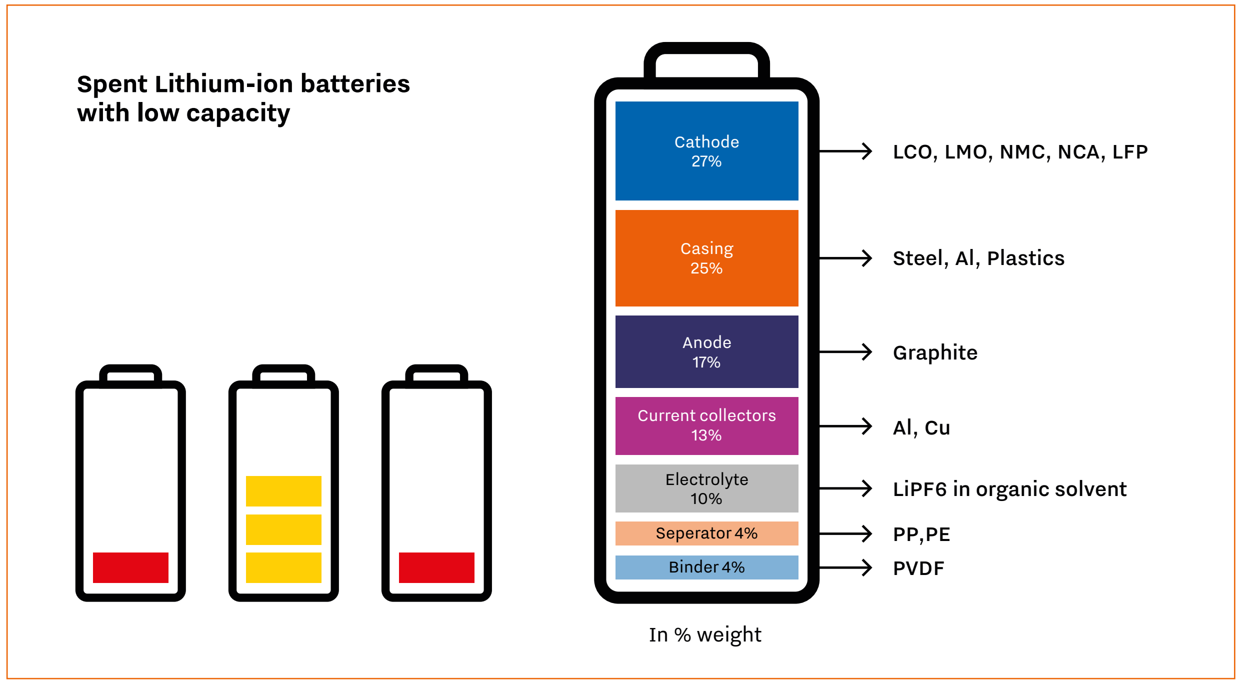
It is the complex materials composition and different cell geometries of LiBs that makes generic, yet comprehensive, recycling extremely complex. Dealing with batteries also requires a high level of precaution due to fire risk from damage or short-circuit. Despite these challenges, there are many incentives for efficient battery recycling, as this can enable:

- improved sustainability over batteries' lifecycle;
- better management of the environmental and safety concerns related to batteries' disposal;
- higher resource recovery rates for CRMs and valuable metals and minerals, with considerable cost savings.

Ultimately, establishing a steady, local supply of secondary raw materials from recycled batteries will effectively increase EU market resilience and independence from third parties. Currently, this is a critical driver for the development of dedicated facilities inside the EU, including in the Netherlands where the company TES has established itself in the Rotterdam port. Given the need to scale up efficient battery recycling, hydrometallurgical recycling routes are becoming increasingly popular. These processes indeed allow the recovery of additional materials compared to the pyrometallurgy route. This trend is already visible, with most of the facilities planned to open in the EU in the upcoming years following this method.

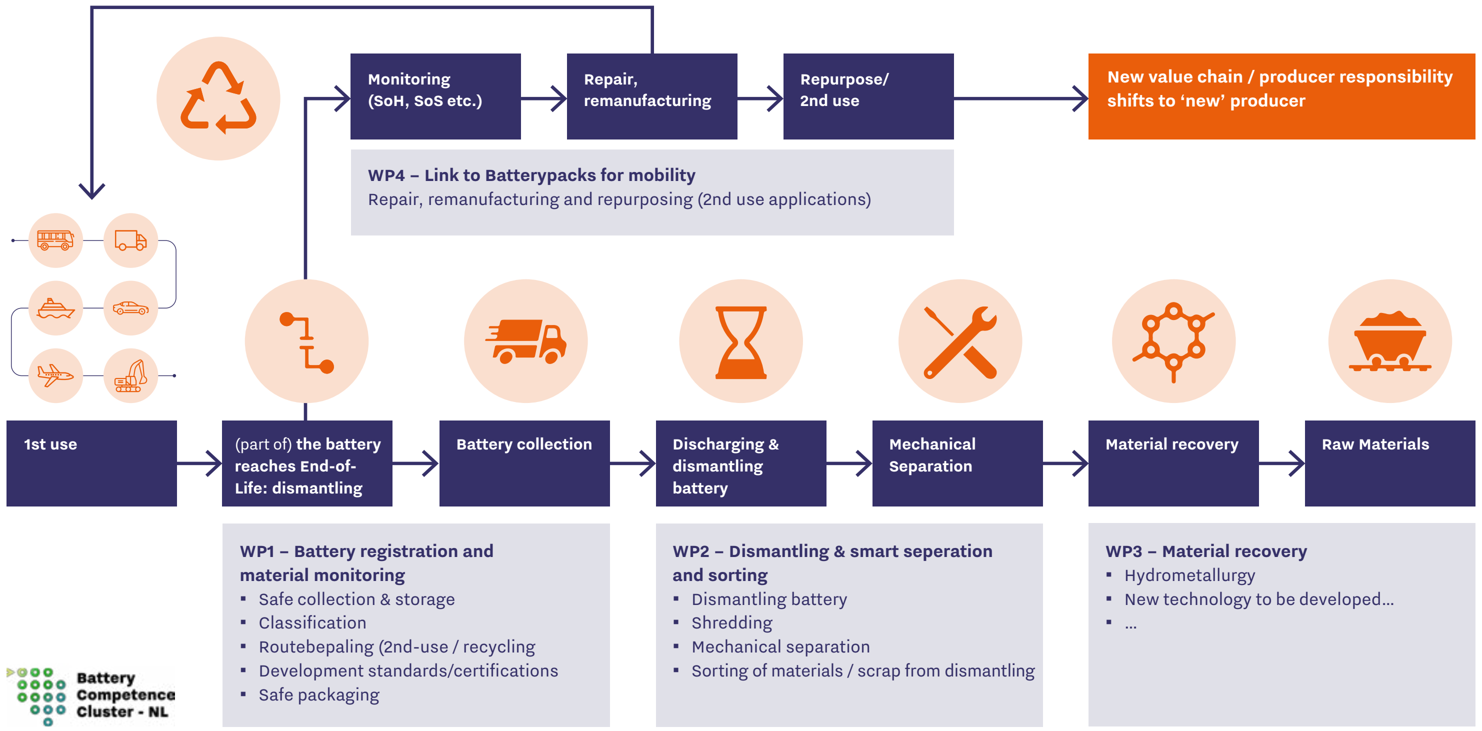
In the last decade, the Dutch LiBs waste collected by local PROs most likely ended up at Umicore, in Belgium, which utilises a recycling process based on a combined pyro- and hydro-metallurgical route. With the EU Battery Regulation[444] coming into force at the end of July 2023, much higher recycling rates will be required in the coming years, as well as the inclusion of recycled materials in the manufacture of new batteries. This is creating a strong momentum for battery recycling and will push investments and technological developments in the field.

Figure 8: The materials inside a battery at end-of-life stage



Source: TU Delft

Figure 9: The process for the recycling of e-car batteries



Source: Battery Competence Cluster

Recycling in Practice: E-Car Batteries

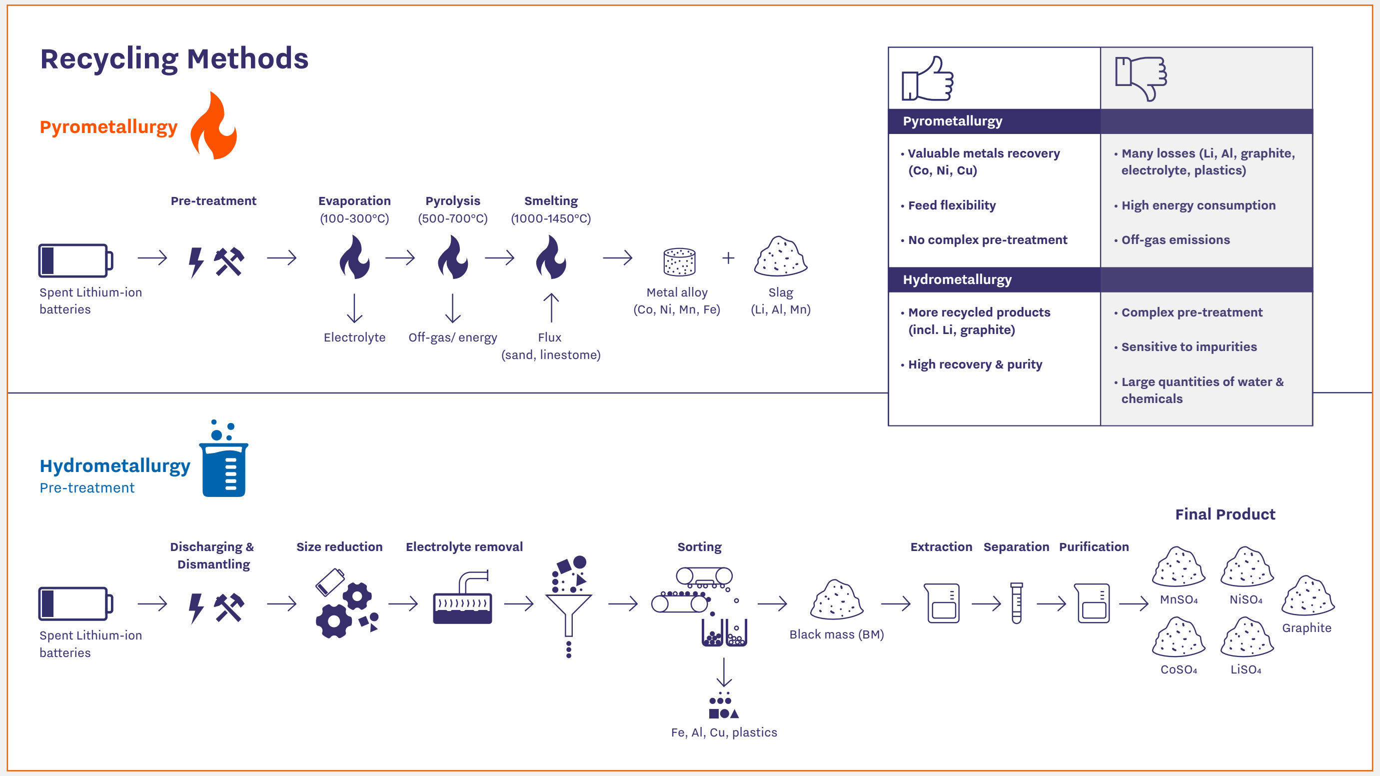
The battery recycling process consists of several consecutive steps that are in most cases carried out by different companies. The recycling process starts with the dismantling of the battery from the vehicle. Depending on its state of health, the battery is either prepared for second life (i.e. for another purpose and use than its original one) or it is treated for recycling and recovery of its materials. Dismantled batteries are collected in accordance with ADR restrictions for transport of hazardous waste. Spent batteries are brought to specialized recycling companies that have the necessary permits to treat them safely.

Propulsion batteries have a high voltage system. To ensure their safe treatment, they are usually first discharged. The battery discharging process and the separation of all wires, casing, electronics, and modules and/or cells are done manually. The modules and/or cells are then shredded, and with a mechanical separation process, the different mix of materials is extracted. The output of the shredding process is the 'black mass', which mainly consists of the active electrode powder.

The black mass is subsequently treated to recover its valuable materials. This can be done via a pyrometallurgical process (smelting) or with a hydrometallurgical process (solvent extraction). The next step is to refine the output fractions of the pyro- or hydrometallurgical processes into materials that can be used as secondary raw materials in the production of anodes or cathodes.

Source: EcarACCU

Common and Emerging Routes for Battery Recycling[45,46]



👍	👎
Pyrometallurgy	
• Valuable metals recovery (Co, Ni, Cu) • Feed flexibility • No complex pre-treatment	• Many losses (Li, Al, graphite, electrolyte, plastics) • High energy consumption • Off-gas emissions
Hydrometallurgy	
• More recycled products (incl. Li, graphite) • High recovery & purity	• Complex pre-treatment • Sensitive to impurities • Large quantities of water & chemicals

Source: TU Delft

Pyrometallurgical Recycling involves a high-temperature route consisting of a few steps. Battery cells are charged into a furnace and the processing starts at relatively low temperature to evaporate the organic electrolyte. Afterwards, all the plastics are decomposed through pyrolysis, providing additional energy to the process. Finally, some of the primary components in the cathode are smelted and transformed into a metal alloy consisting mainly of Co, Ni, and Cu. After further hydrometallurgical treatment to create single or mixed metal salts, these elements can be used as precursors for new batteries.

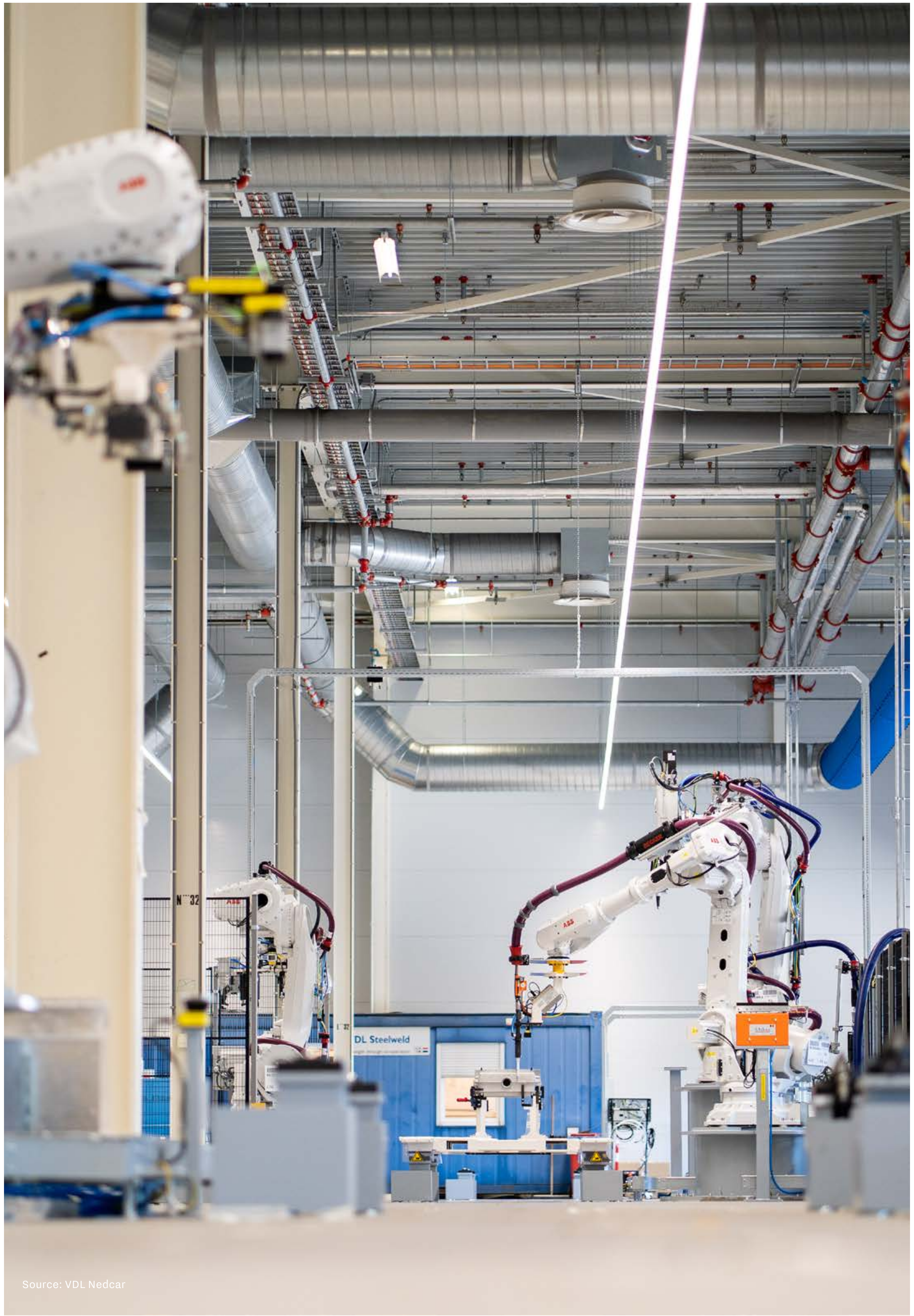
This method is sometimes criticised as it focuses on the recovery of a few strategic metals (Co, Ni, Cu). Other elements such as Al, Mn and Li are instead diluted in the slag, a low value by-product. Several other elements such as the graphite, electrolyte and plastics are also lost, generating large amounts of off-gas emissions (and energy to the process). However, this route does include a large flexibility regarding the range of battery chemistries (LCO, NMC, LMO, LFP, NiM) and only requires minimum pre-treatment.

Hydrometallurgical recycling begins with a much more complex physical (and possibly thermal) pre-treatment designed to segregate various components and materials into concentrated streams for subsequent recovery. On small-scale operations, batteries are initially discharged. On an industrial scale, this step is frequently omitted entirely. Instead, the batteries are directly shredded or crushed into small pieces in an inert or cryogenic environment to reduce their reactivity and therefore, limit fire and explosion risks. It is possible to then extract the electrolyte for recycling. To remove the binder that connects the active materials to the current collectors, either thermal decomposition or dissolution follows. Afterwards, it is possible to use a variety of traditional recycling techniques to separate the battery components into various materials streams, including Steel, Al, Cu, plastics, and finally a fine fraction known as the black mass. The black mass is then treated in aqueous solutions to extract metal ions into solution. To separate and selectively recover the different elements, a combination of procedures is often developed. The two most common methods are chemical precipitation and solvent extraction, both making use of variation in the solubility of elements. The end products are salt compounds that can be directly used as secondary raw materials in the manufacturing of new batteries.

This recycling route recovers a wide variety of products with a high recovery rate (>90 %) and purity (>98%). However, it requires a complex pre-treatment, consumes a large amount of water and chemicals, and is highly sensitive to the nature of the cathode and the presence of contaminants, so numerous treatment stages are often required for purification.

Finally, an emerging alternative named **direct recycling** involves a shorter variation of the hydrometallurgical route. The composition of the extracted solution is modified to directly co-precipitate the required chemistry (in the desired morphology and crystal structure) for remanufacturing of cathode materials. Although the direct regeneration process is relatively simple, impurities in the waste stream and damages to the structure will affect the electrochemical performances of re-synthesised materials. This method is therefore well suited for the recycling of production scrap, but requires highly refined inputs of spent LIBs streams, which is currently difficult to achieve on an industrial scale.

Source: Stibat



Source: VDL Nedcar

The Netherlands: Paving the way towards the circular batteries of tomorrow

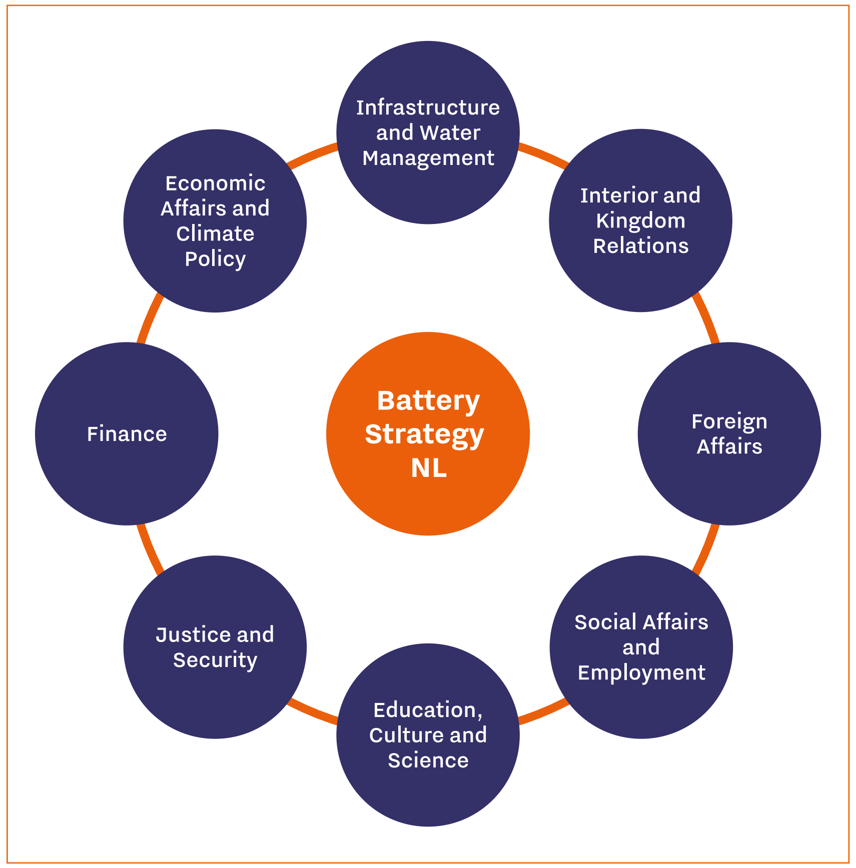
With a strong focus on fostering public-private partnerships and enlarging R&D investments, the Netherlands is establishing itself as a key innovator in the global battery value chain.

A pioneer country in the field of circular strategies and innovations, the Netherlands is committed to a climate positive future and actively supports investments to accelerate the clean energy and mobility transition. Developments towards a climate positive future are directed through targeted actions and regulations at both national and international level.

Circularity is an important overarching policy theme for the Dutch Government. The Netherlands strives to have a circular economy by 2050, while already in 2030 the goal is to achieve a 50% reduction in the use of primary raw materials. In 2022, the Dutch government also published a **raw material strategy** (see page 67), to ensure the availability of sufficient raw materials and achieve strategic independence. Examples of ways to improve the latter include: diversification of imports; substitution of critical materials; and circularity.

Furthermore, as an EU member the Netherlands actively supports supranational policies and legislations in this field, such as the **EU Battery Regulation (2023)** which represents a major milestone towards battery circularity, as well as the **European Critical Raw Materials Act**.

Figure 10: The government-wide approach in the Dutch Battery Strategy (2020)



Source: The Netherlands Ministry of Infrastructure and Water Management

The Netherlands Strategic Approach on Batteries

In light of the vitality of batteries for the energy transition, the Dutch government started a national strategic approach on batteries in 2020 - the **Dutch Battery Strategy** - where circularity plays a key role. The strategy recognises that focusing on circular battery design is necessary for two reasons. First, to minimise the ecological and carbon footprint of batteries across their lifespan. Second, to reduce the amount of virgin raw material extraction.

The central aim is ensuring that the increase in battery usage in the society is safe, responsible and sustainable, and that the opportunities that arise from it are leveraged. Eight out of twelve Dutch Ministries and several other government organizations collaborate in this integrated and coherent approach.

The governmental strategy is organized around the following pillars:

1. **Raw Materials**: with the goal to foster the availability of raw materials in a responsible and sustainable manner. This is achieved e.g. by promoting responsible mining, the development of a National and European Battery Passport, or by stimulating innovation in alternative battery chemistries.
2. **Circular Economy:** circularity is important for long-term sustainability as well as for increasing access to CRMs. Refurbishment, repurposing and recycling are thus key strategies.
3. **Safety:** to ensure a safe use of batteries in society, the government supports the development of know-how on risks and safety. Relevant insights are then used to adapt and update relevant regulation, and to inform relevant actors like government bodies, companies, professionals and end-users on safety risks and measures.
4. **Economic Opportunities:** the goal is to foster innovation leading to safer, more sustainable and higher performance batteries, while creating a thriving battery ecosystem in the Netherlands that is well integrated with the European value chain and competitive on the international market.
5. **Energy System:** the government supports knowledge development and adapts policies accordingly, fostering the role of batteries in supporting the energy system. For example, by adjusting regulation (e.g. energy tax) to facilitate the role of batteries in providing flexibility to electricity grid operators. Here, batteries can be both stationary and from vehicles through vehicle-to-grid applications.

Governments at different levels play an important role in stimulating and ensuring the path towards circular batteries, for which pillar 1, 2 and 4 are particularly relevant. Each pillar has several underlying actions, which are continuously updated and whose progress is annually reported. Actions include: creating new legislation or improving existing one; providing (financial) support; and increasing transparency.

Source: Battery Competence Cluster

Fostering Innovation through targeted Investment Funds

With the **National Growth Fund** initiative, the government invests in fields showing the highest potential for structural and durable economic growth.

The most important investment program for the battery sector, called ‘Material Independence & Circular Batteries’ is part of this initiative. This is an 8-year national innovation program devised by the ecosystem ‘Battery Competence Cluster NL’, together with the Ministry of Economic Affairs and the Ministry of Infrastructure and Water Management. It is part of a long-term national battery strategy and aimed at supporting R&D in the field of circularity and sustainability in the Dutch battery value chain.

Recently this program was approved (under conditions) to start in 2024. This will translate in the commitment of several industry and public parties to invest around €800 million - including €296 million in government subsidies. The primary aim of the plan will be to establish recycling capacity in the Netherlands and further develop circular batteries.

Other Relevant Netherlands Subsidy Programs

1. **BatteryNL:** Developing safer next generation batteries with higher energy density and longer lifecycle. Grant: NOW-ORC, Project budget: € 9,3 million. Period 2023-2031.
2. **Inland Shipping:** The investment will be used for the development of 77 battery containers for maritime application (ZES-packs), 14 docking stations where the ZES-packs are loaded and 45 electrified inland vessels. Grant National Growth Fund, €50mln subsidy and additional company investments. Period 2023-2031.
3. **NXTGEN Hightech:** Developing new types of battery production technologies. New generation equipment for batteries and materials. Grant National Growth Fund, €64.17 mln subsidy and additional company investments. Period 2023-2031.
4. **Material Independence & Circular Batteries:** Sustainable battery technology and a circular value chain. Grant National Growth Fund, around €800 million, of which €296 mln subsidy. Period 2024-2032.

Public-Private Partnerships for an innovative Dutch Battery Ecosystem

Under the battery strategy, the Dutch government specifically seeks cooperation with companies, universities and knowledge institutes to create public-private partnerships. With this aim, the Battery Competence Cluster NL (BCC-NL) was launched in 2022 as the first ecosystem of its kind in the country. Through this cooperation the Netherlands can operate even more effectively towards circular batteries.

BCC – NL is the innovation program for companies, knowledge institutions and organizations that want to work together to exchange knowledge and develop skills in the field of battery technology. Three major Dutch economic sectors - battery, transport and energy - joined the cluster to devise a national action agenda and implement it through a series of projects and funding initiatives.

How the Battery Competence Cluster NL Works

The Ecosystem develops activities to acquire knowledge and increase Dutch competitiveness in the global battery value chain by:

1.
Ecosystem development: connecting Dutch companies with foreign parties to jointly address challenges and projects and focusing on knowledge and collaboration togenerate new business ideas and opportunities.

2.
Strategy formation: cooperating with diverse actors to identify the right challenges and opportunities and draw up technological roadmaps. The National Battery Systems Action Agenda is an example of this.

3.
Innovation collaboration: investing in shared R&D facilities to save costs for a large number of companies in the Dutch battery chain. Developing battery technology is complex and costly, since lots of testing and pilot production is needed to show that the technological compositions work.

The Netherlands has strong competences in several parts of the battery value chain, like heavy-duty mobility, material science for next generation batteries and high-tech equipment. The BCC-NL aims to use and combine these strengths to strategically position the Netherlands in the global battery value chain, create economic value and enhance sustainability.

The ambition is to create a leading circular battery value chain with a focus on the development of new battery technology for niche applications like heavy-duty mobility and bulk batteries. Sustainability and circularity are at the centre of all developments in order to create access to critical raw materials in the Netherlands. This means that circularity is integrated throughout all developments in the value chain, such as cell design and pack design, by taking into account the recycling processes. The expected results are a unique position within the international battery value chain, reduced dependence on the international supply chain (critical raw materials), and the preservation and growth of national employment and industry.

Fostering Battery Collection & Recycling through EPR

Another field in which the Netherlands has invested to support battery circularity is **extended producer responsibility (EPR)**.

EPR has been recently included in the new EU Batteries Regulation (2023), which increased the collection targets for portable batteries (45% as a percentage of the average weight of batteries put on market in the previous three years before 2024, 63% before 2028 and 73% before 2031) and for batteries for light means of transport (51% by 2028, 61% by 2031). A new target for lithium recovery from waste batteries (50% before 2028, 80% before 2032) was also set.

How does EPR generally work?

Through a mix of policy instruments, governments at different levels can effectively make manufacturers accountable for the environmental costs and impacts of their products at end-of-life[47]. Around the globe, different EPR schemes - both voluntary and mandatory - have long applied to product groups such as batteries, cars and vans, packaging and electronics, and more recently to textilesand single-use plastics[48].

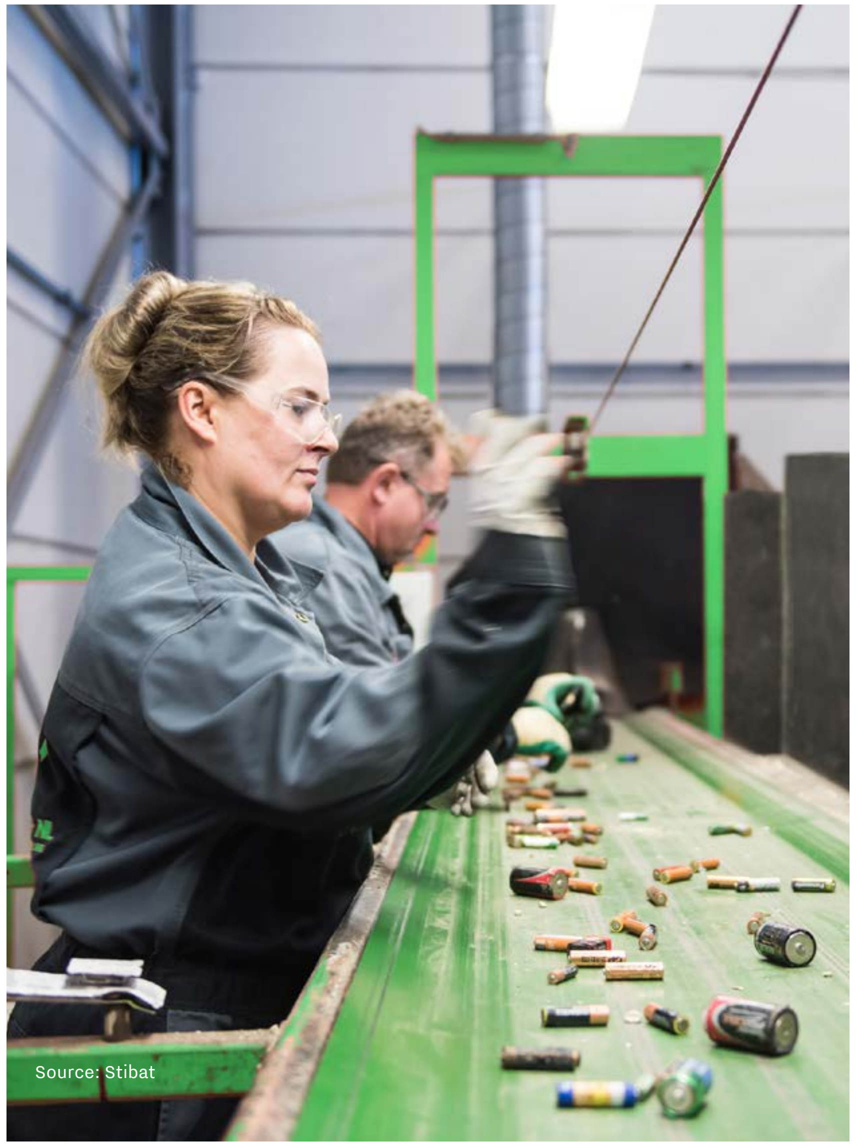
EPR approaches are in line with the 'polluter pays' principle. The costs of a product's end-of-life management from collection and sorting to recycling are reflected in its price, with the long-term ambition to stimulate an environmentally friendlier product design, through e.g. design for durability, reuse and recycling[49].

How does EPR work in the Netherlands?

Dutch EPR schemes for batteries and accumulators are very well established. They were first introduced in 1995 and included in the Dutch regulation management in 2008, following the EU Batteries Directive 2006/66/EC. The Directive - which is in 2023 repealed by the new Batteries Regulation 2023/1542 - set quantitative collection and recycling targets for batteries, varying by application and chemistry. Collection targets are defined based on the average weight of batteries put on market in the past three years, while recycling targets are based on the weight of collected batteries. Over the years, EPR has helped enhance collection rates and customers' awareness, rendering separate collection of batteries a standardised activity nationwide. Rules apply to the actors introducing these products to the Dutch market, i.e. producers and importers, who are then financially and organisationally responsible for their products across their lifespan[50].

The separate collection and responsible end-of-life treatment of batteries is financed through fees paid by consumers when purchasing a battery, or a product with an incorporated battery. The fees levied for lithium batteries are generally higher than the fees levied for counterpart batteries of other chemistries (e.g. lead-acid, nickel-metal-hydride), reflecting the relatively limited current potential to recycle lithium at reasonable costs[51].

There are three distinct Dutch producer responsibility organisations (PROs) tasked with fulfilling EPR requirements in practice. Stichting Stibat for portable batteries, Stichting Auto & Recycling (ARN) for starting, lighting and ignition, light means of transport (excluding electric bicycles) and electric vehicle batteries, and Stichting Epac for electric bicycle batteries. All 3 also work towards increasing consumers' awareness on proper disposal, as a means to streamline collection and prevent improper disposal and pollution[52].


Source: Stibat

Stichting Stibat Services for portable batteries

Since 1995, producers and importers of portable batteries have been working together as Stichting Batterijen (~1.700 participants). Producers and importers of bicycle batteries followed suit in 2015, joining forces as Stichting EPAC (~150 participants). Stichting Stibat Services carries out the statutory tasks for both foundations when it comes to producer responsibility. Starting in 2024, Stibat Services will merge with PRO E-waste Netherlands (OPEN), with the aim to strengthen its operations.

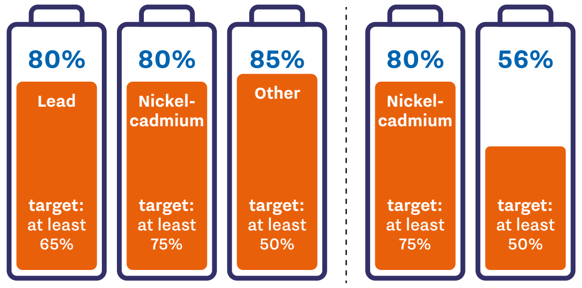
Recycling efficiency Stibat Services focuses primarily on the recycling of batteries. The latest and most efficient recycling technologies are used (provided that they are not excessively costly) in order to recover as many metals as possible and optimise the environmental performance. Stibat Services only works with recyclers who have a valid permit and meet the strictest quality standards. Every year, Stibat Services draws up a detailed report that reveals whether the prescribed recycling efficiency was achieved and whether the proper processes were used, according to the Ecotest. The recycling efficiency targets are amply met.

With the new Battery Directive, the European Union is further refining its legislation pertaining to the recycling of batteries. This includes, among other things, the recycling percentage for scarce resources such as lead, lithium and nickel-cadmium, which will go up to 75%, 65% and 80% respectively. This further improves the circularity of batteries.

Recycling results

The realised reycling percentage for portable batteries in 2022

The realised reycling percentage for bicycle batteries in 2022




Source: Stibat

Circular initiatives In collaboration with Refurb Battery, Stibat Services started a pilot in 2023 to give bicycle batteries a longer life. The usable cells from discarded bicycle batteries are reused in a new product with a different application: energy storage. With this repurposing initiative, Stibat Services explores the possibilities to not only contribute to the waste phase of batteries, but also to extend their lifespan.

REFURB BATTERY

In 2021 Refurb Battery with Stibat Services and Accell Europe piloted a safe and efficient process to dismantle eBike batteries and harvest battery cells for reuse in stationary storage solutions. Refurb Battery now harvests cells from thousands of batteries each month. They test and then reuse these battery cells in storage solutions such as its 350 kWh energy storage container which it rents out to business users. These products are designed for circularity, so when battery cells ultimately reach their end of life, they are replaced and the reuse of all other materials is maximized. Refurb Battery won the Rabobank Duurzame Innovatie Award 2023.

refurb.battery

Ecotest

Stibat Services developed the Ecotest based on the principle that 'knowledge is power'. This test maps out how environmentally-friendly and efficient the various processes are being conducted. For example, all truck drivers are ADR certified for the safe transportation of hazardous substances and the trucks are set up in accordance with applicable legislation. Furthermore, Stibat Services has obtained an ISO 9001:2015 certification and maintains thorough reporting standards.

Ecotest

Portable batteries	Bicycle batteries
In 2022 **190 million kilos** of toxic emissions were prevented from being released.	In 2022 **41 million kilos** of toxic emissions were prevented from being released.
And **2.6 million kilos** of carbon emissions were avoided.	And **656 thousand kilos** of carbon emissions were avoided.

Stichting Auto & Recycling (ARN) for LMT & EV batteries

ARN serves as the Dutch PRO for automotive/mobility industry batteries. Through their Battery Management plan, ARN meets the legal obligations stemming from the Dutch interpretation of the Battery Directive 2006/66/ec on behalf of Dutch importers. This directive will soon be superseded by the Battery Regulation introduced in July 2023.

The Battery Management plan is a collective voluntary system, whereby importers that introduce battery-equipped vehicles to the market — such as cars, trucks, buses, motorcycles, or mopeds — and their corresponding batteries, actively participate. Funding for this plan comes from a fee levied on every battery introduced to the market. This fee is assessed annually in close collaboration with the Dutch importer association, RAI Vereniging, and is designed to cover both current and prospective costs associated with the collection and recycling of batteries in Dutch vehicles.

Coordinating Operations

ARN oversees the collection and recycling of end-of-life batteries by collaborating with collection and recycling companies. Batteries that remain viable are transferred to specialised Dutch firms for potential second-life applications. When this occurs, the original producer's legal responsibility concludes. Batteries deemed unfit for reuse are instead dispatched to European recycling entities. As of now, the Netherlands lacks the capacity to recycle Li-Ion batteries. In 2022, while 24% of batteries found a second-life application, 76% were recycled. Over recent years, fewer batteries were repurposed for second-life uses, but a recycling efficiency of over 80% was reached. In 2022 alone, 113kTon of batteries were recycled.

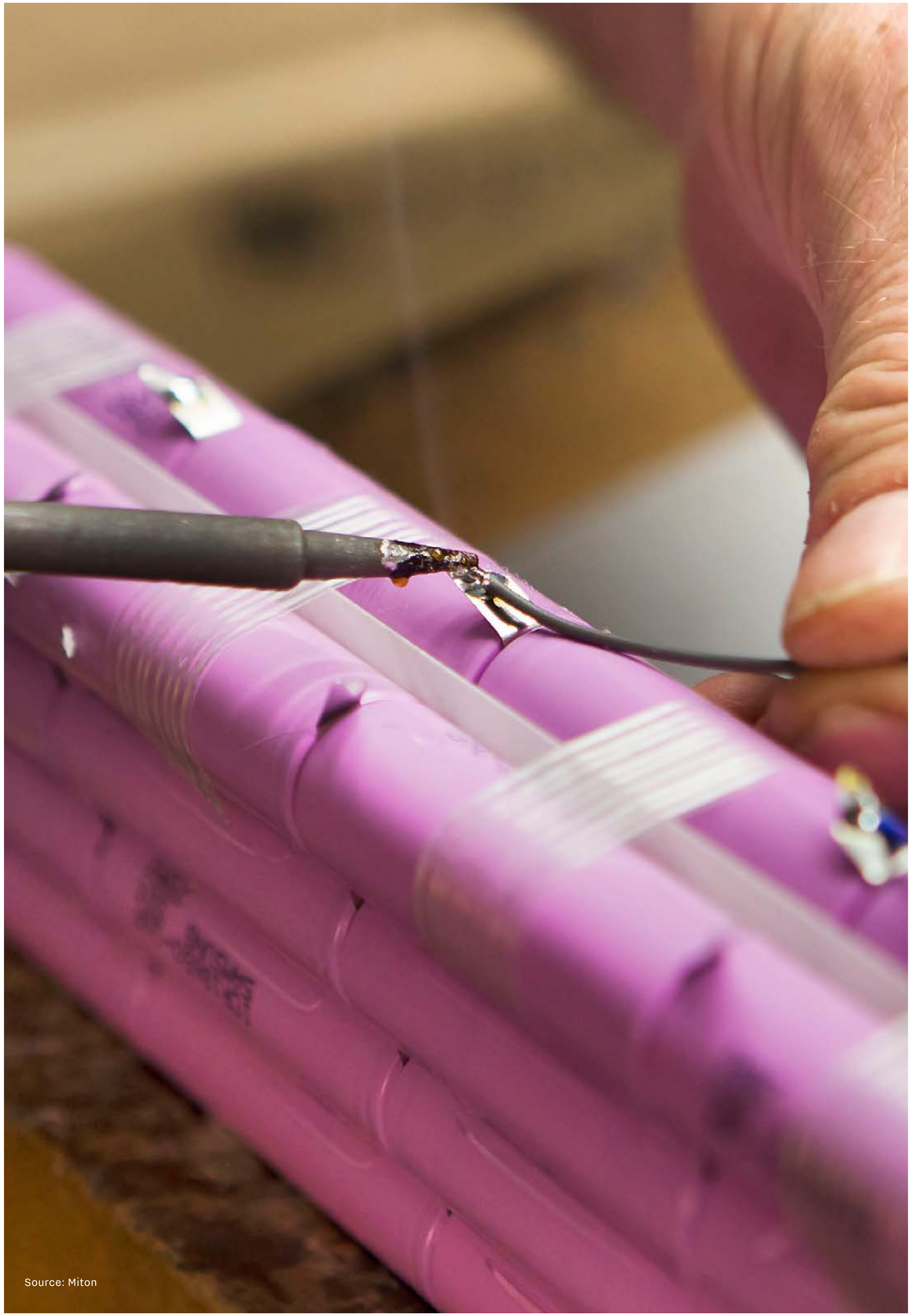
Predominantly, end-of-life batteries are collected at dealerships and garages, with a minor percentage sourced from aged or total loss vehicles. ARN anticipates a significant surge in end-of-life batteries in the coming years. This is because since 2011, hybrid and electric vehicles have been more prevalent in the market, bolstered by Dutch government subsidies. While many combustion engine vehicles, as well as EVs/hybrids, are exported, a considerable number remain active on Dutch roads. Predicting the lifespan of an EV battery is challenging, but latest data suggests a durability of over 10-12 years.

Safety Trainings

To future-proof operations, ARN is launching training programs for car dismantling companies. These firms will be tasked with safely removing batteries from end-of-life vehicles in the near future. Specialised training is imperative to ensure the safe and environmentally-sound handling of these high-voltage batteries. A certification initiative is underway to ensure that dismantlers adhere to safety protocols for the disassembly, storage, and management of these batteries.


Source: ARN

Source: ARN



Source: Miton

Chapter 3

The Dutch Best Practices fostering a circular battery value chain

We have selected some of the leading Dutch best practices when it comes to circular batteries for e-mobility, energy storage and consumer electronics. Although not exhaustive, this account of pioneering companies and initiatives shows how thriving the Dutch circular battery sector is.

Pioneering examples of successful circular strategies, services and products can be found across the Dutch battery value chain. Each of the companies and public or private initiatives showcased here exemplifies one or more of the battery R-strategies presented in the last chapter.

In the following sections, you can discover companies young and new working on topics as varied as circular design, remanufacturing, logistic services and energy supply. We have cluster them in the following categories:

- **Research & Development and Knowledge Exchange**
- **Circular design, manufacturing & logistics**
- **Repair, reconditioning and remanufacturing**
- **Circular energy storage**
- **Recycling & recovering - consumer electronics**

Research & Development and Knowledge Exchange

R&D efforts into new and improved battery compositions and chemistries are crucial to move away from CRMs, polluting and hazardous substances and processes, and linear business models.

These Dutch initiatives and research and knowledge platforms are bringing technology and circular strategies forward by fostering exchange, experimentation and international collaboration. This way, they all contribute to directly tackling the top R-strategies in the ladder - Refuse, Rethink, Reduce - and indirectly, also all the other ones.

BATTERYLINE.COM

Batteryline.com is a community of international experts and partners specialising in the manufacturing of lithium-ion battery cells and packs, and in their reuse and recycling. Together, they foster a collaborative environment where knowledge and development projects are exchanged, propelling the industry forward. The ambition of Batterline is to scale up high performance and sustainability of battery production so as to enable greener impact and innovation. By connecting with multiple partners in battery manufacturing, the platform has facilitated innovative projects in the field. The platform aims at sharing knowledge and information through related blogs, articles, and webinars with machine builders, battery makers, and solution providers. This way, it creates networks to help consumers and end-users in the field, while embarking on a transformative journey where expertise, innovation, and sustainability converge, shaping the future of the battery manufacturing industry.

www.batteryline.com

BATTERYNL

BatteryNL is funded by the NWA-ORC programme of the Dutch Research Council. The consortium gathers senior experts and scientists from multiple stakeholders groups, from academia, high-tech startups and multinationals to societal partners. Their aim is improving the safety, energy density and lifecycle of Li-ion battery technology, as demanded by a society increasingly based on renewable energy sources. To realise this, the researchers of BatteryNL investigate the heart of batteries - the electrolyte-electrode interface - with the aim to reveal the relative bottle-neck processes, and improve these with scalable interface technology. The successful integration of new generation battery materials and technologies however requires accurate analysis of costs and sustainability developments, detailed consideration of safety aspects, technology integration through collaboration with manufacturers and knowledge institutions, and interaction with stakeholders. By working side by side and exchanging knowledge and insights also with relevant European partners and stakeholders, BatteryNL creates a crucial position for the development of next-battery technology.

www.batterynl.nl

Source: Circo

CIRCO

With support from the Dutch government and through design thinking, CIRCO assists companies in (re)creating circular business propositions in cooperation with their value chain in four sectors: construction, plastics, consumer goods and manufacturing. In the field of batteries, CIRCO is focused on enabling Dutch companies to stay a step ahead and take advantage of the opportunities arising in this growing market, always with a circular approach. The team focuses on value creation in the battery use phase, where the existing challenges (value loss, decreasing power capacity, etc) can be turned into business opportunities for the extension of the battery lifespan. Two EV battery tracks have been completed. Each involved ten companies evaluating how each other's business case could become circular without adding materials or producing waste in the process. The main findings showed agreement on improving the whole battery, its battery management system and the reuse of single cells, and also on strengthening value chain collaboration.

www.circonl.nl/english/

THE RESOURCES SCANNER

This web-based tool enables companies and entrepreneurs to assess and improve supply chain risks for their products and materials. Industry actors can discover to what extent the materials they depend on pose a potential risk to their business, to the people in their supply chain and to the natural ecosystems. The assessment is based on security of supply, price volatility and the conditions under which the materials are produced. Action perspectives are presented to mitigate the supply chain risks. The tool is available in Dutch and English and is supported by the Ministry of Economic Affairs. Such knowledge and understanding is crucial for the battery supply chain, which depends heavily on scarce raw materials with often high socio-environmental footprint.

www.grondstoffenscanner.nl/en

E4BATTERY DELFT

E4Battery is an open research network bringing together 100+ researchers from all faculties at TU Delft. Their combined expertise covers the entire battery value chain, creating a unique environment to advance progress in sustainable battery technologies. Their mission is enhancing battery performance, reducing dependence on CRMs and using a circular design and engineering approach to enable battery use, reuse and recycling. Their research programs focus on developing battery systems that are smart, resilient, safe, economically viable and fully integratable. For this, e4Battery hosts state-of-the art infrastructure, collaborating with both public and private partners. Several facilities for the testing and validation of battery technologies are part of the network and situated within the TU Delft innovation ecosystem. These include the Battery Lab for material development, processing and assembly; the Electrical Sustainable Power lab featuring digital twin and various environmental control chambers for battery testing; and the 24/7 autonomous living lab at The Green Village for novel battery systems implementation.

https://www.tudelft.nl/en/2023/e4batterydelft/tu-delft-focuses-on-battery-of-the-future

Circular battery design, manufacturing and logistics

From consumer electronics to heavy-duty applications, batteries and their design and manufacturing must be reviewed in order to address the downsides of production and material extraction. Equally, the way in which we move these quite dangerous goods across nations and borders must be future-proof for enhanced safety and increased recycling and recovering potential.

The companies showcase how technological innovations and developments in a circular perspective can deliver profitable and scalable solutions to the battery value chain and for multiple applications.

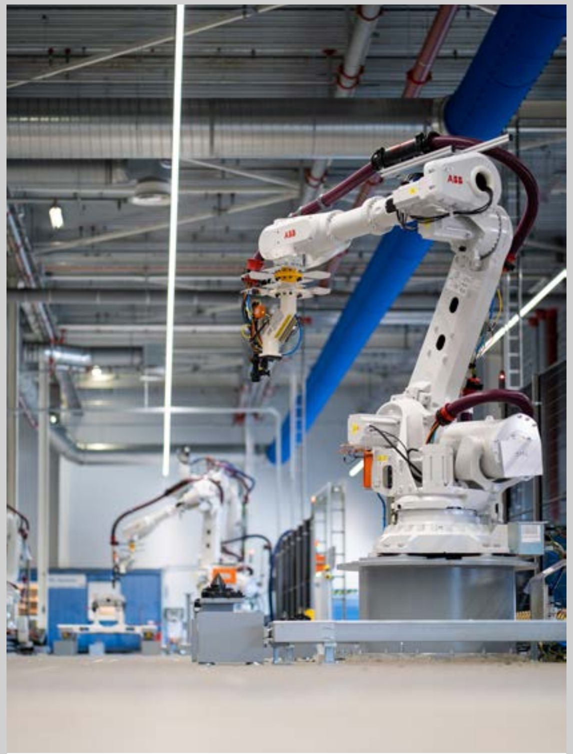
Source: Fairphone

FAIRPHONE

As an international leader in sustainable smartphone manufacturing, Fairphone is committed to significantly reducing the environmental and social impact of their phone batteries. The recently released Fairphone 5 is an example of the company's ambitions and mission. Its battery is entirely replaceable, in line with the company's modularity, repairability and longevity goals. It also contains 100% lithium from an IRMA-audited mine site, 100% recycled tin solder paste, 80% recycled steel, 75% post-consumer recycled plastics, and 100% Fairtrade gold across the supply chain. Additionally, 100% of the cobalt and silver employed is matched with Cobalt Credits and Fairmined Silver Credits. These initiatives enable Fairphone's consumption of these materials to contribute to the living and working conditions of artisanal and small-scale mining communities producing an equivalent amount of these materials. Simultaneously, the workers involved in battery assembling receive a living wage bonus and are part of a 'worker voice' programme established at the battery supplier. The latter has also set CO2 reduction targets in line with the Science-Based Target Initiative and is undergoing strict social auditing. Furthermore, their battery supplier is planning to produce the battery with 100% renewable energy from 2024 onwards.

www.fairphone.com

FAIRPHONE



VDL

Founded in 1953, VDL Groep is an industrial company with global presence developing machines, components and total solutions for different sectors, including mobility. The group is a founding partner of the Battery Competence Cluster - NL and is fostering sustainable battery development through multiple projects. Their strategic focus is on the production of low-volume, high-complexity battery systems (cell-to-module, module-to-pack) for the automotive and heavy duty (e.g. trucks, buses, maritime) sectors. Additionally, VDL leads other initiatives in collaboration with multiple stakeholders. For example, as part of the Green Transport Delta - Electrification project, VDL is working on a flexible and scalable battery production environment, where up to 6 complex battery packs of multiple customers can be produced on one single line. VDL is also setting up an ICAI lab in collaboration with Maastricht University to build a broad expertise in Machine Learning and AI and create a thriving hub for sustainable battery process and production technology. These activities fit VDL's ambition to develop and build innovative and sustainable mobility concepts and are supported by the VDL Mobility Innovation Centre.

www.vdlgroep.com/en

VDL

VAN PEPERZEEL

Van Peperzeel (VP) offers reverse logistics services such as battery storage, repacking and transportation to PROs in the Benelux area. The company sorts all the portable batteries collected by Stichting Stibat and ships them to their chosen recyclers in Europe. A delicate task for which VP transporters are specifically trained. Every year, VP processes ~ 5.000 tons of all kinds of portable and industrial batteries, ~ 15.000 tons when including Lead Acid batteries. In 2017, VP developed special storage containers for Li-ion and Lithium primary batteries. These are equipped with special fire suppression systems, which ease fire risk management during Li-ion batteries storage. The containers are a pioneering product certified by KIWA. Currently, VP is also investigating the automation of the battery sorting process via AI technology, aiming at launching operations by mid 2024. VP is now undergoing the renewing of the permit at their Lelystad facilities, where they plan to remain for the coming 10 years.

www.peperzeel.nl/en

VAN PEPERZEEL
NON FERROUS METALS / BATTERY RECYCLING

Source: Powall

POWALL

Powall develops next generation nanocoatings for energy applications at scale. Their proprietary continuous gas-phase technology, a game-changer in the protection of powders, plays a big role in the conversion and storage of energy, powering the energy transition in close collaboration with our clients, unlocking their maximum potential. As technology advances, there is a constant need for better performance, lower costs and more sustainable solutions. Powall nanocoating on battery materials (cathode and anode active materials) has demonstrated to significantly improve battery lifecycle. Precise deposition of Platinum Group Metals (PGM) enhances coated catalyst reactivity and performance for PEM electrolisers and fuel cells. As a result, it reduces the usage of these expensive and scarce raw materials. The company coats powder materials of clients from 12+ countries and recently secured investments to accelerate growth and R&D towards new applications.

www.powall.com

Repair, reconditioning and remanufacturing

Extending the lifespan of batteries by repairing them and enabling their reuse in the same applications as the original or in for other purposes is key. These strategies, processes and business models slowing the loop on batteries in fact ensure that materials are kept in use and considerable amounts of waste are avoided.

From reuse to repair, refurbish, remanufacture and repurpose, these companies all have found their own unique way to give batteries from e-mobility a second-life. This ensures affordable and sustainable solutions for customers, who no longer need to replace their ageing batteries with completely new ones.

ECARACCU

EcarACCU has created an innovative process to refurbish lithium-ion batteries used in EVs and currently reuses ~100 tonnes of battery cells annually. Their system can recover, reuse and recycle up to 98% of multiple battery packs that would previously be rejected for reuse. This extends the life of hybrid and EV batteries by five to ten years. The process starts with battery dismantling. Inner materials such as metals and plastics are recycled by EcaACCU partners. The battery cells are tested for reuse. Several products can be created from refurbished EV batteries. Often they are used for energy storage with a new management system. For example, off-grid street lights with solar panels on the outside and a battery storage system on the inside and EcarPOWER trailers that can be rented to supply off-grid energy during events and festivals, for film productions, at construction sites and more.

www.ecaraccu.nl

Source: EcarACCU

BNA-BATTERY

In 2018, the founders of BNA-Battery developed a software to test on different characteristics the cells inside Nickel Metal Hydride (NiMH) battery packs from hybrid cars. Through this process, broken or weak cells can be identified and individually replaced with better ones. The original frame and electronics are maintained, whilst cells are usually replaced or processed for further recycling when they cannot be restored or reused. By doing so, the company can expand the lifetime of a NiHM battery by two to four years. Today, BNA-Battery gives a second life to ~150,000 cells annually. This is approximately 1000 battery packs and results in significant savings in raw material use. Currently, the team is working on expanding capacity as increasingly more NiMH battery packs reach their end-of-life in hybrid cars. They also strive for a collaboration with the major car brands to ensure that each battery is first refurbished before it ends up in recycling.

www.battery-bna.com/en

Source: Heskon

HESKON

Since 2017, Heskon BV specialises in reconditioning, repairing and testing small EV batteries. The company focuses on different phases of the battery life-cycle, from right after the battery is installed to its end-of-life. Their service is offered to both individual consumers and manufacturers and sellers of e-bikes, pedelecs and e-scooters. Batteries that would normally be replaced with new ones after 4-6 years due to their low residual capacity, are rebuilt by Heskon with an average extension of the total battery lifespan of 5 years. During the rebuilding process, all the original electronic components of the circuit board and the casing remain untouched, and the parts that are not directly suitable for reuse in EVs are processed for applications elsewhere. More than 30.000 EV batteries from the Netherlands and Belgium have been successfully rebuilt since 2019, making the company the largest service provider in these markets.

www.heskon.nl

JOHAN CRUIJFF ARENA

The Johan Cruijff ArenA in Amsterdam owns one of Europe's largest energy storage systems in a commercial building. Situated in the Netherlands' biggest multifunctional stadium, the 3 MW storage system provides a reliable energy supply for the stadium, visitors and the Dutch energy grid. This combination of specialised energy distribution and storage systems, consisting of 148 second-hand Nissan LEAF batteries, ensures both a sustainable energy storage and a second life for EV batteries. The system plays a crucial role in balancing the ArenA's energy supply and demand. It is sufficient to power several thousand households with electricity and to store the energy produced by the +4,200 solar panels on the stadium's roof. This provides backup power, reduces the use of diesel generators and eases the pressure on the grid by smoothing out the peaks that arise during events or concerts. This contributes to the stadiums' goal of being Net Positive by 2030 and completely and positively transforming its socio-environmental impact by giving back more than it uses.

www.johancruijffarena.nl/ennet-positive/

MITON

Miton has over 20 years of experience in the refurbishment of NiCD, NiMH and lithium-ion e-bike batteries. The company reconditions dozens of e-bike batteries daily, from 170 different brands. They work for private end-users as well as business customers, such as bicycle manufacturers, dealers and repairers. When batteries age or lose capacity, Miton replaces their cells and returns them to customers like-new. The team tests the battery packs to check whether the residual capacity can be improved via refurbishment. By replacing only the inner battery cells (and when needed the electronics), costs and materials are saved compared to making a completely new battery. Particularly, for batteries that are no longer in production, which makes their respective bikes unusable. The old cells are disposed safely via Stibat and those battery parts still in good condition - such as plastic or metal housing and contact points - are reused to make the refurbished pack.

www.fietsaccu.nu

NOWOS

With operations in the Netherlands and France, NOWOS builds on decades of battery manufacturing experience and works to treat lithium-ion batteries not as waste but as a valuable source for secondary raw materials. It promotes sustainable practices in the lithium-ion battery industry by repairing and refurbishing batteries within UN 38.3 and CE standards, thereby contributing to reducing waste while also conserving valuable resources. The primary company focus is on the urban transport segment of the mobility sector. NOWOS offers industrial-scale lithium-ion battery repair and refurbishment services for a range of market segments. Reuse and repurposing are prioritised over recycling, which is the last-resort strategy. Through their services, NOWOS helps battery manufacturers, fleet owners, and producers of electric vehicles prolong the lifespan of their batteries, reduce costs, and contribute to a circular economy. Additionally, NOWOS offers consulting services for circular battery design.

www.nowos.com

Source: NOWOS

Circular Energy Storage

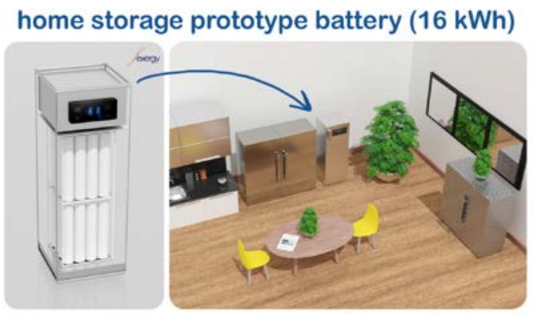
Batteries for energy storage are increasingly needed for integration in renewable-powered electricity grids as well as for off-grid applications in remote areas. These batteries too need to be designed, manufactured, used and reused in closed loops.

These companies provide leading examples of how new materials, technologies and also procedures can significantly enhance circularity in the energy storage sector. In doing so, they show concretely how we can rethink stationary batteries and reduce their impacts, while maintaining a focus on reliability and affordability.

ELESTOR

Founded in 2014, Elestor has created an innovative electricity storage technology for large-scale stationary applications, based on flow battery technology. Set-up and operational costs are minimal: low-cost, abundant hydrogen and bromine (which is extracted from seawater and estimated at 100 trillion tons of global reserves) are combined with a patented system design and easy to manufacture cells. The company counts on multiple partnerships, including with research teams at Fraunhofer ICT, TU Eindhoven and TU Delft, and on Equinor and Vopak as investors. Their technology can eventually replace fossil-powered plants and has the potential to become the equivalent in large-scale, long-duration electricity storage of what lithium-ion is today for e-mobility. For this, Elestor has won multiple international awards. Currently, the company is establishing its international sales and service network, with a US branch opening in Boston, Massachusetts in 2024. By then, Elestor will count on a team 100 strong.

www.elestor.com



EXERGY

Exergy Storage is scaling up a sustainable battery technology for energy storage based on abundant raw materials such as salt, (recycled) aluminium and iron. The new battery is characterised by high energy density and safety, being deployable both in densely populated residential areas or used in large utility-scale systems. It also has a long lifespan, allowing high deep cycling numbers and it is fully recyclable, easy to refurbish and designed for closed material loops. These characteristics also make the battery suitable for containerized solutions, as well as for electrification of transport over rivers and coastal waterways, including barges and passenger transport. At the same time, the company aims to increase consumption of home-generated renewable energy in an affordable and efficient way. Together with value chain partners such as Nobian, Stanstechniek, Nouryon, and NL Defence and scientific institutes such as TU Delft, the company is currently preparing for series production and market roll-out. In parallel the technology is being optimised and validated through prototypes and pilots.

www.exergy-storage.nl

TENNET

TenneT is the Transmission System Operator for the Netherlands and a significant part of Germany. It operates over 25,000 km of high-voltage lines and cables, delivering electricity to 43 million domestic and business users. TenneT recognises that the energy transition requires an entire system transformation, not only from a grey to green electron, but also from a circular material perspective. This is true for every existing and new component of the system, where batteries will play an important role together with other already existing TenneT assets. All components need to work with challenges and opportunities of circularity. For example, power transformers are at the heart of the TenneT grid, with an operational efficiency of +99%. Their function, size and material requirements also make them an interesting candidate for reducing the environmental impact of the grid. TenneT wants to treat power transformers as sustainably as possible. In a recent tender, the grid operator purchased for the first time power transformers with 100% recycled copper. Recycling the copper windings of scrapped transformers is a technique that sets high standards for the material purity of the reused copper. TenneT suppliers are gaining experience with this new process technology, with one amongst them to be working together with a subcontractor on the production of sustainable copper with 100% renewable energy. Currently, Tennet is also investigating the possibility of using the old copper used in their transformers for this goal, with the ultimate goal to really close the loop on this important material.

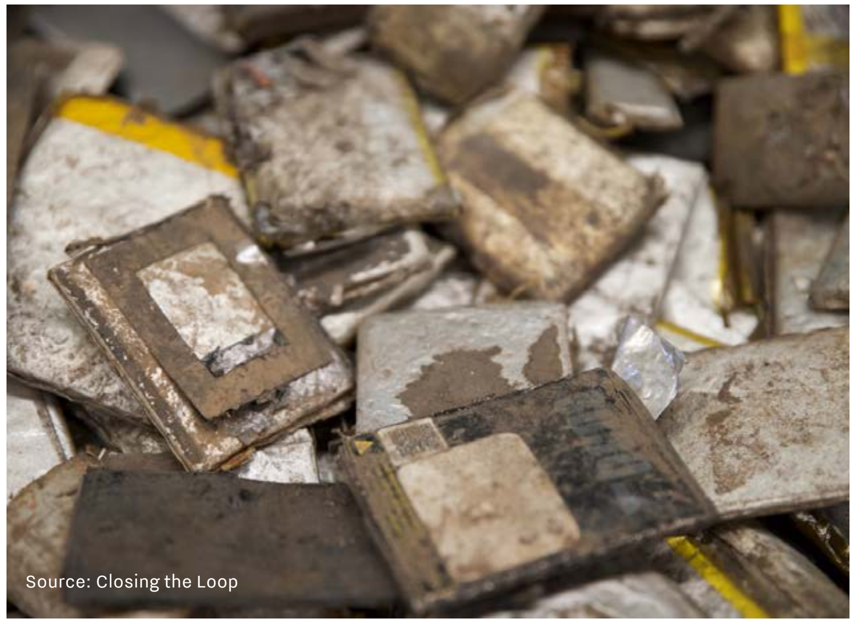
www.tennet.eu

Source: Tennet

Recycling Waste Smartphone Batteries in Emerging Markets: The Waste Compensation Model of Closing the Loop

Batteries make up a significant share of the soaring amounts of e-waste globally. As the volumes of devices being used around the world increase - including in most countries in the global south - so does the need for the proper recycling of the batteries contained in these devices.

Unfortunately, their effective treatment is still in its infancy, with no solution currently available in the global south. This leads to considerable quantities of valuable materials getting lost and to several detrimental consequences that affect the health of local ecosystems and workers[53]. International programs and businesses have thus attempted to solve this pressing challenge.



Source: Closing the Loop

Amsterdam-based Closing the Loop (CTL) has successfully scaled up a circular business model aimed at making electronic products and devices 'waste-neutral'. Their services are centered around the principle of 'one for one' or 'waste compensation'[54], uptaken also by the TCO Certified ecolabel for IT products. The service thanks its success to the commercial value it creates (e.g. brand value, marketing benefits), while delivering a proposition that funds the collection of waste from emerging markets, where proper financing is the biggest hurdle to improved waste collection and management.

In practice, for one new hardware sold by international tech brands - such as Samsung, Vodafone, Fujitsu - another one in its end-of-life state is collected for recycling, in emerging countries. This service is voluntary for clients and thus not replacing EPR requirements. It is seamlessly included in clients' procurement processes for a fee usually equivalent to <1% of the cost of the device[55].

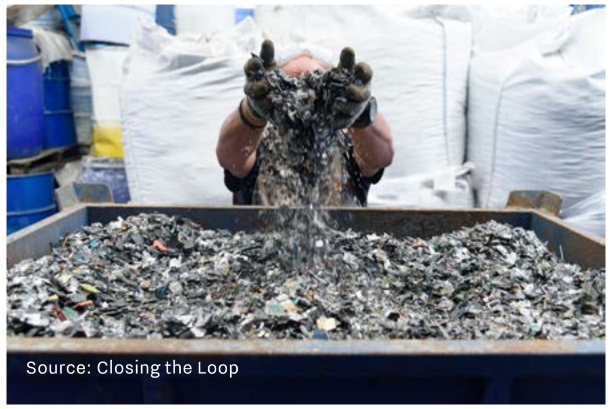
Typically, CTL recovers scrap ICT hardware from West Africa, where local recycling infrastructure is lacking and informal handling of this hazardous material is widespread. Their urban mining initiatives focus on diverting these waste streams to other countries for sound and efficient recycling.

In 2017, CTL started assessing the feasibility and profitability of the recovery of end-of-life phone batteries. These had previously been excluded from waste compensation projects due to safety risks and complex bureaucracy connected to cross-border shipment[56]. Nigeria showed potential for the pilot, due to local regulatory advances and abundance of end-of-life batteries, for which no trading market existed at the time.

The first project ran in collaboration with Dutch circular smartphone manufacturer Fairphone and proved profitable despite the high costs of battery collection, safe shipment and processing. Also, it was effective in transparently monitoring the transboundary movement of batteries from start to finish with the tracking system Chainpoint. Finally, it contributed to the local economy and environmental protection efforts.

Through the programme, 5,000 kg of batteries were successfully sourced in 18 months. Of these, only 450 kg came through formal channels, evidencing the need to work side by side with the Nigerian informal sector. Scrap batteries were then safely shipped to Belgium following Basel Convention procedures for hazardous materials. An estimated +1,250 kg of cobalt was recycled into ready-to-use secondary raw materials.

This success proves the feasibility of reverse logistics for batteries and shows opportunities for the further involvement and growth of the Nigerian informal sector. Importantly, the collection of scrap batteries directly delivers a positive impact on the local economy and concrete support to the informal sector, which is paid for the safe collection of electronic waste. Furthermore, through proper collection and treatment, pollution and CO2 emissions are reduced.



Source: Closing the Loop

Despite the successes, the team incurred many delays and complications due to the administrative requirements set by the Basel Convention and related agreements[57]. Also, it was unfortunately not possible to quantify the exact material recovery rate for cobalt (on average ~89% based on calculations by Fairphone) through the involved recycler, due to the limited disclosure possibilities provided by the contract agreement.

CTL thus continues to work on the expansion of the programme. In 2021, the company partnered with international actors within the PREVENT Waste Alliance to further investigate the options for opportunities to scale up the responsible management of end-of-life portable batteries sourced in Nigeria[58]. This second scaled-up pilot was also successful and has paved the road for enabling local recycling on the African continent. The company is currently doing a feasibility study for such a facility to be made possible in West Africa.

Source: Closing the Loop

Source: Unsplash

Chapter 4

Circular Batteries Powering a Sustainable Future

Five independent Future Visions and our joint Action Agenda for the acceleration of the needed transition in the battery value chain and a truly future-proof sector.

Future Visions

A circular economy for batteries can unlock economic, environmental and societal progress in multiple ways, from increasing job opportunities and improving workers' safety to protecting ecosystems and communities from the detrimental effects of currently unsustainable consumption and production patterns[59].

What are the next steps to take to achieve true circularity across the battery value chain? And how can we accelerate the needed change and ensure that different perspectives and our current and future needs are accounted for in this transition?

In this final chapter, we present the independent future visions of four key stakeholders in the Dutch battery value chain: the research consortium BatteryNL, the think tank The Hague Centre for Strategic Studies, the environmental NGO Natuur en Milieu, and the Dutch-German grid operator TenneT. Additionally, we share the future vision of the European Economic and Social Committee and their opinion on what is needed next to accelerate the circular shift for batteries within and beyond the EU.

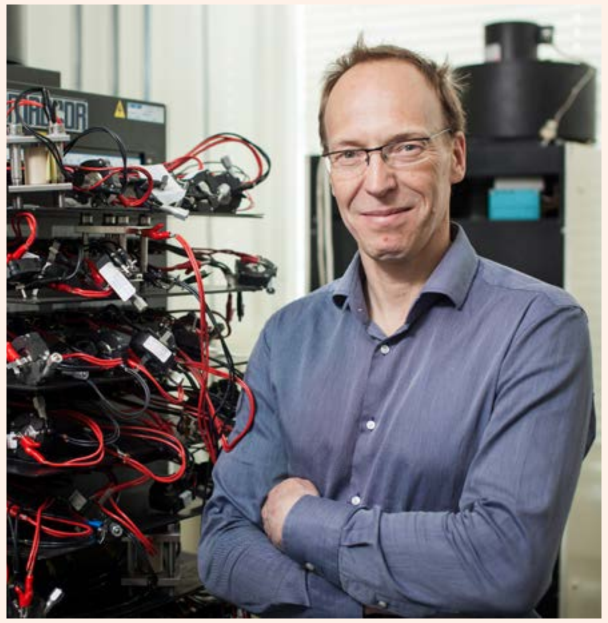
As authors of this brochure, we also wish to share our future vision on battery circularity. The following action agenda is addressed at government, industry and civil society stakeholders. Our observations and recommendations are aimed at actors in the Netherlands and abroad, since no circular economy for batteries can be fully achieved without global collaboration and value chain integration across borders.

Our goal is to mobilise action towards a truly circular and sustainable sector in the long-term, and to foster and facilitate an international debate on actions that could be prioritised to accelerate the much needed circular shift for batteries.

Source: Unsplash

Coordinating R&D efforts is the way forward

Prof. dr. ir. Marnix Wagemaker
Project Coordinator at BatteryNL



Aligned with the core aim and mission of BatteryNL, extending the lifecycle of current and future battery technology is a crucial step in improving battery circularity by reducing their enviornmental footprint. This requires fundamental research as pursued by BatteryNL, where novel passivating interface design that is sustainable and scalable - together with effective low footprint new solid state electrolytes - will be crucial.

For the development of future battery technology and with circularity in mind, several aspects must be considered by the wider R&D community:

- Addressing material criticality in battery material development requires improved and innovative battery material design. Close collaboration with experts in critical material mining and processing, as well as with experts on recycling and integration, is thus paramount. We need to ensure that all aspects of a battery lifecycle and all segments of their value chains are considered and their respective issues addressed.
- Manufacturing batteries that are sustainable by design (in other words, that can be easily dismantled, reused, remanufactured, and efficiently recycled) requires a paradigm shift in battery research and development. So far, efforts have been focusing on optimizing battery performance. Now, it is time to look primarily at full circularity, and energy and material efficiency throughout the battery lifecycle.
- The ongoing diversification in battery chemistries calls upon a swift and concerted standardization of the different battery formats and design. Only this way, we can enable and effectively support circular battery strategies in the near future, from reuse to recycling. For BatteryNL, it is indeed key to work with private actors and leading companies, to understand how standardization can be best achieved.
- Last but not least, it is necessary to set up a battery value chain which includes stakeholders and companies focused on the recovery of battery raw materials. Material recovery - like other circular strategies - is currently a very manual process requiring sophisticated technical skills and capabilities. Hence, it is now time to focus on the needed human capital, and on their specific training, education and (re)skilling in fields such as sustainable chemistry and recycling, battery refurbishing and remanufacturing.

Our consortium at BatteryNL is dedicated to multi-stakeholder collaboration and to knowledge exchange, which we deem crucial for the successful achievement of long-term battery sustainability.

> "Aligning R&D efforts and coordinating actions and priorities towards improved battery circularity is a prerequisite for a true shift in this sector."

www.batterynl.nl

Diversifying battery materials supply through domestic production and international collaboration

Michal Pinter
Delegate of the European Steel Industry to the Consultative Commission on Industrial Change at the European Economic and Social Committee (EESC)

With the recently adopted Battery Regulation, the European Commission has established a unified regulatory framework that addresses batteries' entire life cycle, concentrating on sustainability, performance, safety, and recycling. Adopting the revised regulation is highly welcomed. However, the EESC stresses that other significant issues must be effectively addressed to achieve the circular battery transition, notably in the critical raw materials (CRM) supply chain context.

CRMs play a pivotal role in green transition since they are the backbone of the battery industry and the main cost driver, representing around 65% of the total cost of the cells. For example, a factory producing 30 GWh of batteries requires ~33,000 tons of graphite, 25,000 tons of lithium, 19,000 tons of nickel and 6,000 tons of cobalt. At the same time, the EU demand for the production of batteries will be increasing rapidly. To remain competitive in a new economy driven by green technologies, the EU will need 3500% of current lithium usage, 330% cobalt, and more than 100% nickel by 2050.

The EU's most crucial supply chain constraints have been identified explicitly for the materials essential to manufacture batteries. For instance, in 2021, there was no capacity to refine lithium or graphite for batteries in the EU. Considering this, the EU must diversify its supply chain through domestic production and international collaboration.

It takes about 8-to-10 years to gain a permit for a new mining site on European soil. Given that the EU will need approximately 300 new mines to meet the 2035 demand for critical materials in batteries, it is apparent that the current regulatory burden must be simplified. Furthermore, the Commission must identify priority projects, accelerate the permission procedures, and open up new funding sources to support the expansion of the mining, refining, and recycling of battery materials in the EU.

"The EESC also calls for establishing partnerships with resource-rich countries that comply with EU social and environmental standards."

We must avoid a situation where one dependency is replaced by another and maintain fair trade conditions with all global partners. This can only be accomplished if the EU makes CRMs a top priority in legislation, ensuring the effective implementation of the Battery Regulation and all other related laws required to achieve strategic autonomy while preserving global competitiveness.

As demand for CRMs grows, Europe is exploring mining on European soil to diversify its supply chain with new strategic partnerships with resource-rich countries compliant with the EU's standards. Adopting a circular approach for batteries (and other products containing CRMs) is a no-regret scenario for Europe and the rest of the world. By keeping our resources in circulation as long as possible and at their higher value, we can decrease the demand for new materials.

www.eesc.europa.eu

Leveraging Regional Collaboration to Reshore the Battery Value Chain

Irina Patrahau
Strategic Analyst at The Hague Centre for Strategic Studies

Michel Rademaker
Deputy Director at The Hague Centre for Strategic Studies

Amidst growing tensions between geopolitical blocs, the strategic importance of batteries for the European Union's clean and digital transitions has led to a push to reshore battery value chains under the European Battery Alliance and reduce minerals import dependence under the Critical Raw Materials Act. To achieve this, EU countries should work together along value chains to boost existing capabilities and develop new ones.

The battery value chain is complex and involves many actors. From producing battery raw materials to manufacturing battery cells and battery packs, recycling and then re-introducing recovered materials into the loop. Added to this are equipment and technology providers, traders, distributors and specialised storage providers.

The industrial ecosystem in North-Western Europe can be leveraged into becoming a leading hub for sustainable battery value chains. The Netherlands and Belgium host some of the EU's largest maritime ports and highly efficient logistics infrastructure including trade, distribution and specialised storage for metals and liquid bulk (Amsterdam, Rotterdam, Antwerp (ARA)). The Antwerp-Rotterdam-Rhine-Ruhr-Area (ARRRA) is a highly integrated cluster that accounts for 40% of the EU's petrochemical production, while Germany accounts for a significant part of Europe's largest automotive industry. In addition, the region is setting aside significant funds to boost its recycling infrastructure.

"Together, North-Western European public and private actors can create a sustainable and innovative European battery value chain."

North-Western Europe has wide ranging opportunities to reshore (parts of) the battery value chain. The region hosts great potential for transforming its existing industry, while its open innovative environment brings chances for new companies to establish themselves. A long-term governmentally led industrial vision could bring more clarity to companies regarding their role in the clean energy system. Coordinating initiatives, tenders and investments with actors along the emerging battery value chain can accelerate action, support the development of joint infrastructure and create a more certain business environment.

www.hcss.nl

Rethinking mobility altogether for long-term sustainability

Rob van Tilburg
Programme Director at Natuur & Milieu

It is better for the climate if we switch from petrol-powered to battery-powered cars. However, we do need a lot of scarce raw materials to produce these batteries. That's why it is crucial to have a holistic, long-term vision on how to bring about positive change. This will help us avoid our past mistakes and set our society for a truly sustainable future.

To understand why we advocate for a future with as few raw materials as possible, we must first look back to the rise of the car as a societal commodity, and the role that oil played in it. As the car became a mass product, it forever changed our lives. Whilst people used to live within walking distance to work, it is now quite normal to drive to work. Instead of spending our holidays at home, we now drive across Europe.

The 'car boom' was enabled by the discovery of large oil reservoirs from which we derived fuels. The world went in search of ever cheaper oil, searching in the seabed, in delicate ecosystems, residential areas and indigenous lands. The far stretched consequences of this mass pumping are now evident, from climate change to severe socio-environmental damages worldwide.

For electric cars, we no longer need oil but the lithium, cobalt and nickel needed to manufacture batteries have downsides too. Although we can already partially recycle batteries, the recovered materials are yet insufficient to meet the increasing demand for the needed raw materials. Extraction and refinery thus persist, significantly impacting people and nature.

> "As with oil, the risk is that we continue extracting as much and as quickly as possible to produce cheaper batteries. This would lead to the same detrimental consequences of oil extraction."

We can also choose a different path. We can bring facilities closer to people again, facilitating walking and cycling. We can ensure that public transport is accessible and affordable for everyone, even in places where few people live. Employers could switch from providing employees with leased cars to offering bicycles or public transport passes. And when you do need a car, we could start sharing cars. Eventually, we would also come to the realisation that cars really don't have to be as big and heavy as they are today.

With the advent of the car, we have been able to completely change our society. That's why we at Natuur & Milieu know that we can and should do it again. A hundred years on, we hope to look back at this decade with admiration. Not just because of the introduction of the electric car, but because we have managed to transition to a world where we need far fewer cars and raw materials.

www.natuurenmilieu.nl

Enlarging battery storage capacity to future-proof the energy system

Margriet Rouhof
Head of Strategy STP-STR at TenneT

An affordable, reliable and sustainable energy supply is a key objective and political priority for the EU. To make the economy and society climate neutral by 2050 and secure energy and access to materials, the electricity system must be ready first to facilitate the transition.

TenneT developed Target Grid, a blueprint in the making for the electricity grid in the climate neutral energy system of 2045. Our starting point is to look much further ahead than what was done in the past, setting course to a CO2-free society. We do this by preparing to build a grid taking into account a scenario with the highest degree of electrification. With this, we are committed to the timely delivery of our future-proof and flexible energy system. Flexibility is key and contains a portfolio of complementary measures, e.g Power-to-Gas, Power-to-Heat, Demand Side Response, Interconnection, curtailment, pump storage and batteries.

Battery storage with high ramping capabilities helps to stabilise the system by providing ancillary services, which we highly need as a Transmission System Operator. Our grid is becoming way more dynamic, due to both weather-dependent generation and a tremendous growth in household and industry electrification. Target Grid anticipates market-driven battery storage: 150 GW batteries to be connected to the German part of our grid and 60 GW battery capacity on the Dutch side to be connected by 2050.

That is the end-picture, but to get there we need to strategically develop our roadmap. Already today, battery storage is an important solution for our dynamic future energy system. We expect to need ~9 GW of battery capacity by 2030 in the Netherlands (see this map for exact locations and forecasts), comparable to 750 offshore wind turbines. This increasing demand for battery capacity will foreseeably increase the demand for hardware.

This increase in material need is an important factor for the whole energy transition and one that should be smartly balanced. To realise our future grid infrastructure and energy system, it is necessary to use raw materials and components that are naturally scarce and sometimes even short in supply. These challenges become more severe as global competition over resources intensifies.

> "There is just one way of dealing with resource scarcity: making it a fundamental part of design, tender and decommissioning, so that we can close the loop."

This is not achieved overnight, but with smart steps we can implement change. To reduce the environmental impact of our materials, we are adapting our tenders to include stricter circularity requirements, for example by asking suppliers to provide evidence of the percentage of their recyclable or recycled materials through 'raw material passports'. And for 1,5 year now, we have successfully required recycled copper in our assets. It all starts with transparency and asking the question. In the end, it is not a 'nice to have': the energy transition won't succeed without a circular perspective.

www.tennet.eu

Action Agenda for a future-proof battery sector

We propose here a future pathway for the Dutch battery value chain. We believe 6 set of actions could be prioritised and implemented through the concerted efforts of all involved stakeholders, from public to private sectors and civil society organisations.

1.
Shift to new consumption and production patterns to achieve true circularity

Achieving true circularity for batteries requires commitment to all R-strategies (Chapter 2), starting with Refuse, Rethink and Reduce. Material and energy efficiency in this context calls not simply for reduction, but first and foremost for avoidance whenever possible. These three strategies can however prove to be the hardest to deploy, since they rely on a change of behaviour and a true system shift towards circular patterns of production and consumption.

In fact, the current and foreseen growth of the battery sector demands an increasingly unsustainable amount of energy and raw materials, with all the aforementioned consequent social and environmental impacts (Chapter 1). Closing and slowing the loops on all these batteries will not be enough to halt these unsustainable trends.

All stakeholders - from governments to businesses and civil society - need to reconsider the problem at the source. This would involve pushing for the production of innovative products and services, and stimulating new habits and behaviours which enable a reduction of material and energy demand. This can take a number of shapes, from fostering shared mobility and new concepts of vehicles, such as solar cars and boats that can immediately use the energy they generate, to promoting and increasing access to and affordability of (electric) public transport or lighter means of transport. And even more so, when the latter are offered by companies adopting circular business models such as product sharing, co-ownership, leasing and the like. Making the development of smaller batteries - that need fewer and non-critical materials to be produced - is also a key strategy to reduce material dependence.

For the shift, it will be crucial to bring onboard not just the industry and the workforce or governments, but also battery users. The lifecycle and sustainability of a battery can be significantly impacted by responsible choices during use. Battery manufacturers and importers should thus strive to provide compact and clear information to customers regarding charging, maintenance and disposal, with the aim to help extend battery lifespan and reduce environmental and safety hazards. Information campaigns could also significantly enhance consumers' awareness of the true cost and impact of different battery materials (critical and non-critical), as well as of the hazards associated with improper disposal and treatment of EOL batteries.

2.
Invest in R&D for alternative battery materials to reduce CRM dependency

As discussed in Chapter 1, the last decades have witnessed a clear trend towards increasing diversification of battery chemistries and technologies for both e-mobility and energy storage, with developments being fuelled by the need to increase energy density and safety, and reduce weight. However, applications in these two sectors require batteries with significantly different properties and characteristics.

Through practice and policy, we should thus ensure that different battery chemistries are developed, used and reused for specific applications, for material and energy efficiency purposes. For example, using alternative chemistries to Li-ion for energy storage (where applications have a longer lifespan than in e-mobility) can significantly contribute to resource efficiency and resilience in the EU. Also, switching to Na-ion compositions for heavy-duty vehicles like trucks could prove more fit for purpose, in light of recent studies highlighting the high power capacity of these chemistries.[60] Equally, the wider use of inorganic compositions (Fe, Mn as redox elements) can make batteries safer.

Reducing our dependence on CRMs as a strategy across battery types and applications will yield considerable progress with regards to socio-environmental and economic sustainability. Research has already proven the feasibility of batteries that are made of naturally abundant materials.[61] Now it is for governments and industry to ensure that the difficulties encountered by these new technologies in entering the market and scaling up are gradually removed. These reflections thus also prompt reconsideration of much awaited developments like solid state batteries (requiring 2-8 times more Li than today's predominant chemistries[62]) and the extent to which their uptake could be supported.

The Dutch Raw Materials Strategy
The Dutch Raw Materials Strategy is an example of how a national government can prioritise actions for the medium term and in a coordinated manner to support the clean energy transition. In order to address the supply security and socio-environmental impacts of key raw materials, this policy package focuses on five action areas: 1) circularity and innovation, 2) sustainable European mining and refining, 3) diversification, 4) greater sustainability of international supply chains and 5) knowledge building and monitoring. These are in line with both EU policies, such as the Critical Raw Materials Act, and Dutch policies, like the National Circular Economy Programme 2023-2030. Attention will also be paid to the promotion of R&D in the field of circularity and to the support of economic diplomacy for the exploration of new trade partnerships.

3.
Incentivise circular design to enable second-life strategies and improve material recovery

Overall, it is circular design choices that have the highest influence in unleashing a fully circular economy for batteries, by enabling inter alia that activities aimed at slowing and closing the loops can be efficiently and smoothly carried out. Enshrined also in the recent EU Battery Regulation, standardisation and modularity can considerably ease the preparation of batteries for second-life and their treatment and material recovery at their EOL stage.

For example, standard and modular design across all new manufactured batteries can prevent the use of glues and binding materials that complicate disassembly. It will also enable the direct substitution of single defective cells in otherwise well-functioning battery packs. Nowadays, it is indeed procedurally easier to replace all cells within a battery case during refurbishment than replacing a single cell, with a considerable loss of valuable materials. Additionally, circular design can help achieve higher material recovery during recycling, and thus higher black mass quality, since cell disassembly cannot be automated at present. This leads to highly energy- and labour-intensive recovery processes, and hence high costs.

Rethinking the way batteries are produced, used, reused and recycled is a major challenge that requires the understanding and involvement of multiple perspectives and value chain actors. Circular lifecycle thinking should not only be mandated by law, but also embraced by the industry in view of its subsequent economic benefits, starting from enhanced supply resilience and less volatile raw material prices.

Finally, it is worth noting that circular strategies and processes must be continuously refined to match the pace of development of emerging technologies. Continued R&D efforts will enable ever lower needs for material and energy inputs and for ever more efficient reuse, repair and recycling procedures.

4.
Foster education and reskilling of workers to scale up reuse, repair & recovery

Some clear obstacles need to be overcome to realise the potential of a circular battery value chain.
First and foremost, the reskilling and upskilling of the workforce involved in all second-life and EoL activities is necessary for scaling up repairability, reuse and recovery. With the needed increase in such operations, there will be a lack of technical knowledge and skills to fill in a sector which already faces challenges of decreasing interest and workforce[63].

Local and national authorities could start tackling this challenge through dedicated vocational training and professional programs, such as those organised and funded by the Dutch government (e.g. CIRCO) or the branch organisation Circulaire Maakindustrie, who regularly organises sector-specific webinars and knowledge events.

These initiatives could focus on providing the necessary technical training, but also increase participants' awareness of the benefits of circular battery management, and the related legal and safety requirements which could prove more difficult for smaller enterprises to navigate. Companies could equally strive to provide the same broad understanding and knowledge to their workforce in mid-to-senior levels to foster better informed and more responsible decision making.

Simultaneously, there is an urgent need to integrate all the different study tracks relevant for battery development in higher education and university levels. Doing so will enable students to gain a more complete understanding of all different value chain issues with a direct relevance for batteries' sustainability and circularity. These are the aims of Dutch academic best practices such as the e4Battery research team at TU Delft and the Twente Centre for Advanced Battery Technology.

Reuse vs. Recycling
There is a growing dilemma on whether it Is more advantageous to first slow or directly close the loop on LiBs. Currently, reuse is rendered difficult by the limited availability and access to historical data on batteries (a

challenge that the upcoming Battery Product Passport will be tackling), and by their very design. This makes repair practices very labour-intensive, difficult to upscale and thus costly compared to falling prices for new batteries. Recycling is sometimes advocated as it enables the immediate recovery of key secondary raw materials for new manufacturing. Research insights into which of these practices should be advocated from an environmental perspective are not conclusive yet, but our understanding is developing fast. For example, experts are investigating ways to reactivate batteries through new liquid electrolysers to extend their lifetime and avoid downcycling, in line with the R-ladder principles.

5.
Strengthening international cooperation to enable circular battery strategies

Cooperation of the Netherlands with neighbouring countries, like France and Germany, and trade with CRM-rich countries around the globe is key to remain competitive and sustain innovation for a thriving Dutch economy. A small country with limited raw materials reserves but high circularity ambitions and technological innovations, the NL actively seeks international collaborations to fill in the gaps of its battery value chain (material extraction, battery manufacturing, recycling) and offer its know-how from alternative materials and advanced battery chemistries to refurbishing methods, recycling technologies, and new circular business models and propositions.

The Netherlands should seek new partnerships with countries rich in raw material reserves (e.g. Canada, South Africa, Chile, Australia) as much as with those with a well developed materials processing capacity (e.g. Japan, South Korea). This can rapidly increase supply security and facilitate international agreements on the monitoring and improvement of socio-environmental conditions along supply chains.

From an EU perspective, the next steps in the acceleration of a circular economy for batteries could be fostering sustainable mining and production. Such a strategy would have a significant impact on the improvement of environmental, health and social conditions of the areas and communities involved in material extraction.

6.
Increasing EU policy ambition and effectiveness in circular battery

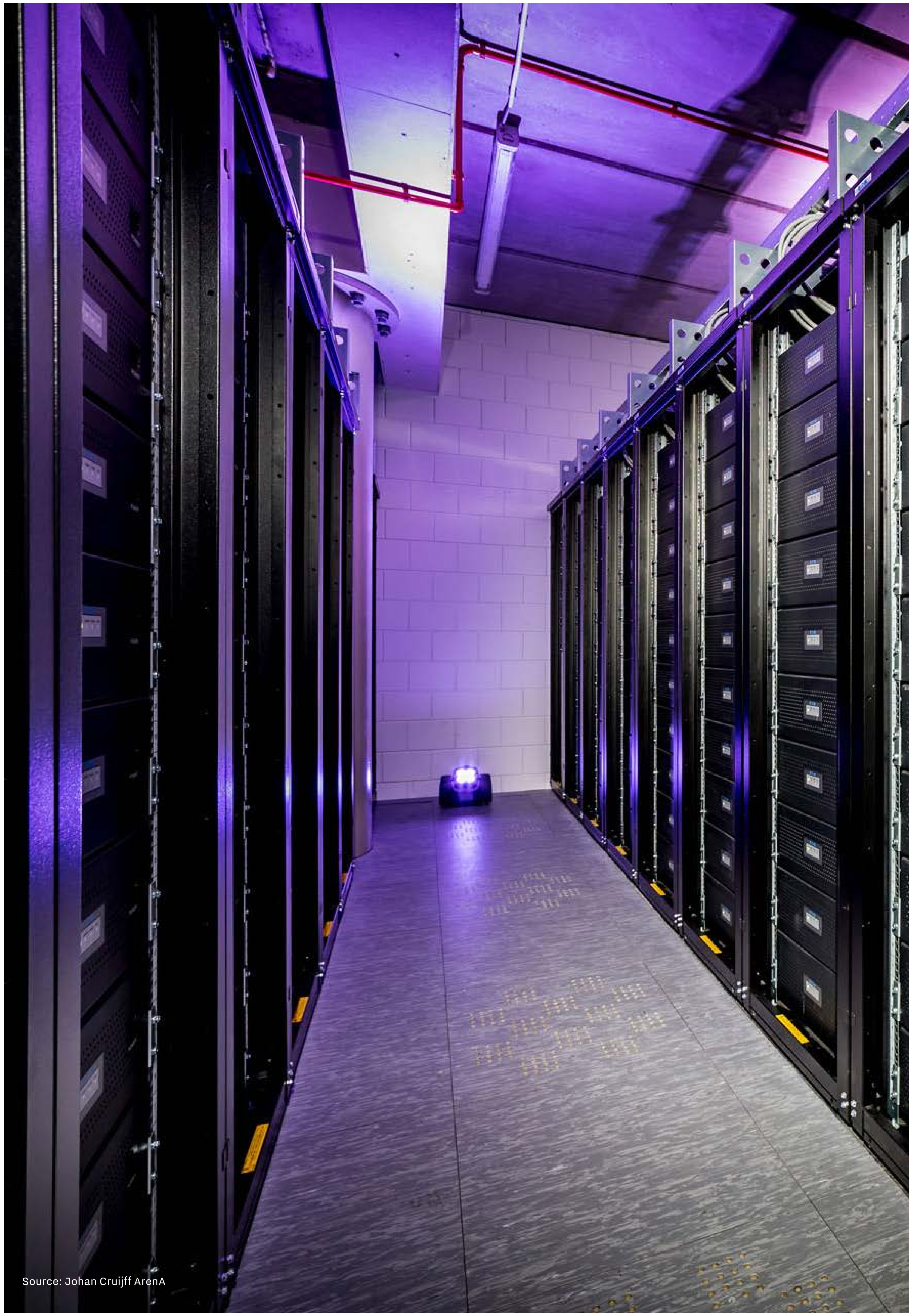
The new EU Batteries Regulation is a major leap forward in battery circularity and industry standardisation. Supply chain actors are now tasked with the difficult challenge to implement all the foreseen requirements, while EU public authorities will have to closely monitor their enforcement. These promising developments should however be seen as a starting point in the transition. A few steps could be prioritised next to enhance ambition for the incremental circular change needed in the sector.

More ambitious goals on Li recycling targets can be achieved. According to Transport & Environment, latest evidence shows that hydrometallurgical battery recycling technologies (using chemicals rather than heat-based pyrometallurgical processes) can recover up to 90% of Li. This figure is significantly higher than the Commission's 50% target before 2028 (and 80% before 2032).[64]

Additionally to increasingly ambitious battery materials recycling goals, battery circularity would be further promoted at the EU level by the use of a different basis for collection targets, especially for portable and LMT batteries. Collection targets are currently based on the average weight of batteries being put on the market over the last three years, which as such may work against higher R-strategies including product life extension and reuse. Instead, these targets could be replaced by an obligation for producers to collect all the batteries available for collection. To this end, a sound methodology for the estimation of the amount of portable and LMT batteries available for collection should be developed, in line with the new EU Batteries Regulation (see p. 19 par. 108).[65]

The development and rapid expansion of refurbishment and recycling facilities within the EU is also advisable from both a sustainability and supply security perspective. In this context, quality should be prioritised over quantity as for the strategic positioning of the EU industry. These steps would enhance CRM independence from third countries, increase material supply to sustain the energy transition and battery scale-up, and allow shorter and easier supply chains that can thus be more closely monitored.

Finally, national and supranational governments should ensure that the economic benefits of circular practices - from the use of more abundant and secondary raw materials to waste prevention, reuse and high-value recycling - is proportionally reflected in the price of batteries. This can prove a powerful incentive towards circular innovation and more sustainable consumer choices. For this, additional measures can prove effective, such as the introduction of a tax on virgin raw materials, which would reflect their implicit socio-environmental and economic costs compared to the use of secondary raw materials.



Source: Johan Cruijff ArenA

Closing words

Through this brochure, we aimed at providing a snapshot of the current status and an assessment of the future potential for circularity across the battery value chain, in the Netherlands and beyond. We strived to present today's hurdles and tomorrow's developments in a factual and objective manner, with the goal to stimulate an international debate on how we can accelerate the circular transition together.

We approached the topic of batteries from several perspectives - primarily economical, environmental, innovation and financing - in the hope to show how multifaceted and interconnected the challenges and opportunities for circular economy in the sector are today. To evidence how this topic is witnessing a real momentum in the Netherlands, we illustrated multiple Dutch best practices, initiatives and approaches, together showing how circularity is already applied in the battery sector. In the last chapter, we presented a pathway and action agenda with our set of recommendations and proposals for what can be done next to foster circular batteries across borders.

By publishing this brochure, the authors and partners hope to inspire regulators, the knowledge community, entrepreneurs and investors to work together towards the circular batteries that will power our future-proof society. By sharing lessons internationally, others can accelerate development in a sensible direction and learn from our insights learnt. The journey is rewarding. Together we can adapt the Dutch solutions and practices to the local context, solve environmental issues and by doing so create meaningful local jobs, and ultimately contribute to the climate, biodiversity and Sustainable Development Goals.

If you want to read more on circular economy opportunities by market segment, you can find our other reports here: www.hollandcircularhotspot.nl/publications/.

If you want to work together with us, you can send your ideas, thoughts and proposals to info@hollandcircularhotspot.nl.

Source: Unsplash

Source: Heskon

Glossary

Battery Energy Storage Systems (BESS): Batteries can be used for stationary energy storage with multiple functions and purposes, from supporting renewable energy production and enhancing self-consumption to peak shaving and as backup power in both industrial and residential systems. Read more on their potential at page 16.

Circular Battery: A battery designed with as little material and energy inputs possible with the aim to keep materials in loop thanks to circular strategies that extend its lifespan and ensure repairability and recyclability. See page 24 for other key characteristics of a circular battery.

Climate Neutral Economy: One with net-zero greenhouse gas (GHG) emissions. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement.

Critical Raw Materials (CRMs): As defined by the European Commission based on their economic importance to the EU economy and their respective supply risk and uncertainty. The 5th list of CRMs was compiled in 2023 and supported the development of the list of Strategic Raw Materials (such as Copper and Nickel) and of the CRM Act, to ensure EU access to a secure and sustainable supply of these resources. Further details at page 17.

Electric Vehicle Battery (EV battery): As defined in the 2023 EU Battery Regulation, these are used for traction in road vehicles (4-wheeled) such as Lithium-ion batteries (LiBs). See full battery classification at page 12.

E-mobility & EV Sector: As transport accounts for over 1/3 of CO2 emissions from end|use sectors, the electrification of mobility is seen as paramount for meeting the 2050 climate neutrality goals. Batteries to power all kinds of vehicles on our roads, seas and skies - from passenger to heavy-duty vehicles - are a major avenue to rapidly decarbonise transportation.

End of Life (EOL): the final stage in the lifespan of a product such as a battery, once it can no longer be reused or repaired and must thus be recycled.

Extended Producer Responsibility (EPR): A mix of policy instruments deployed by governments to make manufacturers accountable for the environmental costs and impacts of their products at end-of-life. Further details at page 38.

Producer Responsibility Organisation (PRO): organisation tasked with fulfilling EPR requirements in practice, such as the collection and recycling of batteries. Dutch examples at page 39.

R-ladder & related R-strategies: A hierarchy for circular practices (R-strategies) from refusing and rethinking products until recovering their materials at EOL, as defined by Rood and Kishna (2019). Strategies higher on the ladder require fewer materials, which reduces their resource-related environmental footprint. Recycling becomes a 'last resort' option, when other R-strategies are no longer possible. R-strategies can be combined with innovations such as new product design, technologies and business models. Further details at page 24.

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Colophon

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