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Report

Managing waste batteries from electric vehicles

The case of the European Union and Japan

Institute for European Environmental Policy

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List of abbreviations

BEV	Battery electric vehicle
ELV	End-of-life vehicle
EPR	Extended producer responsibility
ESS	Energy storage system
EU	European Union
EUR	Euro (currency)
EV	Electric vehicle
GBA	Global Battery Alliance
GHG	Greenhouse gas(es)
JPY	Japanese Yen
LFP	Lithium-iron-phosphate (battery type)
LIB	Lithium-ion battery
MOE	Ministry of Environment
NCA	Nickel-cobalt-aluminium oxide (battery type)
NDC	Nationally determined contribution (under the Paris Agreement)
NMC	Nickel-manganese-cobalt oxide (battery type)
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in hybrid electric vehicle
QR	Quick Response code
RFID	Radio Frequency Identification tag
UK	United Kingdom
UN	United Nations
US	United States
USD	US dollar (currency)
VAT	Value added tax
ZEV	Zero-emission vehicle

1. EXECUTIVE SUMMARY

This report explores the challenges related to the future management of waste batteries from electric vehicles (EVs), with a focus on how Japan and the European Union (EU) are dealing with the issue, and steps that may be taken in the future to improve the management of this type of waste. This comparison is beneficial both in relation to policy learning between Japan and the EU, as well as considering the potential movement of EV batteries between Japan and the EU.

The **sale of EVs is growing significantly** in many countries, especially in Japan, Republic of Korea, China and across Europe. Globally, EV sales were expected to reach around 6.4 million by the end of 2021, an increase of 98% from 2020. Estimates suggest that at the start of the 2030s there may be annual sales of 111 million EVs, or much more. A key driver for the expansion of EVs is the need to **reduce greenhouse gas (GHG) emissions**. Both the EU and Japan have the target to become climate neutral, i.e. net-zero emission of GHGs, by 2050. Transport emissions are a major contributor to GHG emissions and **expansion of EVs is one approach to tackling this**. The EU has a target to have 55% CO2 emission reductions for new cars and 50% for new vans from 2030 to 2034 compared to 2021 levels and 100% CO2 emission reductions (zero emission vehicles – ZEV) for both new cars and vans from 2035. Japan has the policy of 100% of electrified new passenger vehicles (both hybrid and battery) by 2035. Japanese vehicle manufacturers are working hard to produce more EVs to contribute to attaining these targets. However, Japan has seen greater expansion in hybrid vehicles rather than EVs to date, although its automobile companies are responding to EV demand in manufacturing in Europe and the US.

One essential component of EVs is the battery. Until now almost all have been produced in Asia (China, Japan and Republic of Korea) and the United States. The principal type of battery used in EVs is **lithium-ion batteries (LIBs)**. Globally, LIB production for EVs increased by 33% from 2019-2020. Whilst China accounted for around most LIB production in 2020, production in Japan is also growing, led by companies such as Panasonic. In Europe there are announced new production facilities, but it has some way to go to catch up with East Asian production. Currently, therefore, the EU is a major net importer of EV batteries, at around 800,000 tonnes each year.

As EVs reach the **end of their life** in coming years, a new challenge will arise, namely how to manage the increasing number of old and waste batteries. The lifetime of a LIB is typically between 5 and 20 years, and it will typically outlive the EV it was built into. However, its performance diminishes over time with use. One estimate suggests that by 2020 around 102,000 tonnes of LIBs per year would be retired from EVs globally, potentially reaching 7.8 million tonnes per year by 2040. **The principles of waste management mean that all EV batteries should first be reused for their original purpose (where possible), then repurposed for a second-life use and, finally if that is not possible, then sent for recycling**.

With regards to **waste prevention**, the aim should be to **prolong the lifetime** of LIBs, with r**epair and maintenance** and r**efurbishment**. The next priority is then **repurposing or second-life use**, i.e. use other than in EVs, e.g. for stationary energy storage such as excess power from solar or wind energy. Repurposing could save around 63 million tonnes of carbon emissions compared with the manufacture of new batteries. Repurposing is only at the trial stage in the EU, but in Japan there are several initiatives for use of former EV batteries in stationary energy storage, such as use of batteries from Nissan vehicles by the East Japan Railway Company, as well as other initiatives looking at small scale use in businesses and energy storage from solar panels.

Recycling recovers materials for further use, reducing the need for extraction of virgin raw materials and associated environmental damage. It also retains the economic value of those materials. Globally, the LIB recycling market is forecast to be worth US$ 31 billion per year by 2040, with over half of LIBs being recycled in China. In 2019, the EU had sufficient infrastructure capacity to recycle around 160,000 EV batteries annually, which would not be adequate to deal with the expected significant increase in the quantity of waste LIBs in the next few years. In Japan there are several partnerships between automobile manufacturers and recycling and metal companies to recycle batteries. Each has developed specific processes and extracts metals for use in new battery production. The economic basis for recycling is critical for policy frameworks to promote it. If there is money to be made by the recycling sector from managing waste EV batteries, this will be a key driver. If the costs start to outweigh the value of the recovered materials, then policies will need to support recycling activities (such as costs to be borne by vehicle and/or battery manufacturers through producer responsibility schemes, etc.).

The relevant regulatory framework in the EU currently is the **Batteries Directive** (2006, revised 2013), which requires the separate collection and regulated storage or treatment of EV batteries. It has targets for the collection of waste batteries (45% of the amount placed on the market by 2016) and for recycling efficiencies for lead-acid (65%), nickel-cadmium (75%) and all other batteries (50%). Also, the Directive required the development of extended producer responsibility (EPR), whereby battery producers are made responsible for the collection and recycling of batteries when they become waste, and the associated costs. In 2020 the EU proposed a **new Batteries Regulation**. It would require EV batteries to be collected and recycled in full. It sets a **recycling target for LIBs**. It would aim to facilitate the **repurposing** of EV batteries for a second life and require each EV battery to have a **'battery passport'.**

There are several **recycling** acts/laws in Japan, but no specific battery law. The overarching legislation is the Act on the Promotion of Effective Utilization of Resources, first adopted in 1991 and revised in 2000, with the Basic Act on Establishing a Sound Material-Cycle Society. This promotes reduction and reuse of waste. Under the 2000 Law for Promotion of Effective Utilization of Resources made specific requirements for compact rechargeable batteries. Along with the objective for all new vehicles to be electrified by 2035, this sets a framework whereby industry operates to determine the best way forward on collection, how to reuse and refurbish, recycle, etc.. Thus there are no specific targets for levels of recycled material in new batteries as will be the case in the EU. Adopting such legislation would be difficult and it is likely Japan will move forward under the existing general legal umbrella with voluntary schemes adopted by automobile manufacturers.

The report concludes that Japan and EU should explore the following options to ensure effective management of end-of-life EV batteries. These are set out under four headings

Policy and legislation:

- Ensure policy and legislative frameworks for EV batteries are coherent and up-to-date, place a value on the sustainability throughout their lifecycle, and clarify that waste EV batteries should first be reused, then repurposed, then recycled.
- Ensure that legislation is clear with regard to its obligations and to whom they apply.
- Set targets for recycling to incentivise collection and recycling and support the development of the recycling market.
- Provide guidance on secondary applications for EV batteries to facilitate their reuse and repurposing, including clear definitions and minimum quality standards.
- Ensure EPR is applied to LIBs from EVs, and also that it is clear regarding who is responsible for EV batteries when they are reused or repurposed.
- Consider setting targets for reuse and repurposing of EV batteries.
- Ensure stakeholders in the batteries value chain are engaged in policy-making.

Battery design and information:

- Ensure EV batteries are designed with the end of their first life in mind, to enable their reuse, repurposing, disassembly, sorting and recycling.
- Consider setting eco-design requirements, e.g. composition and disassembly.
- Ensure that adequate and accurate information about batteries, e.g. through labelling.
- Consider the introduction of product passports for EV batteries and seek harmonisation of such passports globally to ensure ease of trade.

Economic and financial considerations:

- Provide funding for R&D for the development of circular business models and recycling technologies.
- Consider use of financial incentives to encourage investment in EV battery circularity.

International considerations:

- Ensure there are appropriate requirements, controls and quality standards placed on the export of used EV batteries, to reduce impacts on importing countries.
- Ensure compliance with EV battery-related policy and regulation in export markets.
- Consider alignment of legislation between trading partners (e,g, EU and Japan).
- Consider the introduction of certification schemes for EV batteries based on international standards, to facilitate trade.
- Create platforms to share best practices and lessons learned from national initiatives.

2. INTRODUCTION

The sale of electric vehicles (EVs) is growing significantly in many countries, especially in Japan, the Republic of Korea (ROK), China and across Europe. Globally, 2.65 million new EVs were purchased during the first half of 2021, with growth in sales of EVs 3 to 8 times higher than growth in overall light vehicles sales (EV Volumes, 2021). The share of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) increased from 3% in the first half of 2020 to 6.3% in the first half of 2021 (EV Volumes, 2021), suggesting a true shift towards EVs.

One essential component of EVs is the battery required to power the vehicle. These batteries have until now almost all been produced in Asia (China, Japan and ROK) and the United States (US), though there are now new production facilities in Europe (and further announced). Whilst there are some regulations and procedures in place to manage the disposal of end-of-life vehicles (ELVs) in Asia (e.g. UNEP, 2021) and in Europe, only a rather limited number of EVs have been disposed of to date compared to the number in use, since they are a relatively recent development. As EVs begin to reach the end of their life in the coming years, a new challenge will arise, namely how to manage the increasing number of old and waste batteries. This challenge will have consequences not only for waste management, but also potentially for the production of EVs and batteries, and global trade in these products (either as separate batteries or for the vehicles that contain them).

This report explores some of the challenges related to the future management of waste batteries from electric cars, with a focus on how Japan and the European Union (EU) are currently dealing with the issue, and steps that may be taken in the future to improve the management of this type of waste. It builds on an earlier report which explored the management of waste EV batteries in the EU and ROK (Watkins and Farmer, 2021). This comparison is beneficial both in relation to policy learning between Japan and the EU, but also in considering the potential movement of EV batteries between Japan and the EU.

The report firstly looks at the state of play on EV batteries, including the types of batteries in use, the volume of batteries being used, and the current approaches available for the management of waste batteries from EVs.

It then includes a summary of the existing legal and policy framework in both the EU and Japan that is relevant to the management of used and waste batteries from EVs.

Finally, the report includes a discussion of the current approach to the management of waste EV batteries in both the EU and Japan, presenting some options to improve policy in the future.

3. STATE OF PLAY ON ELECTRIC VEHICLE BATTERIES

This chapter provides an overview of some of the key elements regarding the current state of play on electric vehicle (EV) batteries. It outlines the most common types of battery in use in EVs, trends in the quantity of EVs and their batteries and the policies underpinning those trends, and the different approaches available for the management of end-of-life/waste EV batteries.

3.1 Types of EV battery

The principal type of battery used in EVs is **lithium-ion batteries (LIBs)**, with nickel-manganese-cobalt oxide (NMC) and nickel-cobalt-aluminium oxide (NCA) materials being the main cathode types currently in use, accounting for 95% of new electric passenger cars sold in 2019 (IDTechEx, n.d. e). NMC had a 71% sales share in 2020, with NCA making up most of the remainder and lithium-iron-phosphate (LFP) accounting for under 4% of the electric car market (IEA, 2021b). Nissan, BMW, Hyundai and Renault all use NMC types of battery, with Tesla and Chinese manufacturers preferring NCA types.

The composition of LIBs means they contain several high impact, and high value, materials. Nickel can comprise up to 60-80% of the metallic content of current LIBs. Higher nickel content increases the reversible capacity and energy density of batteries, which is beneficial for EV batteries. It can also replace some of the cobalt (which is more expensive than nickel and also a scarce material). As a result, the future trend is likely to be towards higher nickel content, and lower cobalt content, batteries. The use of NMC batteries with a nickel content of over 60% is expected to increase significantly between 2020 and 2030 (IDTechEx, n.d. c). As well as NMC and NCA batteries, this may also include LFP batteries which are well-suited for use in short-range EVs such as electric buses and two-wheeled vehicles, as well as for some stationary applications.

After 2030, other potential technologies may be developed that exceed the performance constraints of LIBs, such as lithium-metal solid state batteries, lithium-sulphur, sodium-ion or lithium-air. These technologies may prove cheaper, more energy dense, with longer life-cycles and would have the additional benefit of using more widely available materials than existing LIB technologies; however such technologies will require extensive testing before they can be scaled up enough to compete with LIBs. (IEA, 2020)

3.2 Trends in EVs, their batteries and the policies driving them

This section first includes a brief summary of the overarching policies in the EU and Japan related to climate change and greenhouse gas (GHG) emissions reductions, which are key drivers for the shift towards EVs with lower GHG emissions. The transport sector is one of the largest contributors to global GHG emissions, so vehicle manufacturers and governments are increasingly taking steps to reduce vehicle emissions as a core contribution to meeting targets in climate-related policies.

3.2.1 Policies driving the shift towards EVs

Both the **EU** and the **Japan** have the overarching target to become climate neutral, i.e. net-zero emission of GHGs, by 2050 (IEA, 2021b).

The **EU**'s nationally determined contribution (NDC) under the Paris Agreement, last updated in December 2020, commits the bloc to reduce its GHG emissions by at least 55% by 2030 (compared to 1990 levels) (Climate Action Tracker, 2021b). In 2019 the transport sector represented 23% of total emissions (Climate Action Tracker, 2021a). It is estimated that EU transport emissions must be reduced by 90% for the bloc to meet its 2050 climate goals (European Commission, 2020c). From 2020, new cars in the EU must meet an emissions standard of 95g CO_2/km. CO_2 emissions from cars must be reduced by 15% from 2021-2025 and by 37.5% from 2021-2030 (by 15% and 31% for vans) (EEA, 2020). From 2025, 15% of new passenger cars and light commercial vehicles must be zero- or low-emission (emitting less than 50g CO_2/km), rising to 35% for cars and 30% for light commercial vehicles from 2030 (Regulation EU/2019/631).

The EU has announced a target to have 13 million passenger zero-emission vehicle (ZEV) stock by 2025, and a further ambition to have at least 30 million passenger ZEV stock by 2030 and almost all passenger light-duty vehicle (LDV) and heavy commercial vehicle stock by 2050 (IEA, 2021b). It has also announced a target to have 55% CO2 emission reductions for new cars and 50% for new vans from 2030 to 2034 compared to 2021 levels and 100% CO2 emission reductions (zero emission vehicles – ZEV) for both new cars and vans from 2035 (EU Council, 2023). Several individual European countries have pledged that 100% of vehicle sales will be ZEVs in the coming decades[1] (IEA, 2021b). Many individual European countries[2] also have purchase incentives in place for EVs, including purchase

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[1] Norway by 2025; Denmark, Iceland, Ireland, the Netherlands, Slovenia and Sweden by 2030; the UK by 2035; France, Portugal and Spain by 2040; and Germany by 2050.

[2] Including Austria, Belgium, France, Germany, Italy, Portugal, Spain, Sweden and the UK. See (IEA, 2021b) for details.

subsidies ranging from EUR 750-6,000 (USD 800-6,800) (typically increasing with the purchase value of the car) and/or tax reductions (no registration/ownership tax in Italy and some regions of France, and exemption from VAT and BEV exempt from VAT (25%) and weight-, CO_2 and NOx-based purchase taxes in Norway) (IEA, 2021b).

Japan's nationally determined contribution (NDC) under the Paris Agreement, last updated in October 2021 (Government of Japan, 2021), commits Japan to reduce greenhouse gas emissions to net-zero by 2050. By the Act Partially Amending the Act on Promotion of Global Warming Countermeasures (Act No. 54 of 2021), net-zero by 2050 became a Basic Principle of the Act. Japan aims to reduce its greenhouse gas emissions by 46% in 2030 from 2013 levels. Carbon Action Tracker (2021c) report that the transport sector accounts for 18% of Japan's GHG emissions. The Government has the policy of 100% of electrified new passenger vehicles (both hybrid and battery) by 2035. Interestingly, Carbon Action Tracker (2021c) reports that, given Japan's dominance in the global automobile market, its policies regarding vehicles could have impacts well beyond its borders.

Such policies demonstrate the key role of EVs in achieving global climate goals, since they serve to decarbonise the transportation and mobility sector, which is one of the main contributors to greenhouse gas emissions. It is also important to note that GHG are not the only emissions of concern with vehicles. Air pollution from nitrogen oxides and particulates is a concern in urban areas around the world and the World Health Organisation has stressed the need for tougher air quality standards. Vehicles that emit low levels of these pollutants are one route to tackling this problem and EVs certainly contribute.

In addition, technological improvements such as increases in battery energy density (leading to improved performance and longer ranges for EVs), increased availability of charging infrastructures, faster charging speeds, and significant reductions in the price of EV batteries, are all contributing to the rollout of EVs around the world. For example, average battery energy density is currently increasing at 7% per year, whilst LIB prices fell by 89% between 2010 and 2020 (BloombergNEF, 2021).

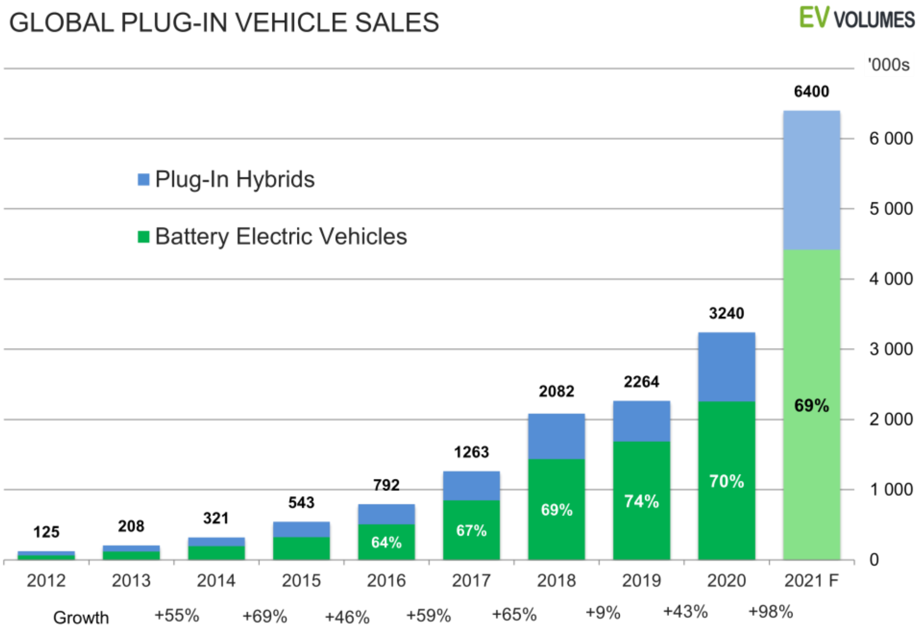
Combined with the policies outlined above, these drivers help to explain the significant increase in global sales of EVs in recent years. The trends in both EVs and their batteries are discussed further in the following sections.

3.2.2 Trends in EVs

There are two main types of EVs: **battery electric vehicles (BEVs)** and **plug-in hybrid electric vehicles (PHEVs)**. BEVs are the most environmentally advantageous, since they have zero emissions at the point of use, though overall emissions depend on the means of electricity production. Emissions from PHEVs depend on the drivers' charging and driving habits, as well as the means of electricity generation, but they provide a short- to mid-term solution by offering more sceptical consumers a longer distance range due to their hybrid propulsion options.

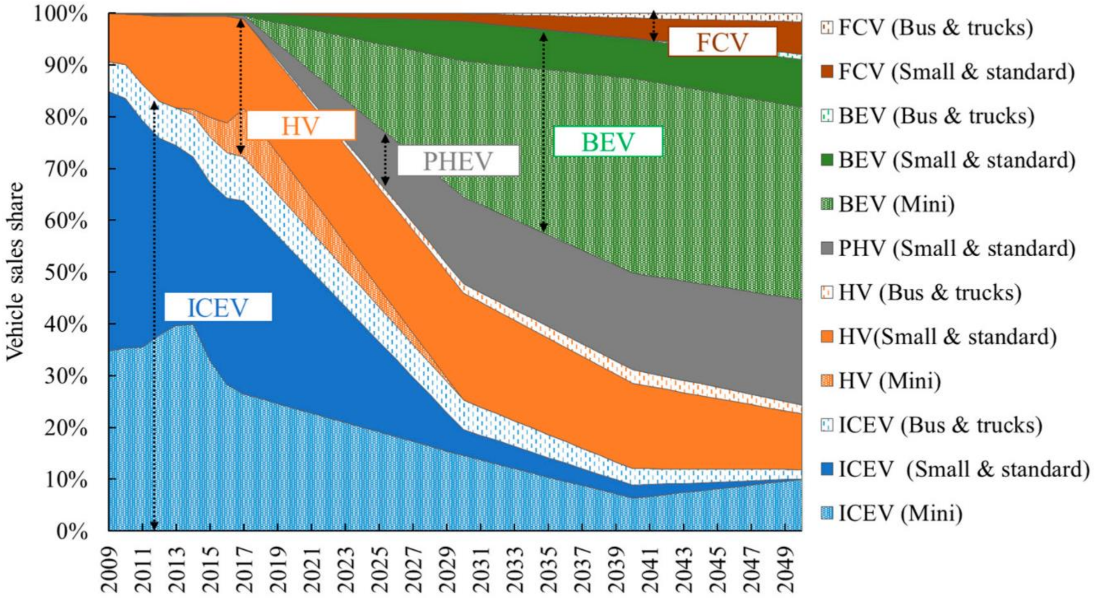
Globally, 2.65 million new EVs were purchased during the first half of 2021, representing a 168% increase from 2020, although it should be noted that sales during the first half of 2020 were 14% lower than during the first half of 2019, suppressed by the first wave of the Covid pandemic (EV Volumes, 2021). Sales growth for EVs during the first half of 2021 was 3 to 8 times higher than for light vehicle markets overall, with the share of BEVs and PHEVs increasing from 3% in the first half of 2020 to 6.3% in the first half of 2021 (EV Volumes, 2021), suggesting a true shift towards EVs. Including a rebound in the popularity of mini-EVs in China, EV sales are expected to reach around 6.4 million (4 million BEVs and 2.4 million PHEVs) by the end of 2021, an increase of 98% from 2020 (EV Volumes, 2021). This would see over 16 million EVs (two thirds BEVs and one third PHEVs) in operation globally by the end of 2021 (EV Volumes, 2021), an increase from the 8.1 million plug-in EVs (BEVs and PHEVs) estimated to be on the road by the end of 2019 (IDTechEx (n.d. b) and 10 million in 2020 (IEA, 2021c). The figure below gives an overview of the global increase in plug-in EV sales from 2012-2021 (EV Volumes, 2021).

Various longer-term estimates suggest that at the start of the 2030s there may be 111 million (IDTechEx, n.d. b), 145 million (The Guardian, 2021a) or even 300 million (IEA, 2021a) EVs in use globally, and that by 2040 anywhere between 150 and 900 million EVs could be on the road (Tsiropoulos et al., 2018), depending on the policies pursued by different governments around the world. EV sales are predicted to reach almost 15 million in 2025 and over 25 million in 2030, which represents 10% and 15% of road vehicle sales respectively (IEA, 2021b).



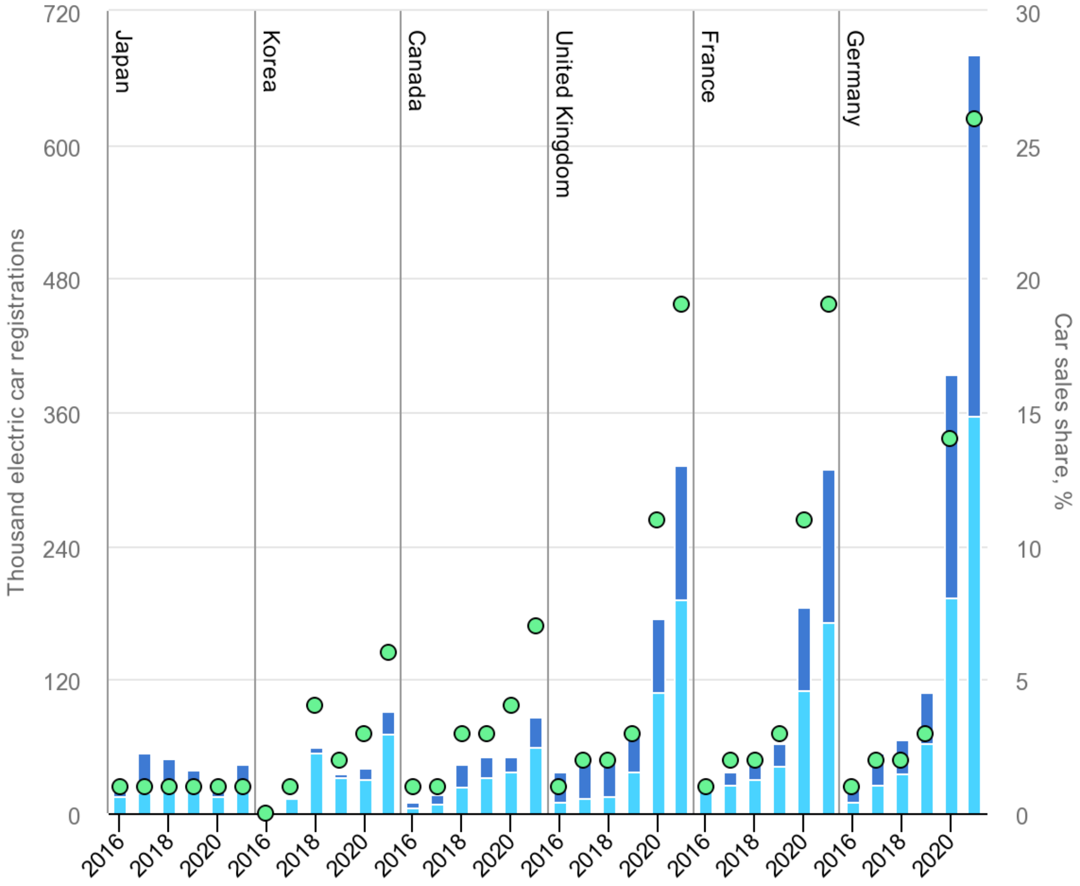
In the **EU** (plus Iceland, Norway and the UK), new registrations of electric cars (including both BEVs and PHEVs) rose from only 700 units in 2010 to around 550,000 in 2019, accounting for a market share of around 3.5% of newly registered passenger vehicles (EEA, 2020). BEVs specifically accounted for around two-thirds of electric car sales, and 2% of total new car registrations, with Germany, Norway and the Netherlands alone accounting for around half of BEV registrations (EEA, 2020). PHEVs accounted for around 1% of total registrations (EEA, 2020). In addition, over 20,000 electric vans (mostly BEVs) were sold in the EU in 2019, representing a market share of 1.3% and an increase of around 0.5% from the previous year. In 2020, EVs accounted for around 10% of new vehicles (52% of which were BEVs, compared to 64% in 2019). In the first half of 2021, EVs accounted for 14% of European vehicle sales, with around 44% of those sales being BEVs (EV Volumes, 2021). EVs had a 40% share in Sweden, 28% in Finland and 27% in Denmark, whilst in several other countries (including Poland, Estonia, Slovakia, Slovenia, Croatia, Romania, Cyprus and Lithuania) they had less than a 3% share (Climate Action Tracker, 2021a). Demand for EVs is being driven by a mix of subsidies, falling costs and growth in EV charging infrastructure (Climate Action Tracker, 2021a). Looking to the future, it has been estimated that there will be 28 million EVs on the road in the EU in 2030, comprising 31% of the vehicle fleet (Engle et al., 2018).

In contrast with the majority of European sales being PHEVs, around 80% of EVs sold outside of Europe are BEVs (EV Volumes, 2021). In **Japan** Sato and Nakata (2019) analysed data from the Ministry of the Environment, the Japan Automotive Manufacturers Association and the Next Generation Vehicle Promotion Centre to predict future vehicle sales. This is shown in the following figure. It shows battery EVs increasing significantly from the 2030s onwards.



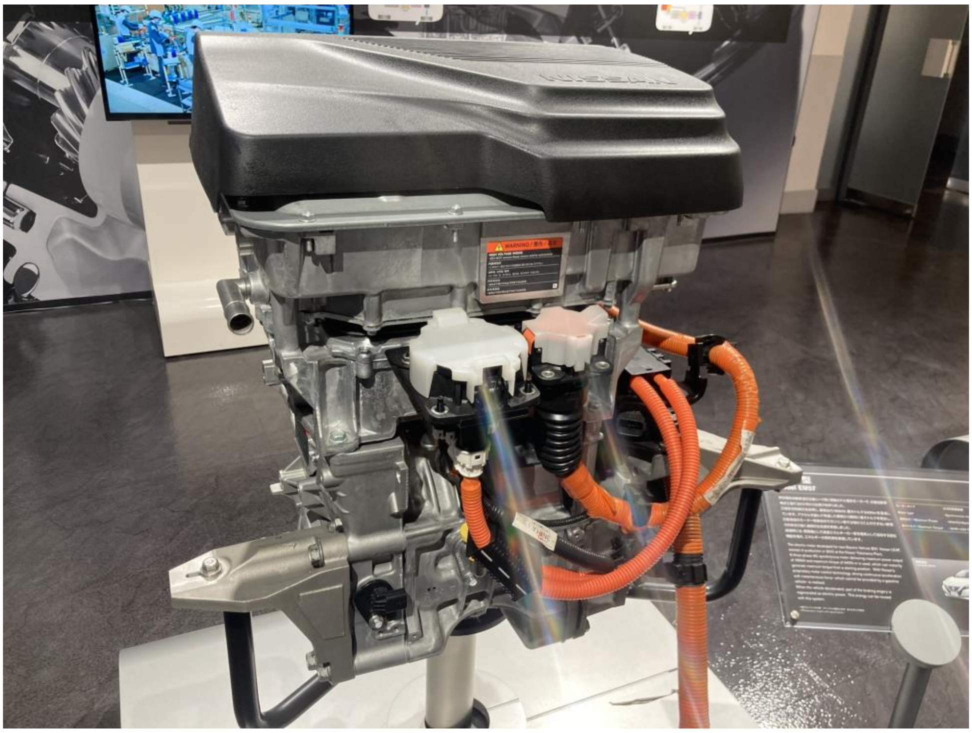
Mini: mini passenger cars, mini trucks.
Small and standard: standard passenger cars, small passenger cars.
Bus and trucks: small trucks, standard trucks, small buses, large buses.

The following figure from IEA (2022a) shows changing vehicle registrations in selected countries in Europe, Asia and North America. For both PHEV (plug-in hybrid electric vehicles) and BEV (battery electric vehicles), registrations have increased significantly in France, Germany and the UK. There have been small increases in Canada and Korea, but little change in Japan. Clearly, this needs to change in Japan if the Government is to meet its targets. At present the main EV vehicle on sale in Japan is the Nissan LEAF. There are several hybrid vehicles available (with battery issues from these), but EVs are slow to emerge. There are imported EVs in Japan (e.g. Volkswagen, Tesla, Volvo) and Japanese automobile manufacturers are exploring EV production outside of Japan (e.g. in the US). Further, infrastructure (charging points, etc.) for EVs in Japan has grown. It is likely, therefore, that the slow growth rate at present will change in the near future.



Regarding **trade in vehicles**, in 2020 the **EU** exported around 5.2 million cars, 725,000 (around 14%) of which were EVs or hybrid. Of these, 27% were electric, 24% plug-in hybrid and 49% non-plug-in hybrid. In the same year, the EU imported around 3 million cars, 892,000 (around 30%) of which were EVs or hybrid. Of these, 34% were electric, 16% plug-in hybrid and 50% non-plug-in hybrid. These trade figures showed an increase in spite of COVID-19; EU exports rose five-fold from 2017 (when 150,000 cars were exported) and imports tripled (from 301,000 in 2017). The main destinations for EU exports in 2020 were the UK (39%), US (16%), Norway (10%) and China (9%), whilst the main imports came from **Japan** (23%), the US (23%), ROK (15%), the UK (14%), Turkey (10%) and China (9%) (Eurostat, 2021).

The Nissan LEAF and its engine (own pictures)



3.3 Trends in batteries for EVs

Globally, LIB production for EVs increased by 33% from 2019-2020 (IEA, 2021b). Whilst China accounted for around 77% of overall LIB production in 2020 (S&P Global, 2021). Global demand for **batteries** has been predicted to increase 14-

fold between 2018 and 2030, driven largely by the increase in EVs (European Commission, 2020c). The market for EV batteries is predicted to increase to be worth US$304.7 billion by 2030 (Financial Times, 2021), with the market for LIB cells in EVs alone forecast to reach US$ 70 billion by 2026 (IDTechEx, n.d. a).

One estimate suggests that the **global** material demand for EV batteries sold in 2019 was around 19 kt of cobalt, 17 kt of lithium, 22 kt of manganese and 65 kt of nickel, and that demand will increase to 180 kt per year for cobalt, 185 kt for lithium, 177 kt for manganese, and 925 kt for nickel (these figures are based on existing stated policies, but demand could be more than twice as high if additional policies are introduced) (IEA, 2020). Important countries for the raw materials contained in LIBs include: China (80% of global refining capacity for the relevant raw materials, 60% of global graphite production), Australia (around 50% of global lithium production, second largest reserves of nickel), Brazil, Chile and Argentina (together accounting for around 58% of global lithium reserves), Indonesia (largest nickel producer globally), the Democratic Republic of the Congo (around 68% of global cobalt mining) and South Africa (28% of global manganese production, largest manganese reserves) (Bhutada, 2021). This emphasises the importance of global trade for LIB production.

Around 800,000 tonnes of automotive batteries enter the **EU** each year (European Commission, n.d.). EV batteries account for around 80% by weight of industrial lithium batteries placed on the EU market, and around 41% by weight of all lithium batteries placed on the market (European Commission, 2019). In terms of production, the EU produces battery packs for EVs using imported cells (mostly from East Asia), but also wishes to increase its production capacity (European Commission, 2019). In 2016, the EU produced over EUR 1 billion worth of nickel cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel iron and other electric batteries, imported EUR 5.5 billion worth, and exported over EUR 2.5 billion worth (European Commission, 2019). In 2019 it was estimated that the EU produced around 5% of the global volume of NiCd, NiMH and lithium batteries (European Commission, 2019). Demand for batteries in 2020 exceeded domestic European production capacity, with capacity at roughly 35 GWh per year, but with potential future capacity of up to 400 GWh by 2025 thanks to the construction of new battery plants (IEA, 2021b). Over the next 10 years, it has been estimated that Europe may serve between 7% and 25% of global demand for LIBs (with notable production capacity in Sweden, Germany, Poland and Hungary) (Oeko-Institut et al., 2021).

Japan has a considerable share of the supply chain downstream of raw material processing for batteries. Japan accounts for 14% of cathode and 11% of anode material production. Japanese companies are also involved in the production of other battery components such as separators. (IEA, 2022b). Battery cell production itself is a capital-intensive process and global production is highly concentrated. In 2021 the top-three producers accounting for 65% of production were CATL (China), LG Energy Solution (Korea), and Panasonic (Japan).

Japan has a problem to ensure recycling of EV batteries and so retain the value of the materials in them within the Japanese economy. This is that a large number of second-hand EV vehicles are sold abroad (particularly to Russia and New Zealand which accounted for 80% of the 7,545 vehicles exported from Japan in the first half of 2022). In 2020, the total amount of recycled automobiles was 3.2 million. Of these 56,000 were hybrid and EVs (i.e. 1.8%). However, second hand vehicle exports in 2020 were 1.3 million vehicles, of which 147,000 were HV and EV (i.e. 11.1%). Therefore, HV and EVs are disproportionately exported as second-hand vehicles (Murakami, 2022). It should be noted that all car owners in Japan pay a small fee to recycle vehicles at the end of their life. However, those buying vehicles to export them can claim this money back (thus making the vehicle slightly cheaper for them than for someone living in Japan).

Nissan has sought to address this by granting a monthly subscription for vehicles to consumers rather than selling the vehicles. This means that the vehicles and the batteries they contain stay in the control of the company. This initiative has been spurred on by the rising prices of the constituent metals of the batteries (Financial Times, 2022).

This issue of export of used vehicles raises the question of how far can the battery ecosystem of Japan (or others such as the EU) be a closed system? Analysis shows that while recycled metals will play an important part in new battery production, they will not meet 100% of manufacturing needs. Further, new vehicles and batteries will be exported. It is also possible that new batteries may be imported. For example, Panasonic has opened a large EV battery production facility in Malaysia. Retaining material within the economy is important, but it is unlikely to ever be a closed ecosystem.

3.4 Management of end-of-life/waste EV batteries

In general terms, waste should be managed in the following order of priority: waste prevention, then reuse (including preparation for reuse), then recycling, then energy recovery, with disposal as a final resort once the other options have been exhausted (see for example the EU Waste Framework Directive, 2008/98/EC, but these principles form the basis of circular economy thinking in many countries and in the UN). This order should therefore also be applied to the management of waste EV batteries. This means that, in practice, all EV batteries should first be

reused for their original purpose (where possible), then **repurposed** for a second-life use, then sent for **recycling**.

To frame consideration of EV battery production, use and end-of-life options, Tao et al. (2022) have usefully broken this into the following stages:

1. Manufacturing batteries in response to customers' demand for EV or energy storage system (ESS) applications.
2. Assembling new or second-use batteries with car bodies to produce EVs.
3. Usage: keeping EVs in use by customers.
4. Maintenance: replacing customers' old batteries with new or second-use batteries due to deterioration.
5. Collection: taking back EV and batteries discarded by users.
6. Direct reuse: allows used batteries to be reused in EV applications.
7. Disassembling, inspection, and grading: extracting used batteries from EVs, tests them, and determines their next processes based on the state of health (SOH) of the batteries.
8. Refurbishment: recovering the SOH of used batteries by replacing defective modules or cells.
9. Repurposing: reusing used batteries for ESS.
10. Recycling: recovering materials from discarded batteries as secondary materials for new batteries.
11. Landfill: disposing of the remained parts of batteries that cannot be recycled.

The lifetime of a LIB is typically between 5 and 20 years, depending on the purpose they are used for and how they are used (Oeko-Institut et al., 2021). Indeed, a EV LIB today will typically outlive the EV it was built into (Castelvecchi, 2021). The performance of LIBs does however diminish over time with use. An EV battery can no longer perform to an adequate level for its intended purpose once it reaches 70-80% of its original capacity (for example because it begins to restrict the range of the EV). It therefore reaches the end life for its intended purpose. Its remaining capacity may still be sufficient for less demanding second-life applications such as stationary energy storage. The alternative, and indeed the next step following any period of second-life reuse, is to send the battery for recycling to recover as much of the useful material it contains as possible.

It is estimated that sales of EVs, including hybrid, in **Japan** will reach a peak in 2040 with 4.17 million sold per year. This is 2.2 times the EV sales of 2018 considering that drastic changes in the HV demand are not expected. However, sales of BEV are expected to reach 1.94 million in 2040, an increase of 11.6 times from 2018. On scrappage, petrol and diesel vehicles will dominate until 2038, reaching 2.58 million scrapped per year compared to 2.45 million of EV. The amount of BEV and PHEV expected to be collected until 2025 is likely to be minimal, being less than 2% of the total ELV each year. On the batteries themselves, those recovered will be mostly from hybrid vehicles in the next few years, but then BEV will increase. Recovered number of EV batteries will reach 61 GWh in 2050, 55 times that of 2018 (Sato and Nakata, 2019, based on data from the Ministry of the Environment, the Japan Automotive Manufacturers Association and the Next Generation Vehicle Promotion Centre). As a result, the authors concluded that 34% of lithium, 50% of cobalt, 28% of nickel, and 52% of manganese required for the production of new lithium-ion batteries could be supplied by recovered EV battery recycling in Japan in 2035.

3.4.1 Waste prevention, reuse and repurposing

With regards to **waste prevention**, one recent study suggested that efforts should focus on **prolonging the lifetime** of LIBs, thereby lengthening their first use phase (Oeko-Institut et al., 2021). Battery design options to achieve a longer lifespan (predicted to become available by 2025) include: making improvements to the Battery Management System and sensoring of the cells (for example by measuring more than one physical range to improve cell management); using sensor-less measurement to reduce wiring and improve energy density; or improving the thermal management to homogenise the cell temperature (VITO and Fraunhofer ISI, 2019). **Repair and maintenance** can also prolong an EV battery's life, for example through repair or replacement of faulty components, as long as the battery is designed to enable repair (Andersen et al, 2021). **Refurbishment** may also be an option to allow **reuse** (use of the battery or components for the original purpose as an EV battery). Not all customers need the maximum capacity of an LIB, meaning that refurbished, but slightly less efficient batteries, can still be acceptable to some consumers (Andersen et al, 2021) and can, therefore, be reused. A recent paper identified six examples of repair, five of refurbishment, and one of remanufacturing amongst battery manufacturers in the EU (Andersen et al, 2021).

Increasing the lifespan of EV batteries in these ways has the associated benefit of delaying batteries' end-of-life, giving more time to develop the necessary processes and infrastructure for the waste treatment and recycling of LIBs (Oeko-Institut et al., 2021). As noted above, however, the challenge for increasing the lifespan of EV batteries is to ensure they retain sufficient charge to deliver journey times to drivers. However, all EV batteries eventually reach a point where they cannot continue to be used for their primary purpose. Therefore, reuse and recycling are also important.

Reuse of an EV battery can take two routes. The first is the complete reuse of the battery as a whole. The second is the reuse of components of the battery. The latter, like repair/maintenance, requires battery design that allows for easy disassembly (note that this is different from recycling).

As mentioned above, reuse for the original purpose as an EV battery is technically feasible, but only until the battery loses a certain amount of its original capacity. The next option is then **repurposing or second-life use**, i.e. use in applications other than use in EVs. This can include residential, commercial or even grid-scale applications, e.g. for stationary energy storage (for example temporarily storing excess power from solar or wind energy, or use in 5G infrastructure or data centres (Greenpeace East Asia, 2020)), or to provide energy back-up/mitigate fluctuations in (renewable) energy generation (Bobba et al., 2018). Indeed, some global explore second-life options for EV batteries. LFP batteries may be particularly suited to second-life use, since they tend to have a longer lifespan and also be safer than LIBs, which is a key consideration for stationary storage. Other repurposing options include applications such as use in forklifts, street lighting, refrigerated vehicles, or hybrid and electric propulsion ships (Andersen et al, 2021). One recent report estimated that repurposed EV LIBs could potentially meet global energy storage needs by 2030, with EVs decommissioned from passenger cars having a value of US$15 billion by the same year (Greenpeace East Asia, 2020).

Whilst repurposing is not currently widespread in the **EU**, some small-scale examples and trials do exist (Oeko-Institut et al., 2021, Andersen et al, 2021). In some countries such as France, Finland and Germany, enterprises have reached agreements with large EV manufacturers (e.g. Renault, Hyundai, VW, BMW and Daimler) to use their still-functioning batteries in second-life applications such as storage for solar energy or 'spare parts stores' for corporate vehicle fleets (Oeko-Institut et al., 2021). Honda Japan has a renewable energy storage partnership in Europe with Societe Nouvelle d'Affinages des Metaux (SNAM) (Tao et al., 2022). The Enel Group energy company is using 90 batteries previously used in Nissan cars at an energy storage facility in the off-grid town of Melilla in Spain (The Guardian, 2021b). Reneos is network of five national battery collection systems (Bebat, Belgium; GRS, Germany; Cobat, Italy; BatteriRetur, Norway; and Stibat, The Netherlands) which arrange legal cross-border take-back and provide recycling or second-life uses for LIBs (Reneos, n.d.). In Belgium, Watt4Ever collects LIBs from vehicles and remanufactures them into new battery packs where possible (Watt4Ever, n.d.). Volkswagen Germany undertakes reuse of LiBs for ESS and charging devices and BMW Germany undertakes grid-scale energy storage and EV-charging and re-purposes EV batteries at many global plants (Tao et al., 2022).

In **Japan** in 2010 Nissan launched the 4R Energy Corporation (Nissan, 2018), a joint venture with Sumitomo Corporation that works on EV battery reuse and refabrication technologies. This has tested the use of former EV batteries for stationary energy storage systems. The "4R" business model, reuses, resells, refabricates, and recycles lithium-ion batteries (Nissan, 2022). When an EV battery packs is delivered to 4R Energy, it is initially analyzed and graded. Grade A batteries can be reused as EV batteries. Grade B can be used to power industrial machinery and big stationary energy storage devices, e.g. from solar panels. Grade C ae used in backup power units for traditional electric grid fails (e.g. in shops with refrigeration). Once graded, the batteries are refabricated for the desired use. 4R Energy has been testing different smaller and larger uses of used EV batteries around Japan (Nissan, 2021). In March 2018, operations began at Japan's first facility for the reuse and refabrication in Namie, Fukushima Prefecture. 4R Energy is developing battery storage systems built with used Nissan LEAF batteries. One example is stationary power storage systems reusing 40 kWh batteries from the Nissan LEAF trailed at ten 7-Eleven convenience stores in Kanagawa Prefecture. In addition, recycled lithium-ion storage batteries were developed for East Japan Railway Company as a power source for railroad crossing security equipment reusing modules from used 24kWh batteries from the Nissan LEAF. The system features longer service life and lower operating costs compared to conventional lead-acid battery power supplies. Field trials began in January 2021. Plans are underway to install about 1,600 units of the production version in 24 railway line sections from 2022 onwards. It is also worth noting that the international evaluation standard for evaluating repurposing[3] batteries was awarded to 4R Energy in June 2019 – the first organisation to receive this.

One recent report estimated that repurposing of batteries could save around 63 million tonnes of carbon emissions compared with the manufacture of new batteries (Greenpeace East Asia, 2020). This is a clear indication that reuse and repurposing of EV batteries can make an important contribution to emissions reductions as well as circularity of the materials contained within the batteries themselves.

3.4.2 Recycling

After reuse and repurposing options have been exhausted, the final destination of EV batteries should be **recycling.** Recycling has multiple potential benefits. It recovers materials for further use, reducing the need for extraction of virgin raw materials and associated environmental damage. It also retains the economic value of those materials.

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[3] The UL1974 Standard for Evaluation for Repurposing Batteries defines the process for determining and classifying the suitability of usage when battery packs, modules, or cells used to drive EVs have finished their intended period of use.

The recovery of materials such as nickel, lithium and cobalt through recycling is typically less environmentally harmful than producing the same materials through mining/extractive activities, which can emit hazardous substances to the environment (Recharge, 2018). Nickel is usually mined from ores with a very small nickel content, resulting in a large amount of waste. The Philippines government suspended nearly half of its nickel mines in 2017 for environmental reasons, and recently it was suggested that two nickel mining companies in Indonesia were planning to use deep-sea disposal for millions of tonnes of raw material waste each year. Current methods for extracting lithium rely on significant energy or water consumption (for extraction from rock and water respectively), although more modern techniques that extract lithium from geothermal water, using geothermal energy, are less resource intensive (Castelvecchi, 2021). Two thirds of global cobalt supply is currently mined in the Democratic Republic of the Congo, where there are concerns over workers' rights and health, and alternative sources such as deep-sea mining also come with environmental risks (Castelvecchi, 2021). Use of secondary raw materials from the recycling sector can also reduce the need for imports/exports and the risk of changes in supply, as well as shielding manufacturers from price fluctuations.

Bird et al. (2022) note that there are three main routes to recycling LIBs:

- Direct recycling involves disassembling the batteries and physically separating the battery components. It requires less energy than other methods, but does require labour.
- Pyrometallurgical methods use thermal energy (e.g. from combustion of the battery shell) and reductants to reduce the battery to metals and slag. This requires larger amounts of energy. It cannot be used to recycle lithium. However, it can be used for other batteries, not just LIBs. Batteries need to be pre-treated before this method can be used.
- Hydrometallurgical methods use aqueous solutions to extract metal by selective precipitation. This requires lower energy, but requires reagents. Batteries need to be pre-treated before this method can be used.

The costs of each method depend on the scale of battery recycling. If less than 20,000 tonne capacity, hydrometallurgy is the most economic, but at higher capacities direct recycling and pyrometallurgy have similar recycling costs.

Globally, the LIB recycling market is forecast to be worth US$ 31 billion per year by 2040, with over half of LIBs (4.3 million tonnes) being recycled in China (IDTechEx, n.d. d). From 2025 onwards, it is estimated that end-of-life EV batteries will dominate the recycling market for LIBs, exceeding batteries from consumer electronics (IDTechEx, n.d. d).

However, the recycling market for EV batteries still needs to adapt to manage the expected increase in the number of waste batteries (Oeko-Institut et al., 2021). In 2019, the **EU** had sufficient infrastructure capacity to recycle around 160,000 EV batteries annually (Alves Dias et al., 2018), which would not be adequate to deal with the expected significant increase in the quantity of waste LIBs in the next few years (Oeko-Institut et al., 2021). This capacity may however expand in the future, attracting imports of waste EVs from other countries for recycling (Alves Dias et al., 2018).

In the **EU**, the new regulation on batteries (see below) will provide a major driver to increase recycling of EV batteries and the metals they contain, with recycling efficiency targets of 80-95%.

The value of the materials in batteries is an important factor in determining whether recycling is economically efficient. If material values are not high enough, and/or waste battery volumes are not high enough, recycling will not be profitable. One study has suggested that for cells that do not contain cobalt or nickel, the value of the recovered materials may never cover the costs of the recycling process (Oeko-Institut et al., 2021). Lithium battery recycling typically focuses on the most valuable components (mainly cobalt and nickel) and recycling of lithium was not profitable in the **EU** until 2016, although some recycling of lithium from slags has begun since then. For example, a Li-ion battery recycling plant opened by Accurec in 2016 with an annual treatment capacity of 5,000 tonnes, and with a recycling efficiency of 59.3% (potentially up to 70.6% if by-product slag is also used for other purposes) (European Commission, 2019). In 2019, LIB recycling in the EU was concentrated in Germany, Belgium and France (European Commission, 2019). Estimates suggest that if 65% of industrial lithium-based batteries were collected, and 57% recycling efficiency for lithium achieved, by 2030 the value of recovered materials (lithium, cobalt, nickel and aluminium) in the EU could reach EUR 408 million, as well as creating 2,618 jobs (European Commission, 2019).

There is ongoing research into new battery technologies to reduce or even entirely remove cobalt from EV batteries. Whilst this would reduce their production and sale cost (cobalt is one of the most expensive materials in EV batteries), it also risks making recycling uneconomical since the other materials in EV batteries, in particular lithium, are currently cheaper to mine than to recycle (Castelvecchi, 2021).

The market for EV batteries and material demand is growing too quickly to be sustained only by recycled materials (Oeko-Institut et al., 2021). One report (Greenpeace East Asia, 2020) has estimated that **globally**, from 2021-2030 up to 10.35 million tonnes of lithium, cobalt, nickel and manganese will be mined for new batteries, using 30% of the world’s known cobalt reserves. The same report estimates that from 2018-2030 lithium use for batteries will increase by almost 30 times. Another recent report stresses that without battery recycling, lithium demand will exceed currently-known reserves by 2050, but that universal battery recycling could lead to recycled lithium supply exceeding total annual demand by 2050 (BloombergNEF, 2021).

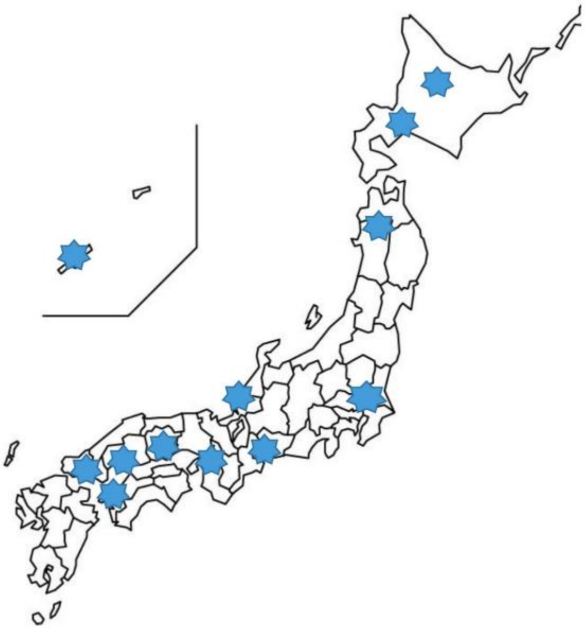
In the **EU**, demand for lithium for EV energy storage batteries is predicted to increase by 18 by 2030 (and 60 times by 2050), and demand for cobalt to increase by 5 times by 2030 (and 15 times by 2050) (European Commission, 2020c). Regarding cobalt, overall demand could increase by 3.7 times between 2017 and 2030, with the growing demand for EVs a significant driving factor (European Commission, 2019). It has also been estimated that 500 tonnes of cobalt could be recycled from end-of-life EV batteries in the EU by 2025, and up to 5,500 tonnes by 2030, providing for 10% of the EU's cobalt consumption in EVs in 2030 (European Commission, 2019). However, the quantities would be hampered if collection rates of waste batteries are not ensured, and/or if there are significant developments in potential for reuse. It has been estimated that recycling and material substitution could reduce the demand of cobalt for EV batteries by 29% between 2020 and 2030 (European Commission, 2019). Meanwhile, on a global level, the growth in the EV market and the trend towards LIBs with higher nickel content has led to an estimate that the demand for nickel from EV batteries may increase ten-fold between 2019 and 2030.

It is important that EV battery recycling is carried out to **high environmental standards**, since careless or improper recycling can have significant negative environmental impacts due to the hazardous materials contained in batteries. The emissions associated with the pyrometallurgical processes used to produce the energy required for recycling, together with emissions from smelting or hydrometallurgical processes, can contribute to climate change, environmental acidification and/or eutrophication (European Commission, 2019). In addition, specific transport, storage and treatment infrastructure is needed for waste batteries, particularly for LIBs, to reduce safety risks (Oeko-Institut et al., 2021). The technology needed for recycling EV batteries, and the environmental impact of recycling, depends on the chemistry of the battery types. The pyrometallurgical process and the refining of copper, cobalt and nickel used for LIBs produces significant GHG emissions, which can be reduced by the use of secondary recycled materials. Overall, around 0.7 tonnes of CO_2 equivalent can be saved per tonne of LIB recycled, in addition to the recovery of lithium (European Commission, 2019).

In **Japan**, a range of laws regulate battery recycling. Vehicle manufacturers must maintain knowledge of battery recycling technology. A nonprofit organization (JBRC – Japan Portable Battery Recycling Center) manages Japanese battery recycling (Nippon Recycle Center Corp, n.d.). There is also an active program to reuse batteries for home emergency power.

The Japan Automobile Manufacturers Association (JAMA) established a common scheme for recovering used Li-ion batteries along with a system for processing these batteries appropriately and put both into operation in fiscal 2018. Toyota Japan undertakes repurposing of LiBs for grid-scale energy storage (Tao et al., 2022). Before this, in October 2010, Toyota initiated a 'battery-to-battery' recycling operation in partnership with Sumitomo metal mining and Prime earth EV energy. A used hybrid battery is removed from the vehicle taken over by offices nationwide. These are sent to one of 12 collection centres around the country. They are then sent to the recycling centre.

Collection centres in Japan for EV batteries (source: Murakami, 2022).



The key recovered materials are sulphuric acid and nickel. However, since 2017 Sumitomo has been recovering and recycling cobalt, copper, and nickel from waste lithium-ion batteries at the Toyo Smelter & Refinery in Saijo City, Ehime prefecture, and its Niihama Nickel Refinery in Niihama City, Ehime prefecture. The waste batteries are calcined at 1,000 °C, causing the cells to open and flammable components like the plastic and solvents to burn off. Magnetic separation is used to separate the metals. The nickel, cobalt, and copper is initially recovered as an alloy, which is then subject to hydrometallurgical processes to separate the individual metals. Note that this system does not recover lithium. The recovered metals can be used to make new batteries or for other uses.

Honda has partnered with Matsuda Sangyo (recycling) and Japan Metals & Chemicals to extract nickel and cobalt from used batteries (Honda, 2018). This involved developing new recycling systems and processes. This involved extracting the two metals as an alloy. A battery pack has four modules, each with 12 cells. In each is a cathode containing nickel and cobalt. The first step is to disassemble the battery. This releases flammable solvents and toxic compounds, so requires care. JMC has worked closely with Honda to determine how to do this. It is important to note that the initiative to tackle recycling of EV batteries is not always that of the automobile manufacturer. Volta Corporation was established in 2018 to recycle large quantities of vehicle batteries and seeks partners in the automobile sector (J4CE, 2022).

The economic basis for recycling is critical for policy frameworks to promote it. If there is money to be made by the recycling sector from managing waste EV batteries, this will be a key driver for the collection and management of those batteries. At present the costs are 10-15,000 JPY per unit (Nakata, pers. Comm.). If the costs of recycling start to outweigh the value of the recovered materials, then policies will need to be put in place to support recycling activities (such as costs to be borne by vehicle and/or battery manufacturers through producer responsibility schemes, etc.). Of course, the economic bottom line for the recycling sector may vary from country to country (depending on type and volume of batteries as well as other costs) and over time. At present automobile manufacturers in Japan bear these costs and the economic rationale for recycling of some metals is not sufficient. This will need to change.

Alongside this are the limitations at present in recycling processes. Effectively there are three types of recycling processes available for EV batteries – thermal, chemical and hydrometallurgical. The former dominates in Japan and this supports recycling of metals such as Co and Ni. However, if other metals, such as Li, are to be recycled, the technologies will need to change. This is what the new EU regulation will do in Europe – it does not prescribe a particular recycling technology, but its targets to recycle metals such as Li will mean that thermal processes will not be sufficient. The danger is that Japan is focusing too much on thermal recycling as the option and this may not be the most desirable option for the future (but changing systems later would be unnecessarily expensive). However, there are initiatives in Japan for recycling of EV batteries with high recovery rates for a range of metals.

More widely, Japan has structural challenges with waste management. Collection is dominated by small companies and there is influence by illegal activity. Waste disposal is heavily dominated by incineration and this locks the system into patterns which are not conducive to a circular economy. There are moves to change this, but it is a major structural challenge. At present the systems to manage EV batteries are developing outside of this wider waste management system, but deeper circular economy challenges will become important in the future.

4. POLICIES FOR THE MANAGEMENT OF WASTE BATTERIES

This section summarises key points of the policy and legislation in place in the EU and Japan relevant to the management of waste batteries from EVs.

4.1 Policies in the EU

The existing EU **Batteries Directive** (Directive 2006/66/EC), dating from 2006 and last revised in 2013, requires the separate collection and regulated storage or treatment of EV batteries. EU Member States must maximise the separate collection of waste batteries and meet targets for the collection of waste batteries (45% of the amount placed on the market by 2016) and for recycling efficiencies for lead-acid (65%), nickel-cadmium (75%) and all other 'general' batteries (50%). In addition, the Directive required the development of extended producer responsibility (EPR), whereby battery producers are made responsible for the collection and recycling of batteries when they become waste, and the associated costs. Finally, the Directive prohibits the disposal of automotive batteries in landfills or by incineration (although residues of treated and recycled batteries may be disposed of in these ways).

The Directive has been successful in creating EPR for batteries, and increasing the collection rate for waste batteries, although it should be noted that by 2019 only 14 of the then-28 EU countries had met the 2016 collection target (European Commission, 2019). Most countries had also met the required recycling efficiencies by 2016. The Directive has also been criticised for not setting specific targets for the collection of waste industrial or automotive batteries. In its current form, LIBs are only included in the recycling efficiency target of 50% for 'other' batteries; there is no specific target for LIBs, nor specific provisions for their treatment or recycling. This means that at present there is not a sufficient incentive to make significant efforts to recover LIBs (European Commission, 2019). The Directive also does not contain a reporting obligation on the collection of vehicle batteries. Although it is assumed that the high economic value of EV batteries ensures a high collection rate, there is no specific data to support this. However, based on information from EV and battery producers and manufacturers, it has been estimated that around 2-4% of waste automotive batteries in the EU are lost each year, for example through exports or illegal scrapping of used vehicles (European Commission, 2019).

In 2020, however, the EU proposed a **new Batteries Regulation** (European Commission, 2020a) to replace the existing Batteries Directive. This has since been debated and amended by the European Parliament and Council who have reached agreement on the text (European Parliament, 2023). At the time of writing, it has not been formally adopted, but it is now clear what the Regulation will require. As part of the new information provisions of the Regulation, it introduces a **digital battery passport**. This contains information relating to the battery model and information specific to the individual battery including as a result of the use of that battery, including information on recycled content in the battery. Information is to be available on the state of health and expected lifetime of EV batteries using a **battery management system**.

The Regulation sets **minimum recycled content** for new of metals recovered from battery manufacturing waste or post-consumer waste. This is for two dates – 8 years and 13 years after entry into force of the Regulation.

Metal	Minimum percentage recycled content after 8 years	Minimum percentage recycled content after 13 years
Cobalt	16	26
Lead	85	85
Lithium	6	12
Nickel	6	15

The Regulation does not oblige EV batteries to be used for **second life** after they are no longer usable in vehicles. However, this is clearly facilitated by different aspects of the Regulation. **EPR** applies to whoever places the battery on the EU market (including if the first time that is done is with a repurposed battery). The financial contributions paid by the producer shall cover the costs for separate collection, transport, etc. of waste batteries. For repurposed batteries costs may be shared between original producer and that selling the repurposed battery. Producers of EV batteries shall **take back**, free of charge and without an obligation on the end -user to buy a new battery, all waste batteries. To reuse or repurpose EV batteries, the battery holder must provide the following information:

- evidence of state of health evaluation or testing confirming the capability of the battery to deliver the performance relevant for its future use;
- further use of the battery is documented by means of an invoice, etc, transferring ownership; and

- evidence of appropriate protection against damage during transportation, etc.

The regulation establishes **minimum recycling efficiencies** by weight for different types of batteries for two dates – end of 2025 and end of 2030.

Battery type	**Minimum recycling efficiency (percentage) by 31 December 2025**	**Minimum recycling efficiency (percentage) by 31 December 2030**
Lead-acid	75	80
Lithium-based	65	70
Nickel-cadmium	80	80
Other	50	50

The Regulation also sets out the **minimum levels of recovered materials** as percentages for five metals, to be met by the end of 2027 and end of 2031.

Metal	**Minimum percentage recovery by 31 December 2027**	**Minimum percentage recovery by 31 December 2031**
Cobalt	90	95
Copper	90	95
Lead	90	95
Lithium	50	80
Nickel	90	95

EV batteries (and other automotive batteries) are also subject to the requirements of the EU **End-of-life Vehicles (ELV) Directive** (Directive 2000/53/EC), including those on recycling and use of substances. The Directive's vehicle reuse and recovery rate of 95% is consistently met by EU countries. However, with recent technical developments and the growth of EVs, it may become harder to correctly categorise new types of batteries, such as those in hybrid cars which can act as both ignition and electromobility batteries. In addition, it can cause confusion that the vehicle batteries retired from ELVs count towards the ELV Directive's targets, but when they are recycled they count towards the Batteries Directive's targets (European Commission, 2019).

It is worth noting that these pieces of EU legislation apply to all batteries (or vehicles, where appropriate) placed on the market in the EU, and therefore Japanese manufacturers must also abide by their provisions in order to export their EVs or EV batteries to the EU, with the accompanying implications for trade.

4.2 Policies in Japan

There are several **recycling** acts/laws in Japan, covering different products, materials, etc. However, there is no specific battery law. The most important overarching legislation is the Act on the Promotion of Effective Utilization of Resources, first adopted in 1991 and revised in 2000, with the Basic Act on Establishing a Sound Material-Cycle Society. This promotes reduction and reuse of waste. Under the 2000 Law for Promotion of Effective Utilization of Resources (LPUR) made specific requirements for compact rechargeable batteries. Business operators are encouraged to conduct independent and autonomous collection and recycling activities. Manufacturers should conduct self-collection of waste sealed batteries by designating self-collection points, or other measures. A March 2001 ministerial ordinance provided further requirements on take-back, including that manufacturers can work with third parties, including on reuse and processing of batteries. Article 2 of the ordinance states that manufacturers shall provide a target ratio to total weight of utilizable resources such as metals in batteries.

The Government of Japan has set a **target** that, by 2035, all new cars sold will be "environmentally friendly". The Government calls these "clean energy vehicles" and they include battery electric vehicles, plug-in hybrid electric vehicle and fuel cell electric vehicles (US International Trade Administration, 2021). In November 2021, the Government agreed to provide JPY 37.5 billion for e-mobility, including vehicle subsidies and charging points. Japan has the target to deploy 150 000 EV charging points by 2030 and it is supporting this with JPY 12.5 billion for new EV charging and hydrogen refuelling stations (IEA, 2022b). Note that while hybrid electric vehicles are classed as "environmentally friendly", they are not eligible for the clean energy vehicle subsidy.

Interestingly, **Tokyo** has adopted a target for EVs that is more ambitious than that of the Government of Japan (Nikkei Asia, 2020). This is that all new cars to be sold in the city are clean energy vehicles, but by 2030 rather than 2035. It will do this by requesting that that automobile manufacturers comply, rather use regulations. The hope, therefore, is that they will comply to avoid a reputational risk. However, Nikkei Asia (2020) noted that while some manufacturers like Toyota and Nissan are likely to be on track to deliver this earlier goal, others like Daihatsu Motor may have a problem as their compact vehicle range is still petrol-based and one, unnamed company, stated it would not be able to meet the target. As a result, some manufacturers, like Honda, complained that Tokyo had not properly consulted the sector.

However, it is also interesting that at the June 2022 G7 meeting in Germany, Japan pushed to remove a target for zero-emission vehicles from the G7 communique (Yamazaki and Abnett, 2022). The draft text stated included a "collective goal of at least 50% zero-emission vehicles by 2030", but the final text instead stated, “We commit to a highly decarbonised road sector by 2030 including by, in this decade, significantly increasing the sales, share and uptake of zero emission light duty vehicles, including zero emission public transport and public vehicle fleets. We recognise the range of pathways that we are adopting to approach this goal” (G7, 2022). Further Yamazaki and Abnett (2022) reported that this coincided with concern from investors that the Japanese automobile sector was being too slow to take up EV technology and had actively lobbied against regulation in this area, for example Toyota lobbying that hybrid vehicles should be supported as much as zero-emission battery EVs.

The Japanese Automobile Recycling Law, passed in July 2002 (in force April 2005), requires that all end-of-life vehicles must be dismantled and recycled in an environmentally friendly way (Japanese Ministry of Economy, Trade and Industry, 2006 and Fricke, 2022). The Government obliges the use of an IT tracking system to ensure this is done. The Government also requires an effective recycling rate of 95% and 13 Japanese automobile manufacturers have joined forces to support recycling facilities. Purchases of vehicles must pay a fee in advance to support recycling, the main responsibility is on the manufacturer. Nissan, for example, reports that it has achieved a 95% recycling rate for ELVs since 2005 and achieved a final recovery ration of 99.4% in 2021 (Nissan, 2022). There are, therefore, strong similarities between EU and Japanese laws on end-of-life vehicles and, indeed, Sakai et al. (2014) argued that the economic relationships between Japan and the EU was a major driver for the development of the legislation in Japan.

Japan does not have detailed legislation on managing end of life EV batteries comparable to the EU. The law making system in Japan means that adopting such legislation is a long process. Firstly, the issue comes under the competencies of two Ministries – Environment and Economy. Both need to be involved in the development and drafting of any law. Further, each Ministry is supported by an Advisory Council of stakeholders who have to agree the new law. In this case, both Advisory Councils would need to agree it. This is before it would go to wider cabinet and then adoption. Of course, adoption of law in this process happens, but it does make the task large for civil servants and politicians. It is possible legislation on EV batteries may be adopted in the future, but at this stage it is more likely that action under the general legislation will continue, with voluntary approaches, and Japan will determine how effective this approach is.

At present, therefore, the drivers for reuse and recycling of EV batteries in Japan comes from voluntary initiatives by automobile manufacturers. This is under the general legal frameworks for recycling and managing ELVs, but the details are not in law. Such actions may be those of individual companies (often an automobile manufacturer with a waste and/or metallurgical company) or collectively through organisations like JAMA.

5. CONCLUSIONS AND FUTURE POLICY OPTIONS

This final chapter discusses some of the key aspects to be addressed to improve the management of EV batteries in both the EU and Japan throughout their life-cycle. Aspects are discussed relating to: policy, legislation and targets; battery design and information; economic and financial considerations; and international considerations.

5.1 Policy and legislative considerations

It is crucial to ensure that there are **policy and legislative frameworks** in place that put a value on the sustainability of EV batteries throughout their lifecycle (IEA, 2021a). Such frameworks have multiple purposes and impacts, including the setting of targets (for collection, reuse, recycling and so on), providing support for the development of recycled materials from EV batteries, and incentivising stakeholders throughout the battery value chain, from manufacture right through to end-of-life, to pursue the most sustainable solutions possible. Legislation also has an important role in clarifying the **priority for the management of waste EV batteries**, namely reuse, then repurposing, then recycling. Legislation should also ban the landfill or incineration of EV batteries, as is the case in the **EU**'s Batteries Directive.

It is also important to **engage stakeholders in policy-making**, to ensure that their expertise and knowledge is used in the design of policy and legislation, and also that policies have broad support. One example of this is the Global Battery Alliance (GBA), which in 2020 agreed a set of guiding principles to create a sustainable battery value chain by 2030 that have been supported by 42 organisations from the automotive, mining, chemicals and energy sectors (IEA, 2021b). They include aspects such as: maximising a battery's first life; enabling a second life use; ensuring the circular recovery of battery materials; reducing GHG emissions; prioritising energy efficiency and renewables; protecting public health, workers' rights and the environment; and supporting responsible trade.

In the **EU**, **setting (legislative) targets for recycling of lithium** from (EV) batteries (as per the proposed new Battery Regulation) will provide a major incentive for collection and recycling, supporting the development of the recycling market. Although LIBs contained in EVs should be relatively easy to track, collect and manage since vehicles are typically well-regulated throughout their life cycle, setting such recycling targets would incentivise more **efficient and effective collection**. Improved collection would help to tackle the shortage of waste batteries (one of the major current barriers to recycling). This would in turn allow greater costeffectiveness and efficiency of recycling, as well as increasing the share of secondary lithium and cobalt available for the manufacture of EV batteries (in the EU) (European Commission, 2019). It would also create a greater incentive to scale up existing recycling infrastructure in preparation for future years, when many more EV batteries will become waste. It is worth noting that some commentators suggest recycling infrastructure will develop precisely in response to the future increase in waste EV batteries, which will create economies of scale that make recycling more economically attractive. Indeed lead-acid batteries (which are used in petrol cars) are economical to recycle because of the volumes available, leading to a recycling rate of over 98% even though they are less valuable than LIBs (Castelvecchi, 2021).

It is important to have a **coherent, regularly reviewed and updated body of legislation** related to EV batteries and their management when they become waste. For example in the **EU**, there are indications that there can be confusion about how EV batteries count towards the targets of the ELV Directive and the targets of the Batteries Directive. There is also confusion over when a battery becomes categorised as waste, which has impacts for how the battery must be dealt with. Issues such as this should be addressed to ensure that targets in different pieces of legislation are complementary without overlapping, and also to ensure that waste management of batteries can be accurately monitored and reported. **It is important that legislation in the EU and Japan is clear and unambiguous so that it can be readily and accurately interpreted by the private actors and public authorities whose responsibility it is to implement that legislation**.

With regards to **reuse and repurposing**, rules and/or guidance on secondary applications for EV batteries after they reach the end of their initial life in vehicles would help to ensure that they can be reused for those purposes. Clear and comprehensive **definitions** for EV battery components and appropriate second-life uses, together with minimum **quality standards** for used batteries would help to enable reuse and repurposing (Hill et al, 2019). Mandatory (legislative) or voluntary (business-led) **reuse and/or repurposing targets** could also be considered (Hill et al, 2019). As of 2017, there were no standards or regulations in place worldwide related to battery reuse (Tytgat & Tomboy, 2017). In the **EU**, the provisions of the current Batteries Directive have been identified as a barrier to reuse of EV batteries in other applications. However, the proposed new EU Battery Regulation will require EV batteries to have a battery management system that stores, and allows easy access to, the data needed to determine the health and anticipated lifetime of batteries.

Regarding **extended producer responsibility (EPR)**, the fees paid by producers via EPR schemes for batteries in the EU and Japan can be used to provide financial support for recycling infrastructure, helping to make recycling (more) financially viable. In the **EU**, there has been some uncertainty around EPR obligations when repurposing EV batteries, and the suggestion that greater clarity is needed on who becomes responsible for recycling when a battery is repurposed (Andersen et al, 2021).

Options regarding policy and legislation in the EU and Japan

Ensure policy and legislative frameworks related to EV batteries are coherent, regularly reviewed and up-to-date, place a value on the sustainability of EV batteries throughout their lifecycle, and clarify that waste EV batteries should first be reused, then repurposed, then recycled.

Ensure that legislation is clear and unambiguous with regard to its obligations and to whom they apply.

Set (legislative) targets for the recycling of lithium from EV batteries, to incentivise collection and recycling and support the development of the recycling market.

Provide guidance on secondary applications for EV batteries to facilitate their reuse and repurposing, including clear definitions and minimum quality standards.

Ensure EPR is applied to LIBs from EVs, and also that it is clear regarding who is responsible for EV batteries when they are reused or repurposed.

Consider setting targets (mandatory/legislative or voluntary/business-led) for reuse and repurposing of EV batteries.

Ensure stakeholders throughout the batteries value chain are engaged in policy-making.

5.2 Battery design and information considerations

The **design of batteries** can pose a challenge to their reuse, repurposing or recycling. If batteries are not designed for recycling, disassembly and sorting can be difficult, time-consuming, costly and even potentially dangerous. It has been estimated that current battery design means around 50-60% of materials can be recovered, but that improved design could result in rates of up to 80-90% recoverability (Oeko-Institut et al., 2021). For example, many current batteries include components that are welded together and can be difficult to break apart (The Guardian, 2021b). This can be addressed by alternative design such as fasteners that compress metal components together and can be decompressed at the end-of-life stage of the components in question (The Guardian, 2021b). The **variety of battery types** also poses a challenge, since it has an impact on exactly how the battery can be recycled. In addition, EV batteries have a lower embedded value per kWh than consumer electronics batteries, which means recyclers will need to extract more and purer material for recycling processes to be economically viable (IDTechEx, n.d. d). Nevertheless, recyclers have stated that all metals recovered from LIBs through recycling processes can be used to manufacture new LIBs, provided they are adequately purified (Oeko-Institut et al., 2021).

To facilitate reuse, repurposing or recycling, consideration could therefore be given to regulating the integration of environmental aspects into battery design, for example through **eco-design requirements** relating to battery composition and disassembly (Hill et al, 2019).

Adequate and accurate information about/labelling of batteries and their chemistry/content, modular design, and greater harmonisation of battery chemistry and design (Oeko-Institut et al., 2021), would facilitate their reuse or recycling. This would enable recycling technologies to be developed, infrastructure to be increased, and safety (both human and environmental) to be maximised, including during the transportation and storage of EV batteries at the end of their life. One approach that has been proposed would be to increase consumer awareness about batteries' recyclability by implementing a label comparable to those already in use for the energy efficiency of domestic appliances (e.g. A+, A, B, C, etc.) (Oeko-Institut et al., 2021). However, some researchers have noted that many producing companies in Japan, the ROK, China and the US are reluctant to share information, which hampers greater harmonisation of battery design and the processes and infrastructure to deal with them during their end-of-life phase (Oeko-Institut et al., 2021).

Nevertheless, significant progress is being made towards the introduction of **product passports** for batteries. This would offer a more reliable and accessible source of information relevant to reuse and recycling, to support the batteries value chain. The **EU**'s new Battery Regulation would require manufacturers to provide a 'battery passport' for each EV battery placed on the market. This will be a unique electronic record linked to information about the basic characteristics of the type and model of battery which will be stored in an electronic system common across the EU (Oeko-Institut et al., 2021). This obligation would apply to any batteries or EVs imported from **Japan** into the EU and, therefore, could have knock-on consequences for the domestic EV market in Japan. The Global Battery

Alliance (GBA) is currently working on a digital passport (possibly a QR code or RFID tag) with information on the materials (and possibly recycled content), health and remaining capacity of a battery, thereby allowing vehicle manufacturers to assess its suitability for reuse or recycling (The Guardian, 2021b). The GBA's battery passport would effectively be a 'digital twin' of its physical battery (in line with the EU's proposed requirement), and the GBA aims to develop it to be fully functional during 2022 (IEA, 2021b).

Options regarding battery design and information in the EU and Japan

Ensure EV batteries are designed with the end of their first life in mind, to enable their reuse, repurposing, disassembly, sorting and recycling.

Consider setting eco-design requirements for EV batteries, for example relating to composition and disassembly.

Ensure that adequate and accurate information about batteries, for example through labelling.

Consider the introduction of product passports for EV batteries, e.g. as mandated in the EU's new Battery Regulation, and seek harmonisation of such passports globally to ensure ease of trade.

5.3 Economic and financial considerations

Whilst reuse and repurposing activities are increasing, many are still not fully operational, or remain at the scale of smaller trials. In addition, the cost of recycling of EV batteries remains high. Further, businesses require a reasonable level of predictability before making investments. As mentioned above, keeping legislation up to date is important as it helps to provide greater certainty to businesses throughout the battery value chain. This can help to encourage businesses to develop appropriate business models to facilitate the reuse, repurposing and recycling of batteries, as well as enabling the development of appropriate collection and waste management infrastructures.

Funding for research and development (R&D) would also help to facilitate developments of this type (Oeko-Institut et al., 2021). Other **financial incentives** can also help to attract investors, such as tax credits or subsidies for certain investments, or reduced tax rates for reuse, repair or repurposing.

Options regarding economic and financial considerations in the EU and Japan

Provide funding for R&D for the development of circular business models and recycling technologies for EV batteries.

Consider the use of financial incentives such as tax credits, subsidies or reduced tax rates to encourage investment in EV battery circularity.

5.4 International considerations

Until the costs of recycling and disposal of LIBs in the **EU** become lower, there is the risk that they (and/or the EVs that contain them) may be exported to non-OECD countries just prior to their end of life for reuse (Oeko-Institut et al., 2021). This is a plausible scenario in particular if demand for renewable energy technologies and EVs in these countries increases in the coming years. If those countries do not have stringent environmental regulations or appropriate infrastructure for the waste management of batteries and vehicles, this could have **severe environmental impacts on the importing countries**. To tackle this, it would be important to **place additional requirements/controls on the export** of used LIBs in EVs, such as quality standards requiring batteries to be "at least as good as new" in terms of their capacity or lifetime, safety measures for shipments and appropriate labelling of hazardous substances (Oeko-Institut et al., 2021).

Exports of waste EV batteries also lead to the **loss of valuable critical raw materials** from the exporting country. Although it may be economically advantageous and efficient to concentrate recycling in a small number of countries or markets, the risks, costs and environmental impacts of the transportation of waste or near-end of life EVs and/or EV batteries also need to be considered.

As noted earlier in the report, **international cooperation**, in particular between trading partners such as the **EU** and **Japan**, would help to ensure safe and environmentally sound trade in EV batteries. Trading partners must of course be aware of the **policy and regulatory landscape** relating to EVs and EV batteries in the markets to which they export products, to ensure that any exported products meet the necessary requirements and standards. For example, the EU legislation outlined in this report applies to all batteries (or vehicles, where appropriate) placed on the market in the EU, and as such Japanese manufacturers must also abide by their provisions to export their EVs or EV batteries to the EU. Deeper cooperation could also be considered. A more formal **alignment of legislation**

and standards may be appropriate, and would also have the benefit of facilitating trade. **Certification schemes** that require international standards to be applied to manufacturing would enable traceability across borders (Hill et al, 2019). Other less formal types of cooperation between businesses could also be considered, for example creating **platforms to share best practices** and lessons learned from national or local initiatives (Hill et al, 2019) throughout the battery value chain.

Options regarding international considerations for the EU and Japan

Ensure there are appropriate requirements, controls and quality standards placed on the export of used EV batteries, to reduce environmental and safety impacts on importing countries.

Ensure compliance with EV battery-related policy and regulatory frameworks in export markets.

Consider alignment of legislation and standards between trading partners (such as the EU and Japan).

Consider the introduction of certification schemes for EV batteries based on international standards, to facilitate trade.

Create platforms to share best practices and lessons learned from national or local initiatives.

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