ZERO WASTE SCOTLAND

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

Scottish Enterprise

BATTERY USE IN SCOTLAND NOW AND IN THE FUTURE

PHASE 2 – THE FUTURE OF BATTERIES IN SCOTLAND

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Investing in a Smart, Sustainable and Inclusive Future

FOREWORD

Scotland's world-leading targets to help end the climate crisis include fuelling half of Scotland's heat, transport and electricity demand from renewable sources by 2030.

Achieving this rapid transition from fossil fuel producer and consumer to global pioneer of green power will involve a huge transformation of our energy systems. To get there, we need to move from centralised to local energy supplies and establish abundant energy storage to ensure supply meets demand.

We will also need more options for zero emission transport, such as electric vehicles.

The UK Government's decision to outlaw the sale of new petrol and diesel cars by 2030 is accelerating that with more people switching to electric cars.

This rising use of electric vehicles is increasing the number of batteries needed to power them. In parallel to this, the last decade has also seen an explosion in ownership of smart phones, laptops and other portable consumer electronics all powered by rechargeable batteries.

All batteries have a limited primary life span. But at their ultimate end-of-life they still contain valuable and potentially hazardous metals and other materials that should be collected and reprocessed. We need a system in place to keep batteries in use for as long as possible, and then to reuse the materials they contain in other ways. With no such system, the growth in demand will put unsustainable pressure on already vulnerable supply chains, depleting raw materials on a global scale.

The single biggest cause of the climate crisis in Scotland is everything we produce, consume and too often waste. Keeping products like batteries in a loop of use through the circular economy is key to ending this waste and the damaging emissions it creates.

It is already possible to reuse, repurpose, and remanufacture batteries but this is not currently taking place in Scotland at any significant level. As a result, these precious resources are being exported to other countries for disposal and recycling – losing their value and increasing carbon emissions.

Embedding the circular economy in Scotland's transition to green energy to help end the climate crisis would retain these resources and their value within our borders as use of batteries grows. This would give Scotland a way to produce batteries which reduces carbon emissions and creates significant new job opportunities in the process. Future innovation should also focus on producing new batteries designed with end-of-life in mind, which are easy to disassemble to increase their value.

This research is the result of an important new collaboration between Zero Waste Scotland, Transport Scotland, and Scottish Enterprise. This joint work recognises that future policy decisions will affect the growth in battery use and production in Scotland, and their wider environmental and economic impact. Our key objectives were to assess the current battery sector in Scotland, in order to identify the potential for Scottish companies to improve sustainability and increase circularity within the supply and disposal chains.

This report builds on the findings within the first report in the series of three, and considers the future for portable, automotive and industrial batteries, excluding electric vehicle batteries which are considered separately in the third report.

The research takes into consideration how battery uses and chemistries may change in future, making projections from the gathered data and then considers what opportunities may be available to Scottish companies to engage in battery developments, and to improve the sustainability and increase the circularity of the battery value chain.

To understand the necessary adjustments that are needed, this report considers the key new chemistry types and technologies being developed, battery uses (primary use and subsequent uses) and circular economy opportunities.

This has provided us with a clearer picture of the opportunities for Scotland in improving the circularity of the battery industry. This will help inform policy decisions, as well as investment in future collection infrastructure and waste management solutions to improve the sustainability of the battery supply chain.

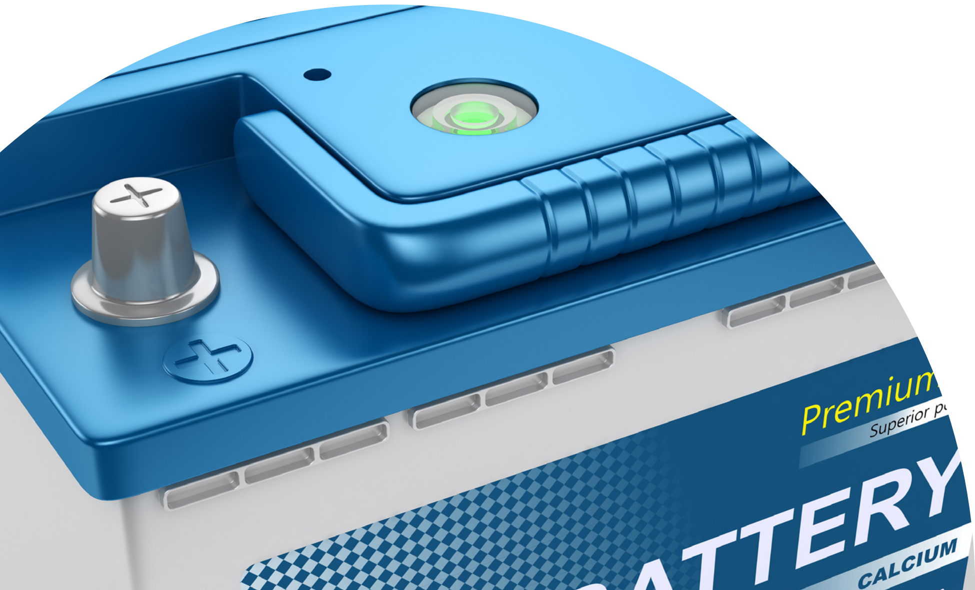
This information and knowledge will help in efforts to ensure the Scottish Government achieves its aim of ending the nation's contribution to the climate crisis by 2045.

This is the first time that Zero Waste Scotland, Transport Scotland and Scottish Enterprise have worked together as a project team to take a joined-up approach to the material aspects of the increasingly decarbonised transportation system. This sector will undergo rapid and transformational change in the next decade and we firmly believe that embedding a circular economy approach will deliver a just and prosperous transition for Scotland.

Zero Waste Scotland exists to lead Scotland to use products and resources responsibly, focusing on where we can have the greatest impact on climate change. Using evidence and insight, our goal is to inform policy, and motivate individuals and businesses to embrace the environmental, economic, and social benefits of a circular economy. We are a not-for-profit environmental organisation, funded by the Scottish Government and European Regional Development Fund.

Transport Scotland is the national transport agency for Scotland, delivering the Scottish Government's vision for transport.

Scottish Enterprise is Scotland's national economic development agency committed to growing the Scottish economy for the benefit of all, helping create more quality jobs and a brighter future for every region.



CONTENTS

1 INTRODUCTION

Zero Waste Scotland, Transport Scotland and Scottish Enterprise (hereafter referred to collectively as the Project Group), have commissioned Ricardo Energy & Environment to:

- Provide a detailed picture of current battery use in Scotland
- Give short to medium-term projections for how that will develop, including specific electric vehicle battery projections
- Highlight future policy or regulation considerations to improve sustainability and support a greater level of circularity across the entire battery life cycle

This report covers Phase 2 of the project and, in parallel with Phase 3, follows on from the Phase 1 report which provided details and discussion of current battery use in Scotland.

The aim of Phases 2 and 3 is to provide insight into how battery use and chemistries may change in future, making projections from the data gathered in the previous phase. The project also aims to understand, through literature research and stakeholder engagement, what opportunities may be available to Scottish companies to engage in battery developments, and to improve the sustainability and increase the circularity of the battery value chain.

This report focuses on portable, automotive, and industrial battery categories, excluding electric vehicle (EV) batteries. EV batteries are discussed in the separate Phase 3 report.

The transition to a more circular economy will require changes throughout the battery value chain. To understand the necessary adjustments that are needed, this report considers the key new chemistry types and technologies being developed, battery uses (primary use and subsequent uses) and circular economy opportunities.

Effective policy mechanisms may be needed to encourage the development of infrastructure to support circular economy approaches for batteries, particularly when the economics may not favour short-term implementation. It will also be important to consider the future regulatory mechanisms, in particular the design and manufacturing stages, that will be integral to the development of a circular economy.

2 METHODOLOGY

This phase of the project focuses on developing a quantitative and qualitative understanding of future levels of battery use in Scotland, and the associated regulatory and end-of-life processes.

The activities undertaken to develop this understanding were:

- Projection modelling of available battery supply and end-of-life data
- High-level policy and literature review
- Stakeholder engagement interviews

The methodology followed for these activities is described in the remainder of this section.

2.1 Projection modelling

Data accessed
In order to project levels for batteries placed on the market and battery waste in Scotland from 2025 to 2050, data was sourced from:

- The National Packaging Waste Database (NPWD)[1] for portable batteries placed on the UK market (POM) and all battery waste in the UK from 2015 to 2019
- The Office for Product and Safety Standards (OPSS)[2] for industrial and automotive batteries placed on the UK market from 2017 to 2019
- The Department for Transport (DfT)[3] for the number of Ultra Low Emission Vehicles (ULEVs) registered for the first time in the UK from 2011 to 2019

Gaps, limitations and assumptions
Based on the data available for this study, the following gaps and limitations were identified:

- General low granularity of battery chemistry (two named types and 'Other')
- No Scotland specific data
- No explicit information on the proportion of industrial batteries POM which are ULEV batteries.

To fill these gaps the following assumptions were made:

- To estimate the Scottish share of battery POM and waste, Ricardo used the share that the Scottish population represents in the UK. Data from the Office for National Statistics[4] was used to calculate a 10-year average from mid-2010 to mid-2019. The result of this calculation is an average share of 8.28%
- To estimate the proportion of industrial batteries POM which are not EV batteries, Ricardo accessed DfT data on vehicles registered in the UK, which provides information on the split between ULEV and traditional internal combustion engine vehicles. Applying assumptions from Ricardo's low carbon transport experts for the average capacity of EV vehicles, and battery pack energy densities[5], we then estimated the capacity and in turn weight of EV batteries POM for the reference years. This was then subtracted from the total industrial battery weight POM to provide our baseline for this phase of the project.

Two scenarios for projections were calculated, a Business as Usual (BaU) scenario following historic data trends, and a revised scenario factoring in various industry-led predictions for the future development of battery market activity from our desktop research, stakeholder engagement, and expert opinion.

[1] Environment Agency (2021). National Packaging Waste Database
[2] GOV.UK (2021). Office for Product Safety & Standards
[3] GOV.UK (2020). Collection - Vehichles statistics
[4] Office for National Statistics (2021). Main figures
[5] Ricardo Energy & Environment (2020). Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA

Business as usual projections

In order to calculate the BaU projections, the Excel formula "FORECAST ETS" was combined with the upper value of a confidence interval of 95% to account for a level of uncertainty in the projections. FORECAST ETS predicts future values based on historical values by using the Exponential Smoothing algorithm. Moving averages were then used on historical and predicted values to smooth out fluctuations in trends.

This methodology was applied to all categories except for the end-of-life (EoL) of industrial batteries with the chemistry classification 'other'. This decision was made as all markets are assumed to be mature and well established except for 'other' industrial batteries. Instead for this category, we assumed a life expectancy of 10 years based on Ricardo expert opinion and used our projection of 'other' industrial batteries POM excluding ULEVs to estimate the amount of batteries reaching EoL.

For Lead-Acid (Pb-Acid) batteries POM, this methodology found that the tonnages would be close to zero from 2040 in the industrial category.

Literature and stakeholder insight, however, indicates that this is not a realistic projection, with Pb-Acid expected to retain a market share in various applications, such as stationary energy storage. We have therefore assumed a plateau of Pb-Acid battery levels from 2040 onwards in the BAU figures, and applied industry led estimates to the revised projection as detailed below.

Similarly, using FORECAST ETS resulted in a total decline of Pb-Acid batteries in the automotive category, due to a decrease in the available data between 2018 and 2019. In the absence of any verified data prior to 2017 on which to base this type of trend projection, we have omitted it from this report altogether, but have developed an industry estimate-based projection as detailed below.

Revised projections

For our industry informed revised POM projections, we have applied further internal expert opinion and market growth insight and forecasts from the following sources:

- Portable batteries
  - o Consumer Batteries - Global Market Trajectory & Analytics, Research and Markets, September 2020
- Industrial batteries
  - o Battery Innovation Roadmap 2030 White Paper, EuroBat, June 2020
- Automotive batteries
  - o Battery Innovation Roadmap 2030 White Paper, EuroBat, June 20207
  - o Future Energy Scenarios 2020, National Grid ESO, 2020

For our revised waste projections, we have applied industry average estimates for first-life expectancies of:

- Portable batteries: 5 years
- Industrial batteries: 10 years
- Automotive batteries: 5 years

2.2 Policy and literature review

Building on the foundation of knowledge from Phase 1, and the review of current regulatory frameworks, a further literature review was undertaken to gather information on successful technologies, new chemistry types, policies, and business models to improve the circularity of batteries in Scotland.

Review of key sources

In addition to the sources used in Phase 1, the literature review for this report used the sources listed in **Table 1** as a basis from which to better understand the available research, and to better identify any knowledge gaps which existed. These gaps were then specifically addressed through in-depth research of further sources as referred to throughout the body of this report, and via the stakeholder consultation activities.

The literature review also used a number of online news articles from Scottish Energy News, Edie, Insider, Digital Trends, ENDS, and Wired to provide relevant up-to-date examples of research and development projects which are happening in the battery industry.

[6] ECision Distribution (2020). Consumer Batteries: Global Market Insights and Projections to 2025
[7] EUROBAT (2020). Battery Innovation – Roadmap 2030
[8] National Grid SEO (2020). Future Energy Scenarios

Year	Author	Document type	Report Title
2020	EuroBat	White Paper	Battery Innovation - Roadmap 2030
2020	Ellen MacArthur Foundation	Report	A circular economy for batteries to underpin renewable energy growth
2020	Avicenne Energy	Report	Worldwide Rechargeable Battery Market 2019-2030
2020	Department for Transport	News Article	Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030
2020	Element Energy	Report	UK Power Networks - Distribution Future Energy Scenarios
2018	European Commission	Future brief	Towards the battery of the future
2017	Y. Kalmykova et al.	Report	Portable battery lifespans and new estimation method for battery collection rate based on a lifespan modelling approach

Table 1 Key sources used as starting point for literature review

Specific research topics
From the high-level view of the market, key areas were identified, and research targeted towards these areas in order to fully answer the research questions:

- Expected changes in manufacturing practices, battery chemistries, battery pack size/capacity and battery use, and the likely implications for end-of-life battery waste
- Battery research and development projects in the UK, Europe and internationally
- Policies and regulations that support greater circularity within the battery industry

Gaps and limitations
Whilst there are several sources available which discuss new battery technology and chemistry, there are very few which provide details on end-of-life management options. There has been a growing number of articles and reports which include reuse options for batteries currently common in the market, particularly those focusing on lithium-ion (Li-ion) technology.

From the literature review, it was clear that most predictions for the battery sector focused on Li-ion battery use – especially for the EV sector and the energy storage industry. It was more challenging to find detailed discussion of the future for portable batteries other than information on general trends linked to increased consumption of smart devices and rechargeable equipment.

2.3 Stakeholder engagement

To complement the knowledge gained from the desktop research and data analysis, stakeholder interviews were conducted to collect information, expert opinion and insight from a wide range of stakeholders. During the interviews, contacts were also asked to identify any further stakeholders across the battery value chain in Scotland who may be able to provide further insights or additional data sources.

31 key organisations were identified in collaboration with the Project Group, based on the collective knowledge of the Scottish battery value chain. These stakeholders included regulators, compliance schemes, trade associations, recyclers, manufacturers, and academic institutions. A total of 18 interviews were conducted. Interviews that were conducted in Phase 1 and provided useful insights for Phase 2 have been included in these figures. An outline of each stakeholder group has been provided below in **Table 2**.

Interviews were conducted during February and March of 2021 by members of Ricardo's project team. Interview questions were derived from the main project research questions, as outlined by the Project Group, and were then tailored to the type of stakeholder and specific business context.

Stakeholder Type	Number invited to interview	Reason for selection	Number of interviews completed
Regulators	5	Insights on regulatory environment	3
Trade Associations	4	Trends and market growth, regulatory environment	2
Compliance Schemes	5	Insights on policy & market trends	4
Manufacturers	8	Information on current research and novel technologies. Trends and market growth	3
Academia	6	Information on current research and novel technologies	5
Recyclers	3	Insights on recycling & reuse of current and new technologies, Trends and market growth	1

Table 2 Stakeholder types and engagement tracking

2.4 Identification and assessment of opportunities for Scotland

The insights gained from our modelling, stakeholder engagement and desk-based research into future developments in the battery sector were combined to develop a list of potential opportunities for Scotland. These opportunities, detailed in Section 5, were then analysed via a Multi Criteria Analysis process, which covered:

- Level of uncertainty / risk in the long-term benefit for Scotland
- Technical or legislative capability within Scotland to implement
- Potential scale of economic benefit
- Potential scale of environmental benefit

A red-amber-green rating was given for each criterion, based on stakeholder insight and our internal experts' judgement, and these scores were combined to give an overall viability rating of low, medium or high for Scotland.

3 FUTURE CHANGES IN THE BATTERY MARKET

3.1 Battery use

Industrial batteries
The power generation and storage system across Europe is changing rapidly as it requires more flexibility and interconnectivity to optimise energy resources. Developments of energy storage batteries are at different levels of maturity, however, it is clear that all battery technologies – lead, lithium, nickel and sodium – have a key role to play at each level of the system: from generation and transmission to distribution and households. It is expected that batteries will deliver important services, such as integration of renewables and grid stabilisation[9].

Batteries can deliver flexible, safe and reliable energy supply systems, which allow for greater decentralisation of the grid and an opportunity to integrate renewable energy sources. According to EuroBat, there are likely to be four key areas of stationary battery application within the renewable energy sector:

- Uninterrupted Power Supply (UPS)
- Telecom
- Residential/Commercial storage behind the meter
- Utility grid-scale Energy Storage Systems at the level of power generators, transmission (TSO) and distribution (DSO) system operators

Uninterrupted Power Supply (UPS)
UPS batteries are usually cells or blocks connected to form a back-up battery for uninterrupted power supply; they provide power to a system instantly if there is a failure in mains power. The UPS market has been dominated by lead batteries for decades and is expected to remain so to 2030. There is an expectation that this market will grow due to the increases in the use of big data and the associated need for new data storage facilities, as well as the need for power stabilisation in emerging economies. With ever greater reliance on digital infrastructure, ensuring power supplies are uninterrupted will protect global networks.

Predictions expect to see an annual global market growth of 4%, increasing from 15GWh to 24GWh by 2030. Within the UPS market, it's expected that lithium-based batteries will also see a growth by 2030 of approximately 7-18%[10].

Current development in UPS battery technology include extending its usage beyond uninterruptible power in order to generate more value, and connecting smaller UPS batteries into a single network to form a larger UPS system or even to form a virtual power plant. The evolution of virtual power plants has been possible due to the development of 5G and artificial intelligence which allows for the distribution of energy production, storage and consumption. The development of 5G networks allows for a number of small and very small data centres, located for example in a city centre where there is limited space for cell towers, to link up to a larger data centre. The larger data centres will still be required for data processing and storage capacity whilst being able to provide faster response times across networks[11].

[1] EUROBAT (2020). Battery Innovation – Roadmap 2030 f
[2] Avicenne Energy (2020). Worldwide Rechargeable – Battery Market 2019-2030
[3] Kohler Power (2019). 5G and its impact on data centres

It is likely that the market will see development of more robust UPS batteries to cope with faster charging and increased energy throughput requirements. Users of UPS battery technology will need to consider the type of load and energy throughput needed and the climate it will be situated in (temperature robustness), as well as the quality of the grid and configuration of the UPS. Cost remains a key factor in the adoption of UPS depending on the type of battery which is used. For example, a traditional UPS system using a Pb-Acid battery has a lower initial cost than a Li-ion based UPS system. However, Pb-Acid UPS systems require more regular maintenance and replacement, batteries need to be replaced every 3-5 years in data centres[12]. In comparison, Li-ion batteries would need to be replaced every 13-15 years[13]. Additionally, the modular UPS system which Li-ion batteries provide, allow for an easier and less costly expansion if required to meet increased demands.

Telecoms
Telecom batteries are made up of cells or a block connected to form a 48V direct current (DC) energy storage system which can supply electricity to an information and communication technology or telecom site when the main power source is unavailable or insufficient. It is worth noting that telecom batteries are designed purely to serve telecom applications.

At the moment, the global telecom battery market is estimated to be 17GWh, and is expected to grow to 25GWh by 2030. Similarly, to UPS batteries, lead based technology has been the dominant force in this sector of the batteries market and growth is expected to remain stable in the coming years. However, lithium-based batteries are predicted to penetrate the market increasing their share by 9-23% by 2030. One of the main driving forces for increased use of batteries in the telecom sector is the demand for increased energy throughput due to the extensive roll out of 5G networks.

Residential/Commercial storage
Stationary energy storage batteries, from renewable sources behind the meter, are used both in residential and commercial buildings, they can also fulfil additional roles, such as peak-shaving or UPS. The primary function of these batteries is to supply energy when renewable power output is low, or electricity costs are high. According to EuroBat, "the residential and commercial sectors are responsible for 12% of the EU's total CO_2 emissions"[14] therefore, by increasing the use and storage of renewable energy the overall CO_2 emissions from these sectors can be reduced. There are two main driving forces behind the increased demand in stationary energy storage systems - increased self-consumption and the need to ensure power continuity. Another influencing factor in this market is the need for an EV home fast charging station. There is the possibility of using different chemistries for stationary energy storage systems which allows for an overall benefit to the decarbonisation of the residential sector.

Currently, lithium-based batteries dominate this market[15] as they take up less space than lead-based battery systems. However, there are concerns over safety of lithium-based batteries especially for residential applications, which may see a move to solid state technology in future.

At the household scale, there has been an increase in solar panels being installed and therefore household storage batteries are required to ensure that users have a clean, reliable source of power.

[12] Technavio (2020). Global UPS Battery Market 2020-2024: Increase in Data Center Construction to Boost Market Growth
[13] Centiel (2019). How much does UPS efficiency actually cost?
[14] EUROBAT (2020). Battery Innovation – Roadmap 2030
[15] IEA (2021). Tracking Clean Energy Progress

These types of batteries are roughly the size of a gas boiler. Sonnen (based in Germany) has approximately 25% of the global market share in home batteries. They have said that Germany, Italy, Australia and the US states of California and Hawaii are the biggest markets so far for their products.

From a UK perspective, according to the 'UK Battery Storage: Opportunities & Market Entry Strategies for 2018-2022' report by the end of 2022 the energy storage capacity in the UK will be 50 times what they were in 2017 in terms of megawatt-hours[16]. This has been reflected by the predictions of a manufacturer of smart energy household storage systems (Powervolt) who expect to see a growth from "1 million customers with solar PV installed to 25 million homes with smart meters installed"[17].

A recent example of rolling out household energy storage systems has been conducted by Scottish Power and Moixa Technology using a 'smart-battery' system to help household consumers save money and use more of the energy they generate[18]. Householders can view energy, battery and solar use in real time on a smartphone or tablet device, and identify improvement opportunities.

Utility grid-scale energy storage

According to UN statistics, there are approximately 840 million people globally living without access to power. One option for countries is to establish mini grids to provide reliable power to their citizens. Mini-grids provide a small, closed-loop energy system for renewably sourced energy, like solar panels[19].

Batteries compete with other storage technologies, such as pumped-storage hydro facilities and thermal energy storage to act as grid-scale energy storage systems[20]. However, batteries are considered to be advantageous since they are easy to install on location and scalable to the power and capacity needed. Batteries also provide grid stability as they can store energy quickly or feed in to compensate the grid if required. Using batteries in this application provides a reserve capacity for the grid and is suitable to supply energy to an island power grid integrated with renewables.

One of the great benefits of using batteries for energy storage at a grid-scale is their quick response time (within milliseconds) to provide greater energy control to meet surges in demand. Decentralised battery storage is already economically viable, but to optimise their use for grid capacity, the creation and use of flexibility within the system for power distribution would be key. This flexibility can also be augmented by the installation of batteries for EV charging, on a larger scale than the 'smart home' systems discussed above, which can help to regulate grid demand. The market growth in this sector across Europe is expected to be 60GWh and over €10bn sales by 2025[21].

Now that the electricity grid in Scotland receives the vast majority of its power from renewable energy sources, more battery installations are coming online to store energy from intermittent wind and solar power. "Hybrid" renewable energy power plants, where batteries are installed alongside solar farms and windfarms, are being developed across Scotland which is particularly important for the economics of solar farms[22]. A key example of this is Scottish Power's Whitelee onshore windfarm where an industrial-scale Li-ion battery captures power from 215 wind turbines[23]. For the first time, the UK as a whole generated more electricity from renewable energy sources than from fossil fuels in 2020. According to the International Energy Agency solar energy is now the "cheapest electricity in history"[24].

[16] Energy Storage News (2018). UK battery storage to enjoy 'explosive growth' to 2022
[17] Powervault (2021). About us
[18] Scottish Energy News (2021). Scottish Power sets up 'smart battery' solar power home energy storage trial as former Big Six utility bosses line up to buy into project
[19] 60_decibels (2020). Why off-grid energy matters
[20] Environmental and Energy Study Institute (2019). Fact Sheet – Energy Storage
[21] EUROBAT (2020). Battery Innovation – Roadmap 2030
[22] The Guardian (2017). This summer was greenest ever for energy, says National Grid
[23] The Guardian (2019). Scottish Power to build vast battery to improve wind energy supply
[24] IEA (2020). World Energy Outlook 2020

There are strong links between intermittent renewable energy technologies and energy storage batteries. This sector will require a rapid increase in capacity to meet clean energy demands in the UK. There are, however, some reservations about the efficiencies of certain renewable energy types being paired with energy storage systems. For example, pairing energy storage with wind is less favourable than solar PV, as the generation profile of wind is less reliable and operates over a longer duration (i.e. peaks in generation of 3-5 days). Conversely, solar PV pairs well with energy storage as it reliably generates power each day[25].

Overall, utility grid-scale energy storage provides a particular opportunity for Scotland in helping to meet net-zero ambitions by 2045, due to high levels of renewable penetration (particularly wind energy) and strong progress in grid decarbonisation.

Portable batteries

Primary (non-rechargeable)

Primary non-rechargeable portable batteries play an important role within the battery sector, especially when charging is impractical or impossible. Non-rechargeable batteries are commonly used in a number of different applications such as in alarm clocks, remote controls, and children's toys. They are also found in pacemakers, hearing aids, smart meters, and smoke detectors. Non-rechargeable batteries provide high energy capacity, long storage times, and are readily available on the market. One of the key advantages of primary portable batteries is that they can instantly provide energy to numerous applications.

Primary batteries are regulated under IEC 60086 standards. The most common format for primary batteries is AA and AAA. In general, an AA battery contains roughly twice the capacity of the smaller AAA at a similar price. However, it is worth noting that the capacity of AA batteries can vary between battery manufacturers/brand names and the retail price of standardised primary battery formats can also vary[26]. Overall, primary batteries are viewed as being more environmentally sustainable than secondary batteries when they are used in low-drain applications[27].

The main chemistry types used for non-rechargeable portable batteries are zinc-carbon, zinc-chloride, lithium-based, silver-oxide, and alkaline[28]. Alkaline batteries are by far the most popular chemistry type for non-rechargeable batteries[29]. Alkaline batteries have a good safety record during transportation and end-of-life waste management. They can be stored for up to 10 years without leaking. On the other hand, alkaline batteries have a low load current which limits their use to applications such as remote controls, torches and portable entertainment devices.

It is very common for end-users to dispose of partially used non-rechargeable batteries, especially in applications where it is critical to ensure energy is provided instantly and to last for as long as possible, rather than estimating the usage. It is also important to highlight that, in certain conditions, there are no suitable alternatives for primary batteries yet, for example in disaster or emergency situations where there is no access to power.

Due to the wide range of applications, easy availability and reliability of primary batteries it is unlikely that the primary portable batteries market will decline drastically in future[30].

[25] It should be noted that this depends what revenue stream the energy storage system is aiming for and how it is connected
[26] Battery University (2017). Advantages of Primary Batteries
[27] Politico (2020). Phasing out primary batteries will go against Green Deal
[28] Croner-I (2021). Batteries: In-depth
[29] Battery University (2017). Advantages of Primary Batteries
[30] Technavio (2020). Alkaline Battery Report – World Market to Grow by USD 493.35 million by 2024

Secondary (rechargeable)

From a portable battery stand point, feedback from our stakeholder engagement exercise predict that there will continue to be an increase in rechargeable consumer electrical products. One of the main reasons for the growth in smart electronic devices is due to changing lifestyle preferences[31]. Lithium polymer (LiPo) rechargeable batteries have become the dominant battery technology for consumer electrical products due to several beneficial attributes, including:

- High energy density
- Slower rate of self-discharge
- Low maintenance
- Smaller and lighter in form factor
- Low memory effect when compared to nickel-metal hydride rechargeable batteries
- Quick and rapid charging cycles
- Longer operating life and durability with the ability to withstand hundreds of charge-discharge cycles

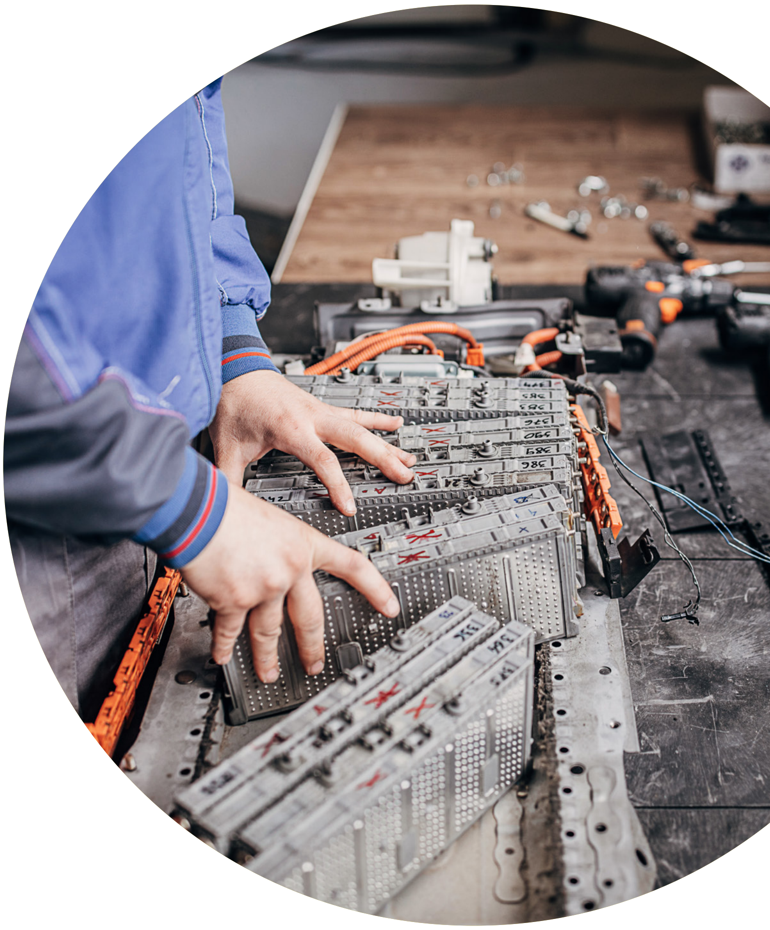
Digital consumerism is rapidly increasing across the world thanks to the rapid development of internet infrastructure, the spread of mobile communication network technologies like 4G and 5G, the falling cost of mobile data and voice tariffs, and the falling prices of smartphones. All of these factors have changed the way people consume digital goods and services, leading the way to rapid proliferation of digital devices and platforms.

Manufacturers are investing in new and efficient battery technologies to overcome the limitation of battery power (dynamic charging) in portable consumer electronic products. Manufacturers acknowledge that there is growing pressure on developing energy-dense batteries due to the rapidly developing competitive microprocessor market performance in comparison to the annual gain in energy capacity in batteries.

Batteries tend to make up a significant portion of the size and weight of an electronic item, such as a smartphone; so there is the possibility that we may see structural battery technology, where the energy storage function is built into the actual structure of the item. Structural batteries could create issues for end-of-life disposal as the dismantling of the battery and other product components will become more complex. This technology is likely to develop for portable batteries sooner than their adoption for vehicles. Further detail on structural batteries in vehicles is presented in the Phase 3 report as part of this project.

Within consumer electronics there has been an emergence of rechargeable, interconnected products which use power bank technologies. In essence, this a portable battery charger which charges from mains electricity and then is used to recharge its related device. The power bank is made up of a number of individual cells which are all connected.

A few examples of products which have grown in popularity in recent years include Bluetooth connected headphones and portable speakers, electric toothbrushes, laptops and tablets, smart phones and watches, as well as larger items such as cordless vacuum cleaners.



[31] Intrado GlobalNewswire (2020). Increasing Adoption of Lithium-Ion Batteries in Consumer Electronic Products Driving Lithium-Ion Battery Market: P&S Intelligence

The inclination toward smart electronic devices has led to portable batteries within consumer products generally getting smaller, lighter, and more powerful, therefore, the waste from these may not be seen for 5 or 6 years instead of the previous average of 3 years.

A combination of non-rechargeable and rechargeable batteries will continue to be necessary to offer consumers the most sustainable solutions for different kinds of applications[32]. Overall, it is important that the upcoming Defra reviews of Waste Electrical and Electronic Equipment (WEEE) and Batteries Regulations (scheduled for summer and autumn 2021, respectively) consider the strong links between portable batteries and consumer electrical equipment to ensure that any requirements in one set of regulations do not adversely affect the other.

Automotive batteries
The primary use of automotive batteries is not expected to change drastically in future for private and commercial vehicles. There will be a rapid transition to electrification of transport propulsion systems, but the vast majority of road vehicles will still include automotive batteries to serve auxiliary functions such as lighting, ignition and safety back-up. Pb-acid batteries are expected to retain a stable dominance in this application, with the potential of some market penetration from Li-ion batteries.

3.2 Battery chemistries

EuroBat[33] acknowledge that "no single battery chemistry or technology can meet all the challenges of end-user demand in a multitude of applications, combining high power and energy density, long life, low cost, excellent safety and minimal environmental impact". However, development in battery chemistries can go a long way towards improving the batteries used in various applications. This section will review the potential new chemistries which are likely to appear on the market in future.

The insights gathered from the literature review and stakeholder interviews clearly suggest that the majority of the battery sector anticipates that Li-ion will continue to be the dominant force over the next ten years. Those involved in the development of battery technologies also expect that Li-ion will continue to experience rapid growth for the next 5 years. Developments for Li-ion batteries will come from lowering costs by reducing the amount of cobalt in a battery and improving energy density by incorporating more nickel in the cathodes and more silicon in the anodes.

Further ahead (10+ years) those in the battery technology industry predict that there will likely be a plateau of Li-ion market, and other chemistries and/or technologies will come to the forefront. However, there are a number of new battery chemistries and improvements from within the Li-ion sector which are being developed and could play a significant role in the battery supply chain in future. A summary of each of these is provided below.

From interviews with stakeholders in the battery development sector, they have confirmed that it usually takes 10 years for a new battery chemistry/technology to become commercially viable and available in the mainstream. There are two main chemistry types which stakeholders believe are likely to succeed - Lithium-sulfur (Li-S) and Sodium-ion (Na-ion).

[32] Politico (2020). Phasing out primary batteries will go against Green Deal
[33] EUROBAT (2020). Battery Innovation – Roadmap 2030

Lithium-sulfur
Li-S batteries are considered to be most likely to replace Li-ion batteries in many applications, but are likely to be most successfully used in markets, such as the aerospace industry, since they are lighter and more energy-dense. These batteries do still contain lithium, but do not use nickel or cobalt. Instead they use sulphur in the cathode which is cheaper and more abundant globally. The chemical reaction is akin to what happens in a Pb-Acid battery where there is a complete structural and chemical transformation. Li-S are predicted to act as a bridge between Li-ion and solid-state batteries, particularly in high performance applications. In the UK lithium-sulfur batteries are being developed by Oxis Energy[34].

Sodium-ion
Na-ion batteries contain no lithium, instead using abundant materials such as iron, manganese and titanium, which allows for an overall reduction in production costs. According to a 2017 academic journal paper[35], these batteries are "without a doubt the most appealing alternative to lithium-based battery technology, from the viewpoint of sustainability" since they are less aggressive on the environment. Na-ion batteries have a life span of approximately 5 to 10 years, matching the lifespan of Pb-Acid batteries which they hope to eventually replace, especially in the large-scale grid energy storage systems. This battery chemistry is a lot safer than other chemistries used as alternatives to Pb-Acid batteries in the grid storage, like Li-ion, as there is no thermal run-away and they can be easily transported and dismantled for recycling as they are not as volatile or hazardous in comparison. However, they are less energy dense than Li-ion batteries.

Pb-Acid batteries in the grid storage, like Li-ion, as there is no thermal run-away and they can be easily transported and dismantled for recycling as they are not as volatile or hazardous in comparison. However, they are less energy dense than Li-ion batteries.
St Andrews University are working as part of the Faraday Institution to develop and increase the energy density provided by Na-ion batteries. They believe that the most likely opportunity for Na-ion batteries to be used is in energy storage systems at an industrial scale initially (e.g. telecom industry) but they could also be used at a household scale in future too. There are also exciting opportunities for using Na-ion batteries to replace small LPG engines in two- or three-wheeled vehicles. It is predicted that the main market for Na-ion batteries will be in developing economies, but production will likely remain in the UK.

Based on the experience of the stakeholders interviewed in the battery sector, they expect to see Na-ion to undergo a similar progression journey to that of Li-ion. Na-ion batteries are likely to start entering the market in the next couple of years and grow from there.

Further developments for lithium-ion batteries
A number of developments to improve the performance of Li-ion batteries have been undertaken by academics around the world, there has been a strong focus on this in American academia. A summary of the various ways in which Li-ion batteries are being developed has been provided below.

NanoBolt lithium tungsten batteries
In order to increase the speed of charging and the ability to hold more energy than standard Li-ion batteries, N1 Technologies, Inc. has added tungsten and carbon multi-layered nanotubes which bond with the copper anode substrate to create a web-like nano structure[36]. This web-like structure creates a much larger surface area for ions to attach to during recharge and discharge cycles.

Organosilicon electrolyte batteries
Researchers at the University of Wisconsin-Madison are exploring the possibilities of replacing the carbonate based solvent system currently used in Li-ion batteries with Organosilicon (OS) based liquid solvents.

The current solvent based systems used can

[34] Oxis Energy. Oxis Energy
[35] C P Grey, J M Tarascon (2017). Sustainability and in situ monitoring in battery development
[36] Gray (2021). 5 New Battery Technologies That Will Change the Future

cause electrolytes to catch fire or explode, so replacing these would provide a safer solution.

Gold nanowire gel electrolyte batteries
Researchers at the University of California are looking for a better electrolyte for Li-ion batteries[37]. They have experimented with gels, as these are not as combustible as liquids.

As part of their research, they coated gold nanowires with manganese dioxide, then covered them with electrolyte gel. Usually nanowires are too delicate to use in batteries, however, these had become robust. Their results show that nanowires coated with manganese dioxide and electrolyte gel are able to go through 200,000 charging cycles without losing their ability to hold a charge. In comparison a conventional battery goes through 6,000 cycles without losing its ability to hold a charge.

TankTwo String Cell™ batteries
One of the main challenges facing Li-ion batteries in several applications is the slow recharging process. TankTwo have developed a modularised battery called String CellTM which contains a collection of small independent self-organising cells[38]. There is an internal processing unit which controls the connections in the electrochemical cell. In order to increase the speed of charging, the spent cells contained in the battery are sucked out and swapped for recharged cells at a service station. These un-charged cells can then be recharged at off-peak hours at the service station.

Cobalt substitution
Manufacturers of lithium-ion batteries are gradually reducing the level of cobalt used in cathodes, instead using alternatives such as manganese spinels and lithium-iron-phosphate (LFP). LFP in particular is cheaper, has more dense energy, longer life and is less combustible. Due to its stability and power capability, LFPs could be useful for large scale applications, such as those in electric grids.

Lithium-air
These batteries use an unlimited resource, oxygen, for the positive electrode. Reviews of their active materials have found that theoretically they could provide energy densities ten times greater than the majority of batteries currently on the market. However, these batteries would likely require additional equipment to avoid pure oxygen degrading in the ambient air. This would reduce their energy density at a system level.

Solid state
A solid-state battery uses solid electrode and electrolytes instead of the liquids or gels used in other battery chemistries. According to the Faraday Institution's SOLBAT research, solid-state batteries provide high energy and power density, fast charging rates, long cycle and storage life, and they are safe and non-flammable[39]. One of the organisations being supported by the Faraday's Battery Challenge to develop solid-state battery technology is Ilika[40]. Ilika are working on two main solid-state batteries:

- Stereax[41] – Micro solid-state batteries for medical use (e.g. implants or on-the body devices), providing opportunities for continuous health monitoring in the patient's home or place of care provision
- Goliath[42] – high-density solid-state cells for use in electric vehicles and cordless consumer electronics

It is predicted by those involved in the collaboration projects that solid-state batteries are probably still 10 years away from commercialisation.

[37] UCI News (2016). All powered up
[38] Tanktwo (2017). Tanktwo Technology
[39] The Faraday Institution (2021). Solbat – Solid State Metal Anode Batteries /
[40] Ilika (2021). Ilika
[41] Ilika (2021). Stereax – Micro Solid State Batteries
[42] Ilika (2021). Battery Innovation – Goliath

3.2.1 Case Study: Battery technology innovation in Scotland – AMTE Power

AMTE Power are a battery producer based in Thurso, Scotland. AMTE Power produce Li-ion batteries for a range of sectors including automotive, aerospace, defence, oil and gas, and energy storage. AMTE Power are actively developing and producing new battery chemistries to bring to market.

There are currently four main types of batteries that AMTE Power are developing:

- Ultra-Safe is an Na-ion cell which delivers high performance, inherently safe and cost-effective battery solution for key applications, including transportation, energy storage, back-up power and energy in remote locations.
- Ultra-Prime is a non-rechargeable cell designed for use in the oil and gas industry. It has a very high energy density and can operate down oil wells at temperatures up to 125 degrees Celsius. The lifespan of this cell is 6 years, at which point it would be pulled back up and disposed of in a similar way to alkaline batteries now. The cells are made from a pure lithium anode/carbon mono-fluoride cathode.
- Ultra-High-Power which is designed to be used for high performance hybrid vehicles (hybrid auto internal combustion and fuel cell engines). The technology has come out of F1 technology. It provides very quick acceleration and makes charging quicker. The battery is Li-ion.
- Ultra-Energy is a cylindrical cell purely for use in EVs (similar to Tesla technology). AMTE Power are aiming to produce 50,000 batteries as part of the scale up which is being funded by the Battery Industrialisation Centre (BIC).

AMTE Power will be using UK BIC funding to scale up and manufacture these new battery types at their Thurso site. They are now making thousands of prototypes of their Ultra-Prime batteries and are planning to manufacture 50,000 cells for use in the oil and gas industry which is a large market in Scotland. In addition, AMTE Power have partnered with a company in Aberdeen to develop 'smart wells' which will be able to turn off power for extraction of oil and gas depending on demand requirements.

AMTE Power were listed on the London Stock Exchange's Alternative Investment Market (AIM) in March 2021, raising £13.7m – nearly double the amount originally sought. The initial success of listing on the AIM shows that the switch to electrification and battery power is fully underway across a number of markets, not just in the automotive sector.

Sources:

AMTE Power (2021). AMTE Power
Insider.co.uk (2021). AMTE Power IPO raises nearly twice its original goal

Alternative materials
As well as Li-ion batteries undergoing a number of developments over recent years, there has also been a surge to develop alternative batteries which use different chemistry types. A variety of the alternative chemistries which are being developed are outlined below.

Zinc-manganese oxide batteries
Zinc-manganese oxide batteries could be a possible alternative to Li-ion and Pb-Acid batteries, particularly for use in large-scale energy storage systems which support the national grid. The key to developing these batteries is to be able to control the chemical conversion reaction in a zinc-manganese oxide battery. This could increase energy density in conventional batteries without increasing cost.

Flow batteries
The structure of flow batteries is different to most conventional batteries. Instead of packing several reactive materials together in one unit (as conventional batteries do), flow batteries store reactive liquids in separate containers and then pump them into the system to create energy. Flow batteries provide greater safety, longer lifetimes and potential cost savings in comparison to Li-ion. However, they are very large and currently are mainly designed for grid energy storage. In order to increase the energy provided by flow batteries, you would only need to increase the size of the liquid reservoirs. The ability to replace the liquids or replace other modular parts means that the potential life of a battery is almost indefinite. The widespread adoption of these batteries is unlikely to occur for another five to ten years.

Sugar
The principles behind the reaction in which maltodextrin is oxidized to create energy were first published by Sony in 2007. More recent developments of sugar batteries have been undertaken by researchers at Massachusetts Institute of Technology; where they created a device called the Thermopower Wave, which is much more efficient than previous sugar battery incarnations and can power a commercial LED light. Whilst this has been viewed as an exciting prospect, the commercial availability of these types of batteries is likely several years away.

Paper
Batteries made from paper have many advantages, they are thin, flexible, and, if fabricated with the right materials, biodegradable. Researchers at Stanford University developed early paper batteries by coating thin sheets with a carbon and silver saturated ink. As an alternative coating, researchers at Binghamton University have developed paper batteries using bacteria, or alternatively, human saliva.

[43] Nanowerk (2016). Unexpected discovery leads to a better battery
[44] IDTechEx (2019). A Look at Li-ion and Alternative Battery Chemistry Innovation
[45] Digital Trends (2020). Lithium-ion is just the begnning. Here's a peek at the future of batteries
[46] Sony (2007). Sony Develops « Bio Battery » Generating Electricity from Sugar
[47] Wonjoon Choi, Seunghyun Hong, Joel T. Abrahamson, et al. (2010). Chemically driven carbon-nanotube-guided thermopower waves
[48] Stanford News (2009). At Stanford, nanotubes + ink_ paper = instant battery
[49] Binghampton University (2018). Scientists create biodegradable, paper-based biobatteries

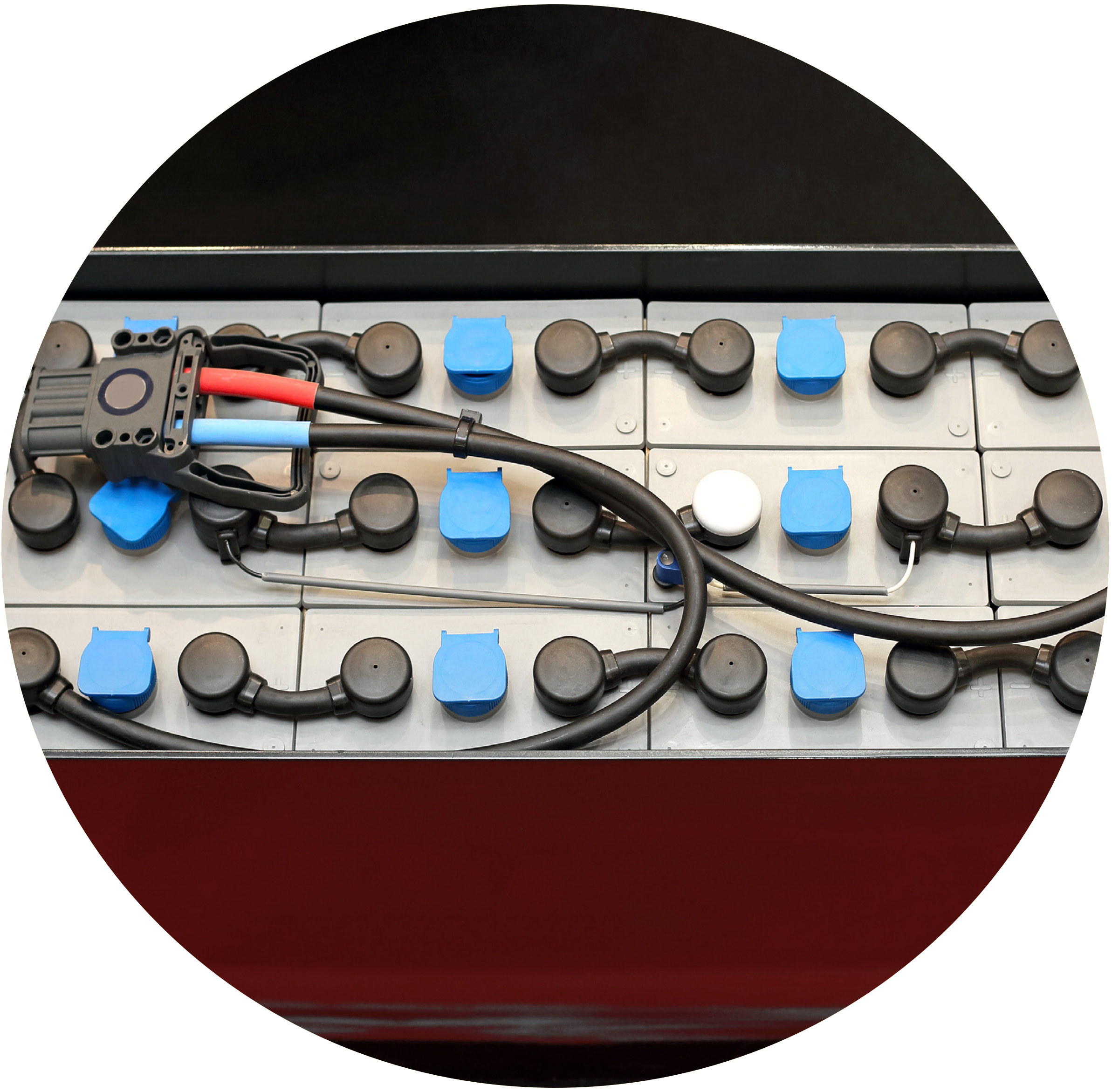
Summary

It is most likely that a combination of battery chemistries will be used in the future, although it is not yet possible to say which of these will have the biggest impact. From the literature review and stakeholder interviews, it seems that the chemistries most likely to have a significant impact in future will be Na-ion, Li-S, solid state batteries and flow batteries.

In terms of battery application, the largest growth sector is expected to be industrial batteries used in grid storage and telecom applications. With Scotland's use of renewable energy being a key element of the grid network, improvements in storage technology from the battery sector will have a significant impact. In addition, the growth of interconnected consumer electronics and development of 5G networks will require greater use of batteries in data centres to ensure quick response times to increased network demands.

It is likely that Scotland will see a plateauing of portable batteries being placed on the market as consumers will become more likely to replace items on a like-for-like basis rather than purchasing more appliances which have similar functions and connectivity potentials.

However, in order to ensure that batteries are as sustainable as possible in future, it is important to highlight the need for battery design to allow for repairability, reuse and recycling whilst still continuing to fulfil their primary function.



3.3 Implications of future battery use and chemistry types for end-of-life battery waste

Reuse

Reuse is an important option for end-of-life waste management of batteries which would support a circular economy and lower batteries' environmental impacts by increasing their lifespan. Usually, once a battery's original capacity has decreased, they are no longer seen as suitable for meeting their original use requirements. However, they may still be used in other, less demanding, applications.

One of the most likely opportunities for reuse to occur will be where the loop of use is kept close to original manufacturers – e.g. manufacturer build battery packs, receive returns, test safety/capacity and then either resell or use themselves to offset their own energy costs for their manufacturing sites.

If second-life reuse does occur, it will help to reduce the cost of recycling (by delay) and increase the value derived from every battery pack.

One of the major markets for second-life batteries is in the stationary energy storage applications of industrial batteries discussed in **Section 3.1**.

The current reuse market is dealing with smaller quantities of batteries than are currently in operation, due to the increase in use of batteries coupled with their lifespan.

There are concerns that as larger quantities of batteries reach their end-of-first life, the reuse market may become saturated with second-life batteries. In this case, there may be less demand for repurposed batteries than there is supply, meaning that large amounts of batteries will still need to be treated as waste, potentially without the recycling capacity to do so[50].

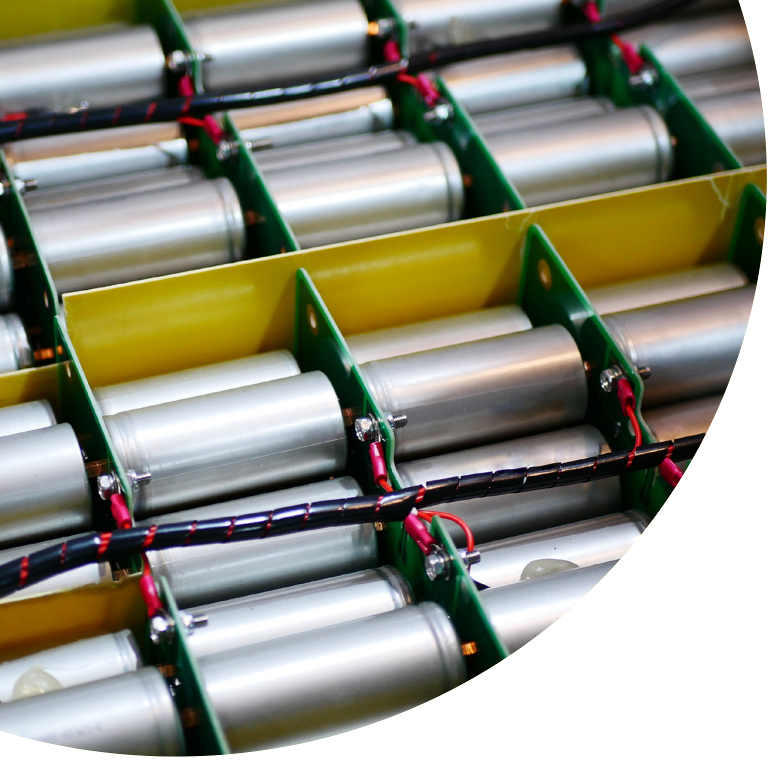
Recycling

Pb-Acid batteries used in industrial and automotive applications are readily recyclable, they are mechanically or manually broken into component parts where the lead components undergo a smelting and refining process. The refining process produces high purity lead or alloys which can be used in the manufacturing of new lead acid batteries. Recyclable plastic components from the battery casing are washed then shredded and melted. The molten plastic is formed into pellets which can be used in the manufacturing process for other plastic products as well as new battery casings[51]. It is worth noting that 85% of lead consumption goes into Pb-Acid batteries.

The current recycling process for Pb-Acid batteries[52] can be extremely detrimental to the environment and human health due to exposure if not strictly regulated[53]. However, there are still opportunities for improvement through regulatory measures and reductions in CO_2 emissions from the recycling processes.

A number of stakeholders in the battery industry believe that there will be a sharp rise of Li-ion batteries to be disposed of in five years' time as the first generation of portable and industrial Li-ion batteries come to the end of their useful life. One of the big challenges for Li-ion recycling is making it cost positive and worthwhile for the recyclers to dismantle the battery packs. The dismantling and recovery of raw materials is a growing sector of recycling in Canada and the USA, with companies extracting valuable raw materials from pre-shredded battery packs. Currently, the dismantling of Li-ion batteries is a cost to the recyclers/manufacturers, and they are not incentivised enough to access the valuable materials within the battery packs, therefore a large number of Li-ion batteries are stored at facilities until cost effective recycling methods are developed.

50 The Guardian (2019). Ion age : why the future will be battery powered
51 World Health Organization (2017). Recycling used lead-acid batteries: health considerations
52 Future Market Insights (2020). Lead Acid Battery Market
53 Forbes (2020). Environmental Implications Of Lead-Acid and Lithium-Ion Batteries



The incentive to recycle batteries will be based on the fluctuation in the price of cobalt. If the price of cobalt drops, recycled cobalt would struggle to compete in term of price with mined cobalt, and manufacturers would choose mined material over recycled[54].

The idea of sourcing valuable metals from an "urban mine" is growing. Urban mining is the process of extracting rare metals and other raw materials from spent products, in particular from waste electrical equipment but the practice could also be applied to batteries. Instead of sourcing raw virgin materials which require destructive extraction techniques, companies can source the required materials from waste batteries locally. Urban mining processes have several other benefits as well, for example, waste electrical equipment can have up to 50 times higher concentration levels of valuable materials than in the ores extracted from mines. Sourcing valuable materials from urban mining processes can also mitigate the impacts of global raw material price fluctuations[55].

However, there are several issues with this as technology continues to develop apace and by the time materials are extracted in enough quantity they may not be as valuable as they once were. In addition, due to the increasing lifespan of rechargeable batteries, there will be a time-lag between the batteries becoming waste. This will impact on the recycling and remanufacture sectors using these "waste" materials. There is also a reluctance from battery producers to use recycled content in their battery packs because they want to know where the materials are coming from and need to ensure the quality of the recycled materials is sufficient to meet any safety issues.

Based in Grangemouth, the CellMine research project conducted by Impact Solutions[56] has been granted funding from the Ecosurety Exploration Fund[57]. The project, in partnership with St Andrews University, will work towards developing a viable new low energy, low cost battery recycling process[58]. The project will focus on recovering rare earth metals (lithium, cobalt and manganese) from portable and industrial Li-ion batteries which are currently lost at end-of-life. They are looking to develop a novel way to separate the cathode materials within the battery, in a suitable form and purity that makes them ready for reuse in new battery cells. The project aims to create a Li-ion recycling process which can be taken forward and used in the battery recycling industry.

[54] Chemical & Engineering News (2019). It's time to get serious about recycling lithium-ion batteries
[55] Recupel (2021). 7 reasons why urban mining is overtaking classical mining /
[56] Impact Solutions (2020). Impact Winners of The Ecosurety Exploration Fund – CellMine
[57] Ecosurety (2021). CellMine
[58] Insider (2020). Scottish company shares in £500,000 funding to develop its lithium ion battery recycling technology

4 PROJECTED BATTERY FLOWS IN SCOTLAND

Based on the methodology detailed in **Section 2.1**, our projections for batteries both POM and reaching EoL are as follows.

4.1 Batteries placed on the Scottish market

Type	Chemistry	Actual 2019	Projection					
			2025	2030	2035	2040	2045	2050
Portable	Pb - acid	100	44	-	-	-	-	-
	Ni - Cd	27	22	1	-	-	-	-
	Other	3,144	3,310	3,561	3,784	4,020	4,237	4,468
TOTAL		**3,271**	**3,376**	**3,562**	**3,784**	**4,020**	**4,237**	**4,468**
Industrial	Pb - acid	5,389	3,841	2,138	1,077	428	428	428
	Ni - Cd	138	-	-	-	-	-	-
	Other	1,117	3,331	5,542	7,762	9,989	12,220	14,454
TOTAL		**6,645**	**7,172**	**7,679**	**8,840**	**10,416**	**12,647**	**14,882**

Table 3 BAU trend projections for portable and industrial batteries POM, in tonnes

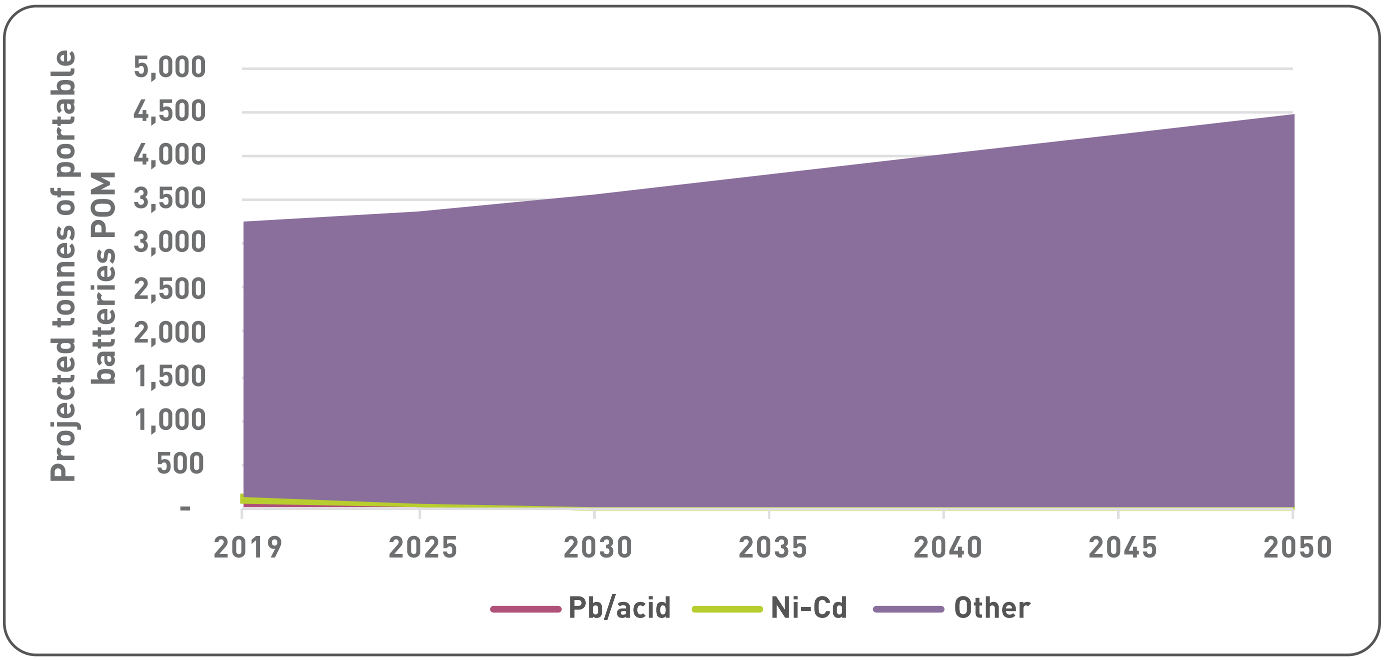


Figure 1 BAU trend projection for portable batteries POM, in tonnes

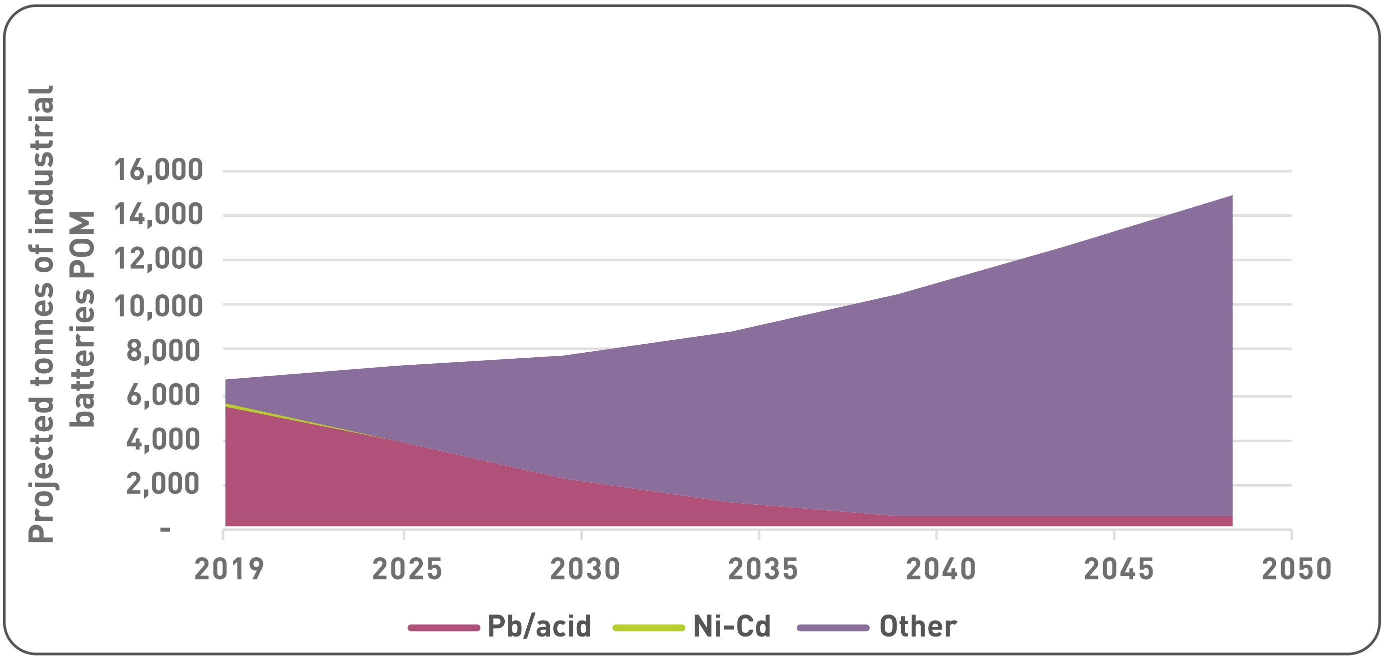


Figure 2 BAU trend projection for industrail batteries POM, in tonnes

Type	Chemistry	Actual 2019	Projection					
			2025	2030	2035	2040	2045	2050
Portable	Pb - acid	100	193	261	313	344	361	365
	Ni - Cd	27	52	70	84	93	98	98
	Other	3,144	6,068	8,192	9,830	10,813	11,354	11,467
TOTAL		**3,271**	**6,313**	**8,523**	**10,227**	**11,250**	**11,812**	**11,930**
Industrial	Pb - acid	5,389	6,379	7,368	8,497	9,645	10,747	11,508
	Ni - Cd	138	-	-	-	-	-	-
	Other	1,117	1,595	2,201	2,985	4,133	5,787	8,333
TOTAL		**6,645**	**7,974**	**9,568**	**11,482**	**13,778**	**16,534**	**19,841**
Automotive	Pb - acid	12,294	12,136	11,910	11,321	10,584	9,824	8,497
	Ni - Cd	-	-	-	-	-	-	-
	Other	-	311	638	1,258	1,868	2,156	2,396
TOTAL		**12,294**	**12,448**	**12,548**	**12,578**	**12,451**	**11,980**	**10,893**

Table 4 Industry informed projections for all batteries POM, in tonnes

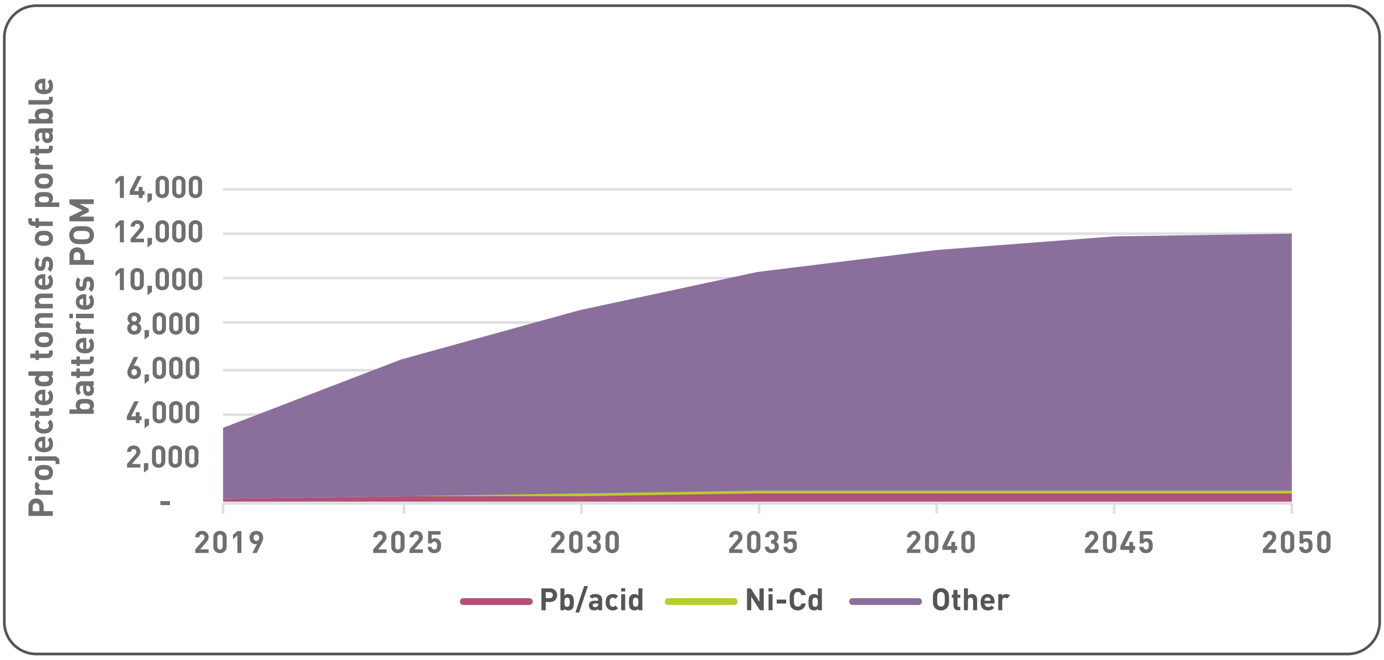


Figure 3 **Industry-informed trend projection for portable batteries POM, in tonnes**

Figure 3 shows a significantly sharper increase in portable batteries POM than the historic data-led trend in **Figure 1**. This reflects an expectation for the global consumer electronics market to rise rapidly by 2030, followed by a gradual smoothing but steady continued market growth.

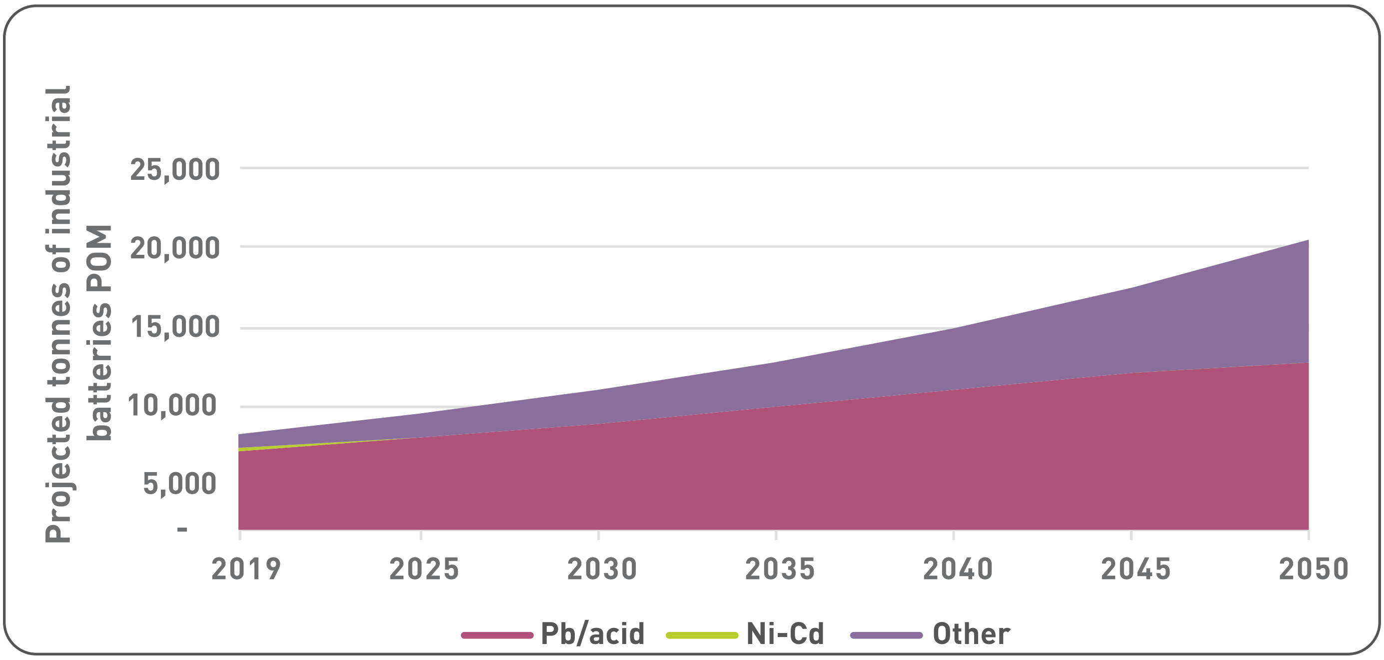


Figure 4 **Industry-informed trend projection for industrial batteries POM, in tonnes**

For industrial batteries, **Figure 2** shows a BAU trend for the market to gradually increase to 2050, with a decline in PB-acid market share. Industry and expert insight reflected in **Figure 4** however predicts a continued dominance of Pb-Acid batteries, with gradual growth of Li-ion alternatives. The overall market growth is predicted to be larger than historic trend data suggests.

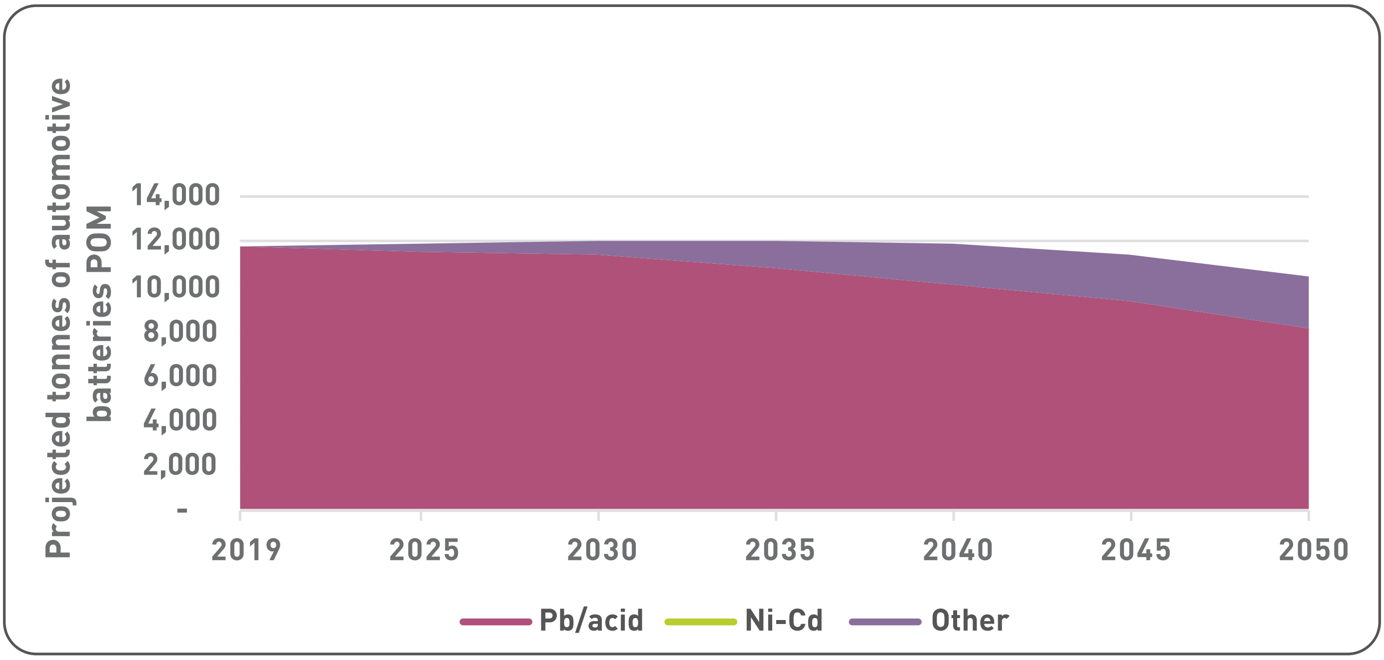


Figure 5 Industry-informed trend projection for automotive batteries POM, in tonnes

As discussed in **Section 2.1**, fluctuations in the limited firm data available for historic automotive batteries POM did not allow for a sensible BAU trend projection. **Figure 5** shows an expected small increase in the total automotive battery market in Scotland, followed by a decrease to 2050. This is modelled on the average estimates from the National Grid Future Energy Scenarios for vehicles on the road. The automotive battery sector is likely to continue to be dominated by Pb-Acid, with all vehicles (including EVs and HGVs) requiring auxiliary and starter batteries. There is some potential for Li-ion batteries to develop market penetration from 2035 onward.

4.2 Batteries reaching end-of-life

Type	Chemistry	Actual 2019	Projection					
			2025	2030	2035	2040	2045	2050
Portable	Pb - acid	859	1,018	1,059	1,059	1,136	1,173	1,210
	Ni - Cd	63	130	174	218	261	305	348
	Other	503	890	1,024	1,155	1,284	1,412	1,538
TOTAL		**1,425**	**2,037**	**2,257**	**2,432**	**2,682**	**2,890**	**3,096**
Industrial	Pb - acid	4,975	7,859	11,465	15,057	18,637	22,210	25,777
	Ni - Cd	39	48	59	70	80	91	102
	Other	1,991	239	2,449	4,656	6,873	9,097	11,327
TOTAL		**7,005**	**8,146**	**13,973**	**19,782**	**25,591**	**31,399**	**37,205**

Table 5 BAU trend projections for portable and industrial batteries reaching EoL, in tonnes

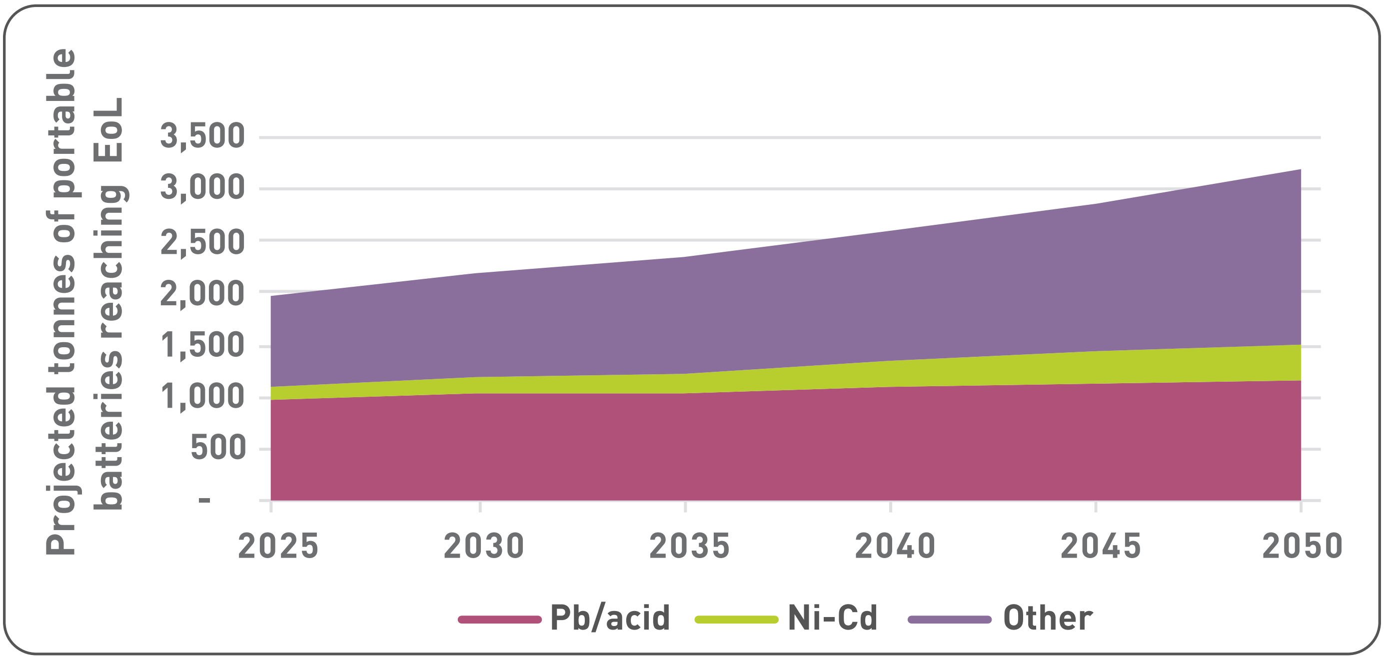


Figure 6 BAU trend projection for portable batteries reaching EoL, in tonnes

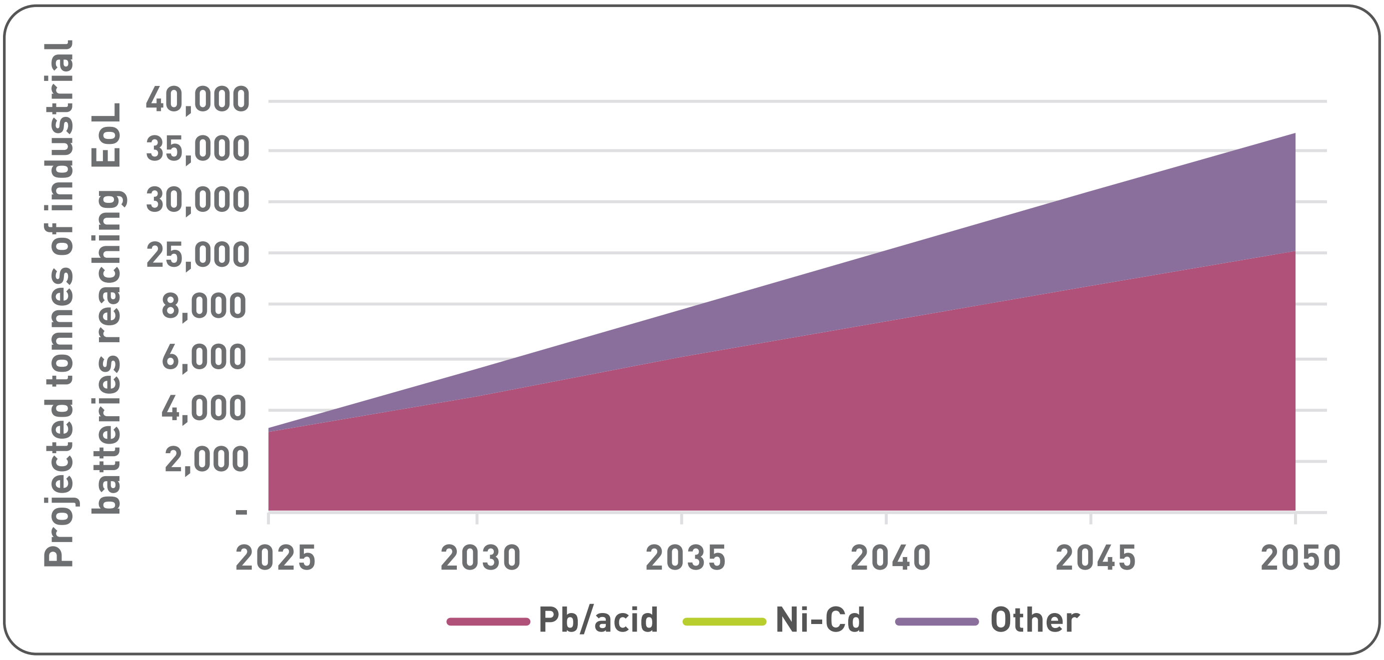


Figure 7 BAU trend projection for industrial batteries reaching EoL, in tonnes

Industry-informed revised projections – expected first lifetime applied

Type	Chemistry	Actual 2019	Projection					
			2025	2030	2035	2040	2045	2050
Portable	Pb - acid	859	100	193	261	313	344	361
	Ni - Cd	63	27	52	70	84	93	98
	Other	503	3,144	6,068	8,192	9,830	10,813	11,354
TOTAL		**1,425**	**3,271**	**6,313**	**8,523**	**10,227**	**11,250**	**11,812**
Industrial	Pb - acid	4,975	5,182	5,389	6,379	7,368	8,497	9,645
	Ni - Cd	39	89	138	-	-	-	-
	Other	1,991	1,554	1,117	1,595	2,201	2,985	4,133
TOTAL		**7,005**	**6,825**	**6,645**	**7,974**	**9,568**	**11,482**	**13,778**
Automotive	Pb - acid	10,410	12,294	12,136	11,910	11,321	10,584	9,824
	Ni - Cd	-	-	-	-	-	-	-
	Other	-	-	311	638	1,258	1,868	2,156
TOTAL		**10,410**	**12,294**	**12,448**	**12,548**	**12,578**	**12,451**	**11,980**

Table 6 Industry-informed projections for all batteries reaching EoL, in tonnes

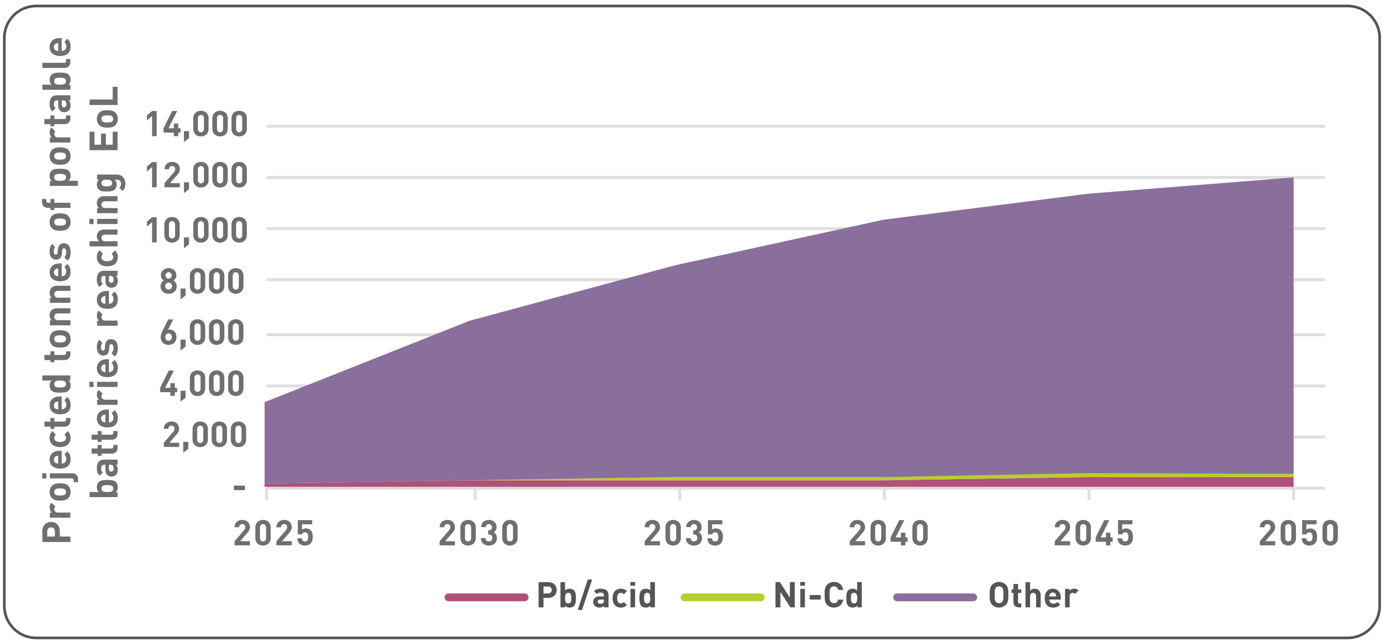


Figure 8 Industry-informed trend projection for portable batteries reaching EoL, in tonnes

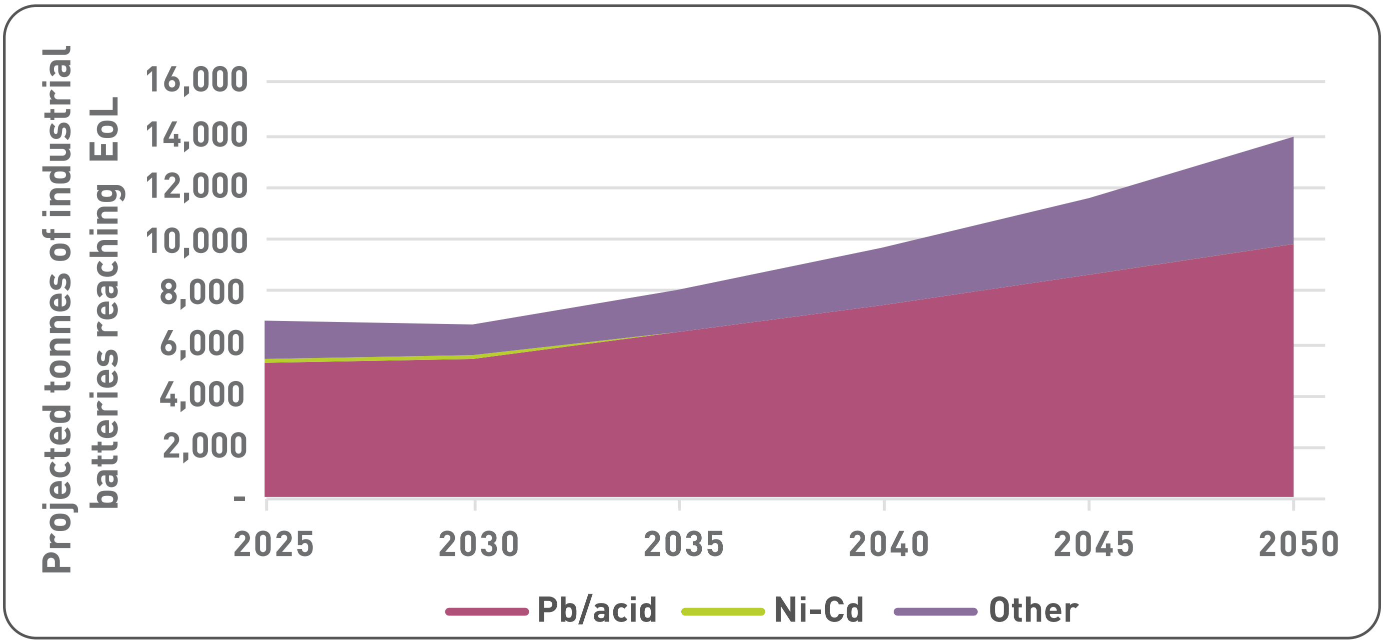


Figure 9 **Industry-informed trend projection for industrial batteries reaching EoL, in tonnes**

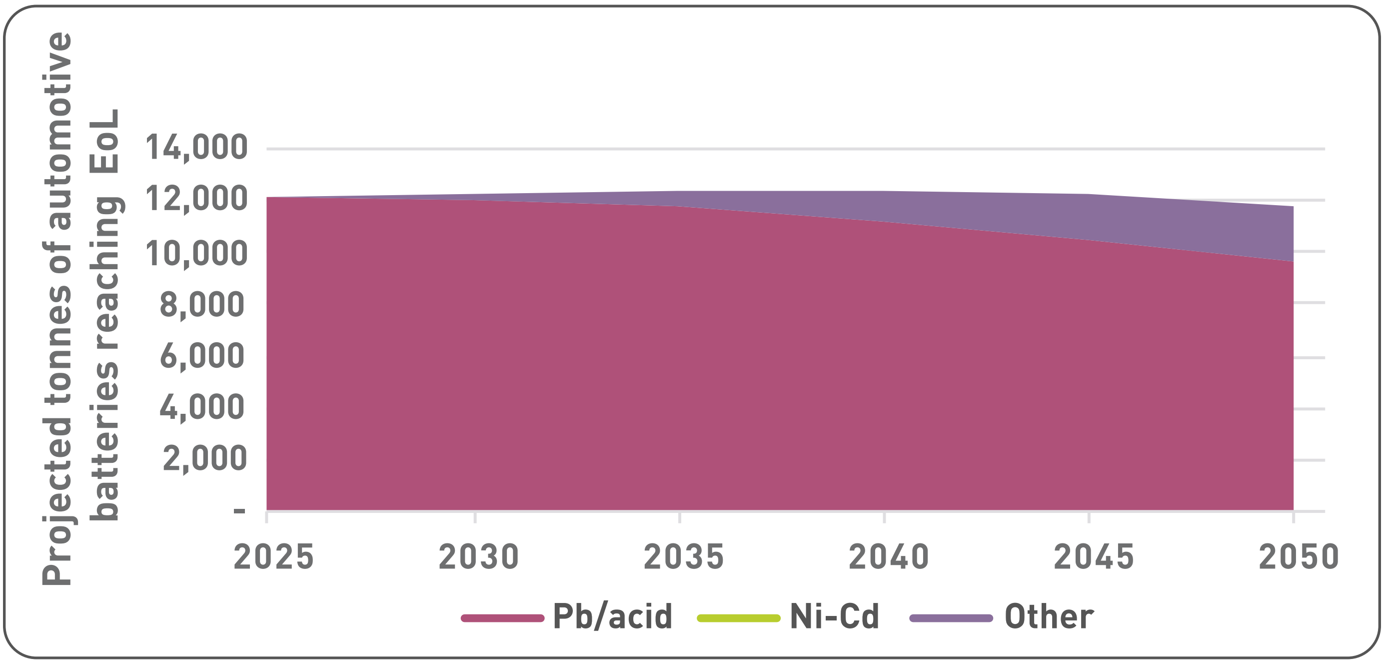


Figure 10 **Industry-informed trend projection for automotive batteries reaching EoL, in tonnes**

5 OPPORTUNITIES AND CHALLENGES FOR INCREASING CIRCULARITY IN SCOTLAND

This section discusses the key opportunities for Scotland to maximise the benefits of circularity principles from the expected development of the battery sector in future, and specific challenges to those. The global drivers for opportunity in the battery sector are:

- Continued rapid growth in consumer electronics demand
- Increasing demand for electric vehicles
- Fast-paced development in sectors requiring stationary energy storage, incorporating renewable generation back-up, grid balancing services and UPS applications.

These drivers are reflected at Scotland's national level and whilst the maturity and global nature of various stages of the battery lifecycle mean that Scotland does not realistically have the opportunity to be a world leader in development, it does have the knowledge and experience, as highlighted in **Figure 11**, to be a credible player.

The overarching challenge, and note of caution, relevant to all of the opportunities mentioned, is the fact that Scotland, as a small nation, does not have a great enough influence over batteries which are imported into the country. However, Scotland can work towards implementing its own standards and policies to ensure that those batteries placed on the market adhere to circular principles and do not negatively impact on Scotland's aims for the future.

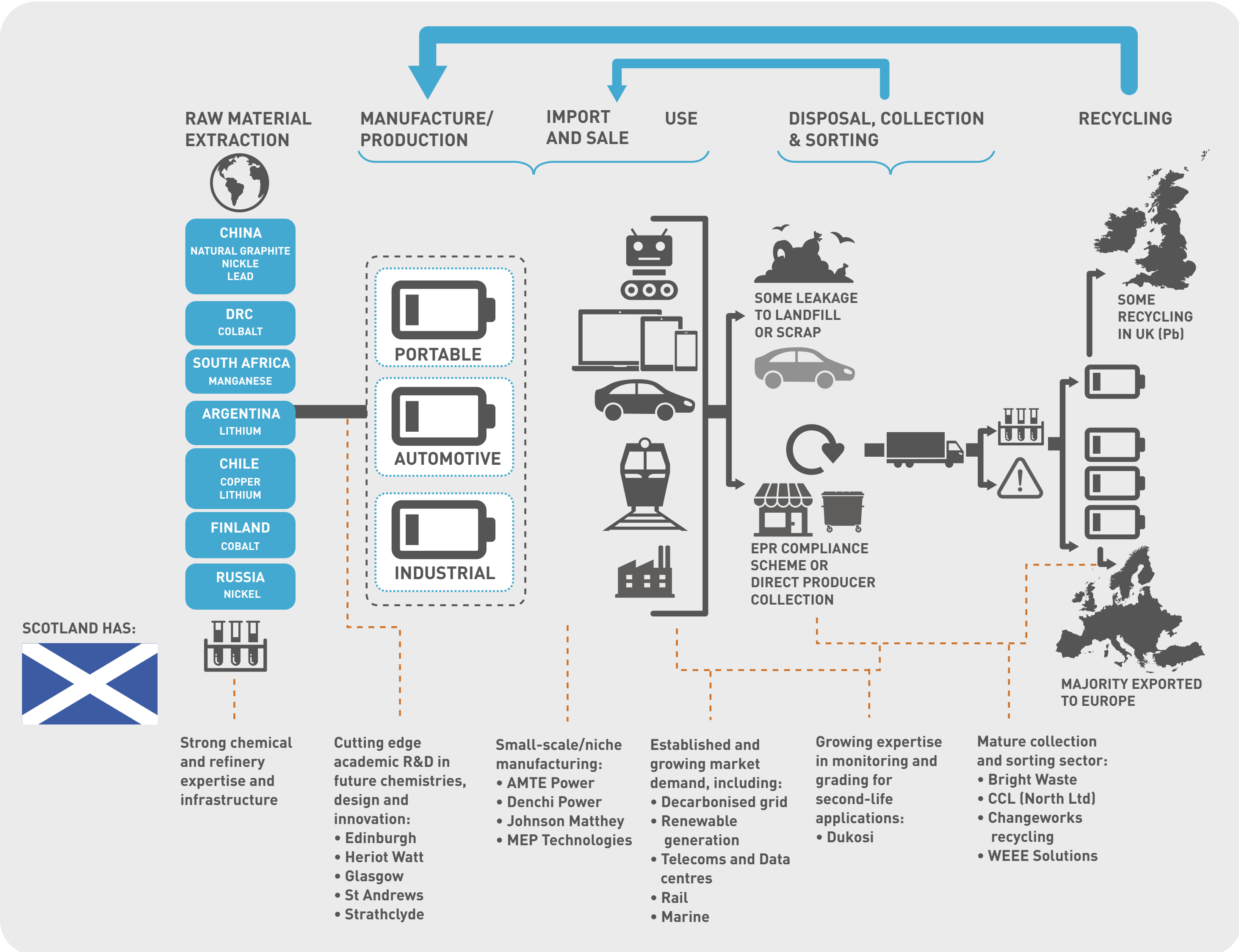


Figure 11 **The battery lifecycle and Scotland's related capabilities**
Source: Ricardo composition for this study

5.1 Technical opportunities and challenges

Opportunities for technical advancement

Alongside the potential for recycling infrastructure discussed above, The Faraday Challenge is pushing development of new battery technology. Opinion gathered from battery compliance schemes and those in academia suggested that the UK is in a position to be a world leader for the development of battery technology particularly for industrial applications for use within the grid network to support the use of renewable energy in Scotland. The Faraday Challenge shows that a supportive framework for innovation and financial support for conducting research and development can influence a market sector and turbo-charge the industry.

Many stakeholders have confirmed that Scotland has a strong reputation for developing new battery technology and innovations with several new designs, patents and intellectual property rights being sought by battery and associated technology producers. This encouragement of start-ups and test pilots is viewed positively within the battery sector. As an example, Dukosi have received targeted help from Scottish Enterprise in building up their technology and commercialising their products. Tracking and grading technology[59] has been developed by Dukosi[60] for battery cells to understand what capacity is left in the cell and whether they would be viable for second-life applications.

However, those who have developed the tracking technology do not expect that second-life reuse for Li-ion batteries will become widespread in the UK. They have grown from a team of 5 to approximately 50 in a few short years in order to meet increases in demand. The next logical step to capitalise on this would be to exploit technical knowledge with an increase in manufacturing facilities and scaling up new innovations. One of the main possible sites in Scotland being looked at to help increase battery manufacturing capacity which was mentioned several times during stakeholder interviews was the Michelin Scotland Innovation Park (MSIP) in Dundee. This site is being considered for the development of a new gigafactory by AMTE Power. Michelin have already been able to prove that a business can successfully run a facility in a 'remote' part of the UK, since this site acted as one of their main EU distribution centres for tyres with easy access to motorway networks and shipping port.

Another potential opportunity for Scotland in the sector is the development of batteries to power electronics for trains, to be used in energy intensive processes such as taking apart oil rigs or to be used at general recycling facilities for energy storage.

The profusion of Scottish based organisations operating in the battery industry demonstrates the technical and innovation capacity within the country to become a lead player in the industry. A separate appendix containing a summary of the key UK organisations operating in the battery industry can be requested from Zero Waste Scotland. It has been noted from stakeholder interviews that the battery sector itself can be agnostic for technical developments, however, innovations in batteries can widely help other sectors to reduce waste and pollution, helping to meet Scotland's overall aims of transitioning to a circular economy and Net Zero carbon emissions by 2045.

Opportunity 1: Provide a supportive framework for innovation and financial support for conducting research and development for new battery technologies.

A key area for battery use in Scotland, discussed in Section 3, could be the greater incorporation of batteries as utility grid-scale energy storage, particularly linking it with the renewable energy generation which already takes place across Scotland on a large scale. In addition, with the roll out of better telecommunications and 5G networks across the country, having reliable sources of energy from batteries would be beneficial to consumers and businesses.

[59] Optics (2021). UK partners developing optical magnetometers to test electric vehicle batteries
[60] Dukosi. Our Technology

Opportunity 2: Engage with key infrastructure stakeholders active in Scotland, such as renewable developers, grid networks, and telecoms operators, to understand their battery needs and facilitate potential collaboration with domestic R&D capabilities.

Opportunities for battery design

Overall, the design of batteries has been, and is, driven by the types of products a producer is putting on the market. This has led to a very wide range of specific battery products, sizes, technologies and chemistries co-existing in the market.

Battery designs that allow easy separation of parts, reversible joining (using nuts and bolts instead of welding and adhesives), labels for parts, using a minimum number of materials and components, and standardising formats and materials, will allow for easy removal of the battery from the device, increasing recycling rates, and minimising use of hazardous materials[61 62 63 64 65]. However, from a safety and use perspective, a battery pack must be nearly indestructible and stakeholders within the battery sector acknowledge that it is challenging to find a balanced answer to both sets of requirements.

Designing batteries and electronic appliances for repairability is of significant importance within the portable battery category and consumer products. Generally, if only one or two cells fail within a battery pack, consumers in most cases would dispose of the whole unit. However, if the battery packs are designed with repairability in mind, the power bank could be dismantled and rebuilt by replacing the failed cells with new cells, helping to reduce the overall waste creation. Again, producers of Electrical and Electronic Equipment (EEE) appliances feel that there is a fine line between safety and repairability. A key example of this in recent years has been the replacement of mobile phone batteries with non-branded batteries causing a number of fires.

If batteries are required to follow design standards such as the IEC 60086[66] standard for portable batteries this will help with designing disassembly and recycling processes. The IEC 60086 is an international standard for portable batteries which ensures that batteries are interchangeable according to standard form, fit and function (e.g. AA batteries). This is not only helpful for end-of-life waste management process, but it is also intended to help consumers, as well as manufacturers of devices, to be able to use standard batteries interchangeably.

One of the most promising elements of battery design to increase circularity in the sector would be to increase the lifespan of a rechargeable battery to extend the use phase of a battery before disposal. The use of advanced materials such as special graphite, zinc powder with engineered particle shape and manganese dioxide with improved particle structure, has improved the runtime of batteries between 25% to 50% over several years[67].

Scotland does not have significant influence to affect battery design requirements from a regulatory perspective, but could play a role in steering design towards greater circularity via its academic and technological R&D expertise.

Opportunity 3: Encourage greater circularity through battery design and standards for batteries being placed on to the Scottish market.

Strength of Scottish academia

Whilst the Battery Industrialisation Centre (BIC) is based in Coventry where there is a central pool of knowledge from the University of Warwick, Coventry University and the University of Birmingham working on battery innovations.

[61] Linda Gaines (2014). The future of automotive lithium-ion battery recycling: Charting a sustainable course Ahmadi et al., 2014
[62] Maryam Arbabzadeh, Jeremiah X. Johnson, Gregory A. Keoleian, et al. (2016) Twelve Principles for Green Energy Storage in Grid Applications
[63] Monsuru Olalekan Ramoni, Hong-Chao Zhang (2013). End-of-life (EOL) issues and options for electric vehicle batteries
[64] Kirti Richa, Callie W. Babbitt, Gabrielle Gaustad (2017) EcoÐ Efficiency Analysis of a LithiumÐIon Battery Waste Hierarchy Inspired by Circular Economy
[65] Leila Ahmadi, Michael Fowler, Steven B. Young, et al. (2014) Energy efficiency of Li-ion battery packs re-used in stationary power applications
[66] TÜV SÜD. IEC 60086 Battery Standard
[67] Interview with stakeholder

Scotland has a number of universities with good reputations in the battery arena, including, the University of St Andrews, the University of Strathclyde, the University of Edinburgh, Heriot-Watt University, and the University of Glasgow. These universities provide a talented pool of experts and students for employment in Scotland. An outline of the current research being undertaken at these universities can be provided in a separate appendix on request from Zero Waste Scotland.

Opportunity 4: Encourage high-quality research into battery chemistries, design, applications, and end-of-life waste management within Scottish academia.

Opportunities for reuse, recycling and recovery

Regardless of the challenges to battery recycling discussed in Section 3.3, and the uncertainty from a significant proportion of the stakeholders interviewed around the potential economy of scale for a battery recycling industry in Scotland, our projections suggest there could be sufficient end-of-life materials to warrant further investigation into the investment case for a Li-ion battery recycling facility. It is likely that Pb-Acid and portable batteries will continue to be exported for treatment to the rest of the UK and elsewhere globally, as the capacity already exists to handle them, but the end-of-life batteries in the 'other' chemistry class for industrial and automotive applications are likely to be dominated by Li-ion. The total projection for these categories, in our industry informed calculations, is for 6,200 tonnes of waste batteries by 2050. This does not include EV batteries reaching end-of life, which will greatly increase that figure. For reference, the Umicore recycling plant in New Jersey USA, one of the largest in the world, has an installed capacity of 7,000 tonnes of Li-ion and nickel metal hydride batteries per annum[68]. Even factoring in the fact that not all waste batteries will be efficiently collected for recycling, and not all those collected will be recyclable, this still represents sufficient feedstock to seriously consider investment in a Li-ion recycling facility of the appropriate scale. Scotland has the academic, chemical and technological innovation expertise to capitalise on this opportunity. This does however need to be approached with caution as the potential for adequate feedstock is subject to our long-term projection which, by its nature, carries a degree of uncertainty.

The introduction of minimum recycled content in batteries will be a good driver for incentivising batteries recycling. Incorporating recycled content into batteries is viewed positively by academics working as part of the Faraday Challenge. However, there needs to be a better understanding of how much recyclate material is available to be reused. This would provide clarity on what the minimum recycled content requirement needs to be. There are greater opportunities for raw material recovery from automotive and industrial batteries due to their size and therefore, a larger value of materials within each battery.

The Battery Directive at the moment focuses on waste generation and the push for a circular economy, however, batteries aren't easy to reuse and the Directive does not provide clear opportunities for second-life applications. One of the key examples of this could be the use of EV batteries to provide energy storage solutions. Legislatively, there is an opportunity to obligate the second-use company to become the legal waste-holder, which shifts the recycling responsibility and puts a value on second-use EV batteries.

It has been widely acknowledged by those within the battery industry that the current collection and recycling system for batteries in the UK is no longer fit for purpose and that "it undermines the environmental objectives it was meant to deliver in the first place"[69].

Battery compliance schemes have suggested that battery recycling facilities tend to be very material hungry and are expensive to install and run. However, our projections show a potential level of EoL battery material significant enough to warrant further investigation and investment consideration for future demand particularly from industrial

[68] Umicore. Battery Recycling
[69] Interview with stakeholder

batteries used in grid storage energy and telecom applications.

The Environment Agency has approved the UK's first full-scale household battery recycling facility operated by WasteCare[70]. The recycling facility is situated in Elland, West Yorkshire and has the capacity to recycle 25,000 tonnes of household batteries. With this capacity level the facility can cover all of the UK's spent alkaline batteries. WasteCare's facility is fully automated and sorts batteries by size and chemistry. Alkaline and zinc carbon batteries enter a sealed processing unit, where the batteries are pulverized before moving on to a multi-staged separation and extraction process. The component materials which are separated by this process can be reused by manufacturers as secondary raw materials.

Opportunity 5: Conduct further investigation into the investment case for a Li-ion battery recycling facility in Scotland.

Opportunities for collection and sorting Scotland has the opportunity overall, to influence the collection and recovery rate of batteries to help develop a stable feedstock for recycling facilities whether they are based in Scotland or the UK more generally.

Portable batteries

Battery compliance schemes would like to see improvement in collection infrastructure across the UK, particularly for portable batteries. If collection infrastructure was decoupled from treatment infrastructure it could have many benefits, such as efficiencies of transport, environmental benefits and allowing for a more localised approach to end-of-life management of batteries. Compliance schemes would be able to choose the best quality or value for money route for producers' batteries in terms of collections and treatments independently from each other.

In order to help meet recycling targets for batteries, one option could be to promote a national campaign to increase consumer awareness on the need to dispose of batteries correctly (i.e. not in general household waste) and encourage battery recycling. Another potential way to help with raising consumer awareness of batteries recycling could be to introduce visible fees for batteries (showing the cost of battery waste management to consumers at point of purchase). Although compliance schemes have found that it is very difficult to make any sizeable changes in collection rates purely through consumer awareness campaigns.

Another potential option to help increase collection rate for portable batteries could be to provide kerbside collections. Following the Commons' Environmental Audit Committee's inquiry into e-waste, UK Government has discussed the possibility of introducing kerbside collection of waste electronic and electrical equipment (WEEE) as part of online retailer obligations to help increase collection rates[71]. Kerbside collections would make it easier for consumers to recycle unwanted electrical equipment and ensure that physical stores are not disadvantaged by their requirement to provide collection services for consumers. The National Association of Waste Disposal Officers (NAWDO) and the Local Authority Recycling Advisory Committee (LARAC) have both been clear that kerbside collections could form part of a solution to increase collection rates for WEEE (as well as batteries, potentially) the full cost of these collections should be met by producers in line with current Extended Produce Responsibility (EPR) systems, and not the local authority themselves[72].

Whilst a few local authorities currently provide kerbside WEEE collections, it may not be the optimum solution for every local authority region. Examples of where kerbside collections have been introduced or tested include certain authorities in Bromley and Waltham Forest[73], Woking[74], and Redcar and Cleveland Borough Councils[75].

[70] WasteCare (2021). Regulator Approves UK's First Recycling Plant for Household Batteries
[71] Circular (2021). Gov to consider making online retailers collect old electronics, MPs told
[72] UK Parliament (2020). Electronic Waste and the Circular Economy
[73] Let's Recycle (2019). Kerbside WEEE collections expand in London
[74] Woking Borough Council. Waste and recycling provisions for new residential developments
[75] Redcar and Cleveland Borough Council. New kerbside waste collection service is launched for small electrical equipment

- **Nickel-based batteries:** Industrial end-users of nickel-based batteries are able to dispose of their spent batteries through long standing partnerships between producers, logistics companies specialised in the transportation of hazardous waste and fully permitted recyclers. This well-established system ensures proper recycling of used batteries, with the reuse of their components to manufacture new batteries or other industrial goods and the protection of the environment in a closed loop.

A more detailed study would need to be undertaken on the feasibility of kerbside battery collection however, the most likely outcome would be to add any battery collections from households onto any WEEE kerbside collections. Defra has commissioned an evaluation of the current WEEE kerbside collection schemes to provide information to the consultation to review the WEEE Regulations, which is expected to take place later this year.

Industrial and automotive batteries
The collection network for industrial and automotive batteries is viewed as being more effective than the collection network for portable batteries. For example, the battery industry has developed a standard colour code (IEC Standard 62902) to provide clarity on separating the different waste streams.

- **Lead-based batteries:** Batteries are collected by specialist companies and recycled within specialised recycling facilities in a closed-loop system that operates under strict environmental regulations. This established system reduces the need to process additional virgin materials, which are known to have a significant environmental impact in the lifecycle of the product.
- **Lithium-based batteries:** In order to recycle lithium-based batteries pyrometallurgy or hydrometallurgy are used. Valuable metals are recovered for conversion into active cathode materials for the production of new batteries. However, lithium represents a small fraction of the recovered material and is not currently reused.

Scotland has the opportunity to work with local authorities, compliance schemes and collection operators to facilitate a more efficient collection and sorting network for batteries. By improving the collection methods, a greater number of batteries can be recovered for recycling to help meet the recovery and recycling targets.

Opportunity 6: Improve battery collection network and infrastructure within Scotland to enhance recovery and recycling opportunities.

Challenges
Scotland is unlikely to be able to exert a great influence on the design of batteries which are imported into the country. There could be limited opportunities to influence those within Scotland's academic institutions and those piloting new battery technologies to adhere to the eco-design principles outlined above so that future batteries being placed on to the market have circular principles designed into them from the beginning. However, to ensure that batteries produced in Scotland are able to reach their commercial potential, they will be required to adhere to various international standards which are already in place.

Academics interviewed as part of the stakeholder engagement for this project believe that the target figures provided for recycled content under the EU directive proposals seem to be "plucked from thin air". They believe that to encourage battery reuse, it would be beneficial for battery producers to better understand the lifecycle of their batteries in greater detail.

Whilst Scotland may have an opportunity to invest in recycling facilities in future, with a particular focus on batteries used in grid energy storage and telecom applications, the demand for recycling of these batteries is unlikely to see an increase in the next decade until the useful lifespan of batteries currently in use has been met. Furthermore, the UK already have dedicated recycling facilities for certain battery types and chemistries which could limit Scotland's potential. A recycling facility would require a large throughput of battery feedstock to make it a viable operation which is seen by those interviewed as challenging for the UK as whole, let alone at a Scottish level.

Certain battery compliance schemes believe that there could be greater regionalisation of collection infrastructure, so that it is more similar to the Irish model where individual compliance schemes operate in a specific region and have collection agreements with all retailers and local authorities in that region. This could, however, lead to regional disparities across Scotland with collection organisations favouring more populated regions or those which have greater transport links.

5.2 Economic opportunities and challenges

Scotland has a significant base of technical knowledge and skills within the oil & gas, mining, and chemical industries. There is a large employment opportunity for Scotland as stakeholders believe that the skills gained from the oil & gas industry could transition easily to the battery industry, especially for the recycling sector. Whilst battery recycling facilities will likely have a certain level of automation, there is also a requirement for a very high-skilled workforce in the facilities.

Additionally, there is the opportunity to grow the battery recycling sector using the technical knowledge of those who are dismantling nuclear facilities in Dounreay, near Thurso. The decommissioning of Dounreay facilities deals with hazardous products, which requires a high-level of technical knowledge, so there is potential for there to be a transfer of this specialised knowledge to the dismantling of waste batteries. Furthermore, facilities which have been used in the dismantling of technically difficult and hazardous equipment could be re-purposed for other uses, such as batteries recycling. Since Thurso is in a remote location, it is away from major centres of population and therefore if there are any issues with thermal run away from batteries, this can be contained.

There is potential economic opportunity for Scotland to develop a Gigafactory facility and bring in investment and create new jobs within the region. AMTE Power plans to build a single digital Gigafactory (2 – 5 GWh). They are yet to decide on a site for this Gigafactory, but one potential site is the MSIP facility in Dundee. If plans go ahead for the Gigafactory, it will likely come online in 2023 and it is expected to build 60-100 million battery cells per year.

The potential economic benefits of having a Gigafactory facility can be seen from an example in Coventry. Coventry City Council has recently announced plans to develop a major Gigafactory in the city to help scale up the local electric vehicle and energy sectors[76]. The West Midlands region plays host to a number of automotive firms – including Jaguar Land Rover, Aston Martin Lagonda, BMW and LEVC (the UK's only electric taxi manufacturer) – who are all transitioning to EVs in order to meet the government's 2030 ban on new petrol and diesel cars. With this in mind, the council has forecast that it could attract up to £2 billion in investment and create approximately 4,000 jobs either directly or indirectly.

In addition, since Scotland produces a large amount of renewable energy, this could be harnessed to help make a battery production or recycling facilities carbon neutral. Furthermore, in order to be able to recycle large scale Li-ion batteries, recyclers have to discharge the energy from waste batteries before they are able to recycle them, the discharged energy can feed energy back into the national grid network, improving the circularity of the battery sector further and helping Scotland to meet its net zero targets.

[76] Edie (2021). Coventry unveils plans to host battery Gigafactory by 2025

Opportunity 7: Develop battery manufacturing within Scotland

Opportunity 8: Develop battery testing and grading capability to assess second-life applications within Scotland.

Challenges

There are certain challenges that Scotland may face in attracting investment for developing Gigafactories for battery production and recycling facilities for batteries. Whilst MSIP in Dundee has been considered as a possible site for a Gigafactory, a number of other locations have been proposed elsewhere in the UK, including Tesla potentially developing a site in Somerset[77] and Britishvolt developing a 30GWh site in Wales[78].

Another aspect battery producers are required to consider when deciding on their manufacturing locations is access to market and customers. There is a very strong market for batteries in the UK in locations close to automotive producers, which historically have been in the West Midlands and North East England.

A challenge which was raised during stakeholder interviews regarding the Dounreay site as a possible recycling facility is the limited access to this location and the distance which waste (possibly volatile) batteries would be required to travel from ABTOs across Scotland and the rest of the UK.

5.3 Policy opportunities and challenges

A supportive regulatory framework is required to allow the battery industry to evolve and innovate in the future allowing the domestic battery industry to remain competitive in international markets and across different applications.

Targets

Under the current Battery Directive, only a small proportion of each battery needs to be recycled to meet the requirements for counting it towards the recycling targets – e.g. the metal 'can'. Therefore, there is greater potential to recycle more of the raw materials within the batteries to increase circularity within the industry. Legislation should set out a more defined requirement for what is counted as "recycled" and increase the proportion of the battery that this applies to. Furthermore, there is a lack of like-for-like recycling obligations under the current Batteries Directive, this means that producers may be placing unsustainable battery types on the market, but are able to meet their obligation under EPR requirements by buying evidence of battery recycling which are made up of different battery types. This does not encourage more sustainable material use and improve recycling innovations for more harmful battery chemistries.

Compliance schemes and academics supporting the Faraday Challenge both support the need to review targets laid out in the battery regulations. The battery recycling targets are viewed as being crude and based on weight. The EU's proposed recycling target of 65% is too high for portable batteries when the UK is struggling to reach 45%. Battery compliance schemes felt that it would be too complex to introduce collection & recycling targets per chemistry type as the legislation would be unable to keep pace with the trends within the battery market and could become outdated quickly. Academics at the University of Birmingham are calling for a more sensible and yet imaginative way to configure targets, for example, they could be based on embedded carbon & carbon emissions impact rather than weight-based collections and recycling.

Furthermore, the average lifespan estimates of portable batteries should be re-analysed for appropriate target setting, and complete placed on market data used. Currently, the UK uses a three-year placed on market average calculation which does not reflect current conditions for waste arisings. Recycling rates should reflect the actual availability of material in the waste stream not an average from previous years.

[77] Autocar (2020). Tesla linked to new UK gigafactory in Somerset

[78] Edie (2020). Wales to play host to Gigafactory and marine energy hub

Opportunity 9: Implement battery recycling targets to encourage the greatest use of valuable materials.

Opportunities for EPR

While EPR is a devolved power, existing schemes (packaging, WEEE, end-of-life vehicles and batteries) operate on a UK-wide basis. The UK-wide producer responsibility system for batteries and accumulators[79] is currently under review. This review is being led by Defra, with input from the Devolved Administrations of Scotland, Wales and Northern Ireland.

In December 2020 the European Commission proposed a new Batteries Regulations that aims to ensure that batteries placed on the EU market are sustainable and safe throughout their entire lifecycle[80]. In the Programme for Government 2020-2021 Scottish Government outlined that the UK Withdrawal from the European Union (Continuity) (Scotland) Bill will help Scots law, where appropriate, keep up with future developments in EU law, and will act as a strong signal to the EU that Scotland continues to uphold the EU's core values[81]. There is an opportunity to align the UK-wide system currently under review with the ambitions of Europe and, where possible, push proposals to leverage better outputs for both the UK and Scotland.

The sections below summarise the key elements of the current EPR regulations which stakeholders believe could be improved upon.

Definitions

Battery compliance schemes are also calling for greater clarity on battery classifications. For instance, although the definition change for portable batteries to 'hand carriable' temporarily lessened the discrepancy between batteries placed on the market and those that were reported as being recycled, the inconsistency in data reporting has now re-emerged, particularly for Pb-Acid batteries fluctuating between industrial POM and Portable EoL figures. A revised EPR system could implement greater transparency in reporting between the types of batteries producers place on the market, and the recycling they are obligated to fund.

Not only is there a need for clarity on the definitions provided for batteries themselves, but also clarity on where the responsibility lies when looking at reuse and remanufacture of batteries between the original battery producer and the producer carrying out the remanufacture/reuse activity and then placing it back on to the market. In addition to a review of the definitions of reuse, to ensure that it happens in practice an effective resale market will need to be established or the manufacturer retains ownership of the batteries so that they can be passed between multiple users. If manufacturers retain ownership of batteries, then they have a vested interest in the battery which can increase the likelihood of repair and remanufacturing[82].

Obligations

In the EU Battery Directive, all battery producers have an obligation under EPR requirements. In the case of small battery producers in the UK (<1 tonnes POM per year), they are mandated to register and submit data to the relevant environmental authority (EA, SEPA, NIEA & NRW), but

[79] HM Government (2018). Our Waste, Our Resources: A Strategy for England

[80] European Commission (2020). Batteries and accumulators.

[81] Scottish Government (2020). Protecting Scotland, Renewing Scotland

[82] Medium (2020). A circular economy for batteries to underpin renewable energy growth

they do not take on any of the financial or regulatory obligations to collect and recycle batteries in order to meet the targets set out in the legislation. The revised EPR system for batteries could look to amend what each actor in the supply chain is obligated for based on their activities, size, or method of sale. The system could also remove thresholds to ensure that all battery producers are captured and paying into the EPR system.

The requirement for producers of industrial and automotive batteries to take-back should be made very clear in the revised regulations in order to layout a structured plan for how they are going to handle the batteries which are returned to them. These plans would need to be in place from the point batteries are put on the market, even if the producer won't see the battery for 5,10, or 15 years after the initial sale. The cost for waste battery collection and end-of-life treatment could be made explicit or built into the cost of the battery at the point of sale (similar to the visible fees requirement under the WEEE Directive) to raise awareness of the importance of recycling batteries to end users.

Data reporting
According to British & Irish Portable Batteries Associations (BIPBA), producers of portable batteries are supportive of proposals to increase the number of chemistry types which need to be reported and already have this information as they are required to report this level of detail in other countries (e.g. Republic of Ireland, France and Germany). A revised EPR system for batteries, should consider the level of detail required from producers placing batteries on to the market. This would provide the environmental regulators with an extensive database from which to make future policy decisions.

However, using this increased chemistry breakdown information to drive compliance by individual chemistry would be misplaced. This type of approach has many flaws, such as batteries not flowing neatly onto and off the market within the 3-year time horizon provided by the current EU Directive and UK Regulations and would thus be counterproductive.

Modulated fees
The UK government's Environment Bill introduces the principle of modulated fees for items covered by EPR legislation. A revised EPR system for batteries could introduce modulated fees on the standardisation of format and size of batteries, for example, looking for the next AA battery, as suggested by battery compliance schemes. Currently, portable batteries which are incorporated in EEE (e.g. mobile phone/laptops) vary in size, shape, and capacity based on the equipment model or brand name. By having standardised formats and sizes, especially for portable batteries, it will help waste operators to be able to remove batteries safely and effectively from consumer EEE products, leading to the possibility of repairing an electronic device rather than it being sent for disposal.

Labelling
One of the key issues to recycling batteries is the lack of information provided on chemistry type, including the percentage of materials, which make up the individual battery cells or packs. If batteries were labelled with a barcode for instance, it could be read by sorting equipment to effectively separate different chemistry types.

As well as the chemical make-up of the battery, knowing the materials which encase the cells (e.g. aluminium and plastic polymers) would be helpful for recyclers to segregate waste streams more efficiently.

By increasing the information required from producers, a revised EPR system could help to improve efficiency of material recovery, especially for larger scale batteries. In addition, providing more detailed information on batteries would help fire services to understand the type of battery fire they may be facing. This has been an important growth area of knowledge with the growing number of electric vehicles on the road. According to industry experts EV battery fires last longer and temperatures are immense in comparison to traditional vehicle batteries.

Opportunity 10: Leverage influence for a revised EPR system for batteries which places greater requirements on producers, data reporting, waste management fees, and labelling, driving a Circular Economy for Scotland.

Challenges

A possible challenge of the revised EPR system for batteries, could arise if European and global producers are required to provide different labelling, chemistry and sale details to separate environmental regulators and authorities.

Furthermore, if a revised system deviated from the EU definitions widely used within the sector this could put UK producers at a disadvantage in the European and global markets if their products do not meet international standards.

6 CONCLUSIONS

The potential opportunities for Scotland identified through this project, and our initial assessment of likely feasibility as estimated following the procedure laid out in **Section 2.4** are presented in **Table 7**.

Opportunity	Likely feasibility for Scotland
Opportunity 1: Provide a supportive framework for innovation and financial support for conducting research and development for new battery technologies.	Medium
Opportunity 2: Engage with key infrastructure stakeholders active in Scotland, such as renewable developers, grid networks, and telecoms operators, to understand their battery needs and facilitate potential collaboration with domestic R&D capabilities.	High
Opportunity 3: Encourage greater circularity through battery design and standards for batteries being placed on to the Scottish market.	Low
Opportunity 4: Encourage high-quality research in to battery chemistries, design, applications, and end-of-life waste management within Scottish academia.	Medium
Opportunity 5: Assess the investment case for a Li-ion battery recycling facility in Scotland.	Low
Opportunity 6: Improve battery collection network and infrastructure within Scotland to enhance recovery and recycling opportunities.	Medium
Opportunity 7: Develop battery manufacturing within Scotland.	Medium
Opportunity 8: Develop battery testing and grading capability to assess second-life applications within Scotland.	Medium
Opportunity 9: Implement battery recycling targets to encourage the greatest use of valuable materials.	High
Opportunity 10: Leverage influence for a revised EPR system for batteries which places greater requirements on producers , data reporting, waste management fees, and labelling, driving a Circular Economy for Scotland.	High

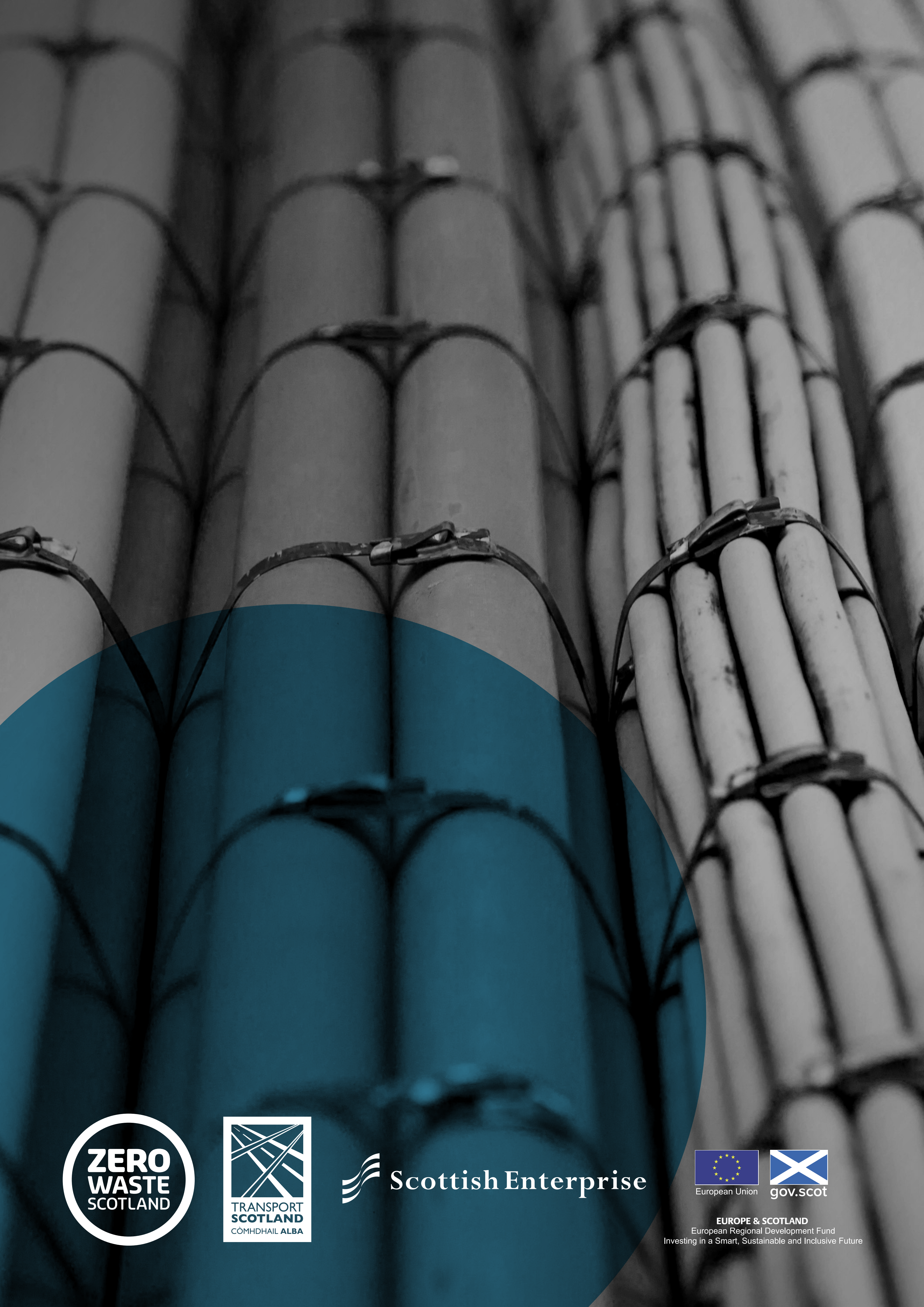
Table 7 Opportunities for Scotland and their likely feasibility

All of these opportunities need to be considered in the context of significant uncertainty in the market surrounding the long-term viability and development of each chemistry type, and the value placed on certain materials in future to encourage the most efficient use of recovered materials. In addition, any policy interventions and any introduction of design standards have to meet international market requirements to ensure that Scotland's battery industry can be competitive.

Our projections show there may be sufficient estimated EoL Li-ion batteries to consider investment in an appropriately sized recycling facility. This should be approached with caution however, as the projections do incorporate a number of assumptions and related uncertainty. The feasibility of a domestic recycling plant may rest on the availability of EV Li-ion batteries, which is also subject to uncertainty until automotive OEMs confirm their EoL business model plans for batteries. Further detail on the future chemistries and applications for EV Li-ion batteries are discussed in the Phase 3 report of this project.

Overall, it is clear from the desk-based research and stakeholder interviews that many in the battery sector no longer see the current regulations as fit for purpose and a full review is necessary, because tweaking the system is no longer sufficient. With the insight from this engagement in development, the opportunities raised in this report can be considered in more detail for their comparative merits and weaknesses.

Key battery applications which the Project Group may wish to consider in more detail include rechargeable portable batteries and industrial stationary energy storage batteries, as these are likely to be used most prolifically in Scotland in future by household consumers and to sit alongside the renewable energy generation capacity which has been developed in Scotland.



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