Written evidence submitted by the Faraday Institution

Introduction to organisation: The Faraday Institution (FI)[1] is the UK's flagship programme for electrochemical energy storage research, skills development, market analysis and early-stage commercialisation. It brings together research scientists and industry partners on major projects with commercial potential to reduce battery cost, weight, and volume; improve performance and reliability, and develop whole-life strategies including recycling and reuse. The FI regularly publishes evidence-based assessments of the market, economics, commercial potential, and capabilities for energy storage technologies and the transition to an electrified economy.

We have addressed the questions that are within the expertise of and most relevant to the Faraday Institution.

Summary: For the UK to achieve Net Zero by 2050 and transition to an electrified future – in sectors ranging from transport and aviation to power generation and distribution – will require many types of batteries, some as yet to be imagined. These batteries need to be researched, developed, commercialised and manufactured in gigafactories here in the UK for environmental and economic benefits to be fully realised. The Government should continue to provide coordinated, ambitious and centralised leadership on attracting inward investment to establish a UK domestic battery cell production capability. Sustained efforts to ensure and localise an efficient and effective UK supply chain will be required to improve availability and affordability of key battery materials and components for battery production. Appropriate regulatory changes will help facilitate the sustainable management of spent EV batteries and thus help achieve the circular economy goals of UK industrial policy. To support all of this, a comprehensive and unified national plan for battery cell production training is required to ensure a consistent delivery of skills across the UK.

Q1) What contribution could battery electric vehicles make to achieving net zero by 2050?
Battery electric vehicles (BEVs) will play a critical role in decarbonisation the transport sector which accounts for around 27% of carbon emissions in the UK.[2] The UK is already on the path to the electrification of road transport, with the UK government recently announcing the end of the sale of new diesel and petrol vehicles by 2030. Sales of BEVs have increased to 6.6% of all new car sales in 2020[3] and are expected to reach a market share of 9.3% in 2021 and 11.9% in 2022.[4] BEVs, plug-in hybrids and hybrids in total are expected to account for around 24.9% of registrations in 2021 and 28.5% of registrations in 2022.

The Faraday Institution estimates that total lifecycle carbon emissions of a BEV will be about one-third that of an equivalent petrol internal combustion engines (ICE) vehicle sold in 2025, with UK-manufactured EV batteries 12% greener than the European average. This cradle-to-grave lifecycle analysis includes an assessment of the carbon emissions generated from the mining of the raw minerals, battery manufacturing, EV production, charging (driving) an EV and end-of-life recycling.

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[1] The FI launched its research programme in 2018 and is a key element of the Faraday Battery Challenge.
[2] Final UK greenhouse gas emissions national statistics 1990-2019, BEIS.
[3] SMMT (2021 February). https://www.smmt.co.uk/vehicle-data/car-registrations/
[4] January/February 2021 - SMMT UK New Car and LCV Registrations Outlook to 2022.

The carbon intensity of the UK electricity grid is the main determinant of the level of carbon emissions from BEVs and as the grid is decarbonised, BEVs will generate lower and lower emissions.

Other studies show a similar picture that EVs emit much less carbon than ICE vehicles. Transport & Environment[5] estimates that BEVs in UK emitted 92 gCO2/km in 2020, compared to 253 gCO2/km for petrol engines and 233 gCO2/km for diesel engines in 2020. Ricardo[6] also recently undertook a detailed study of lifecycle impacts for the European Commission with country differences in emissions largely explained by the carbon intensity of electricity generation.

Q2) How well is Government policy aligned with high-level commitment for growth of battery electric vehicles to support its net zero ambition?

The Government ambition to deliver Net Zero by 2050 and to end the sale of petrol and diesel engines assumes that new technologies will be found. However, this is not a given and substantial investment in academic and commercial research is needed to develop the technologies of the future.

For the UK to play a significant role in battery manufacture and to decarbonise a range of industrial sectors it will require long term commitment in R&D. The Faraday Institution is the UK's flagship national programme for electrochemical energy storage research and early-stage commercialisation. The FI was intended at the outset to be a 10-year programme, which is the time needed to make research breakthroughs and to commercialise them for the benefit of the UK economy.

Q3) Are the UK supply chain opportunities around supply of batteries and power electronics, machines and drive supply chain clear?

The UK supply chain opportunities are reasonably well defined at a high level. However, the UK is in a global race to secure them and, moreover, much more detailed analysis is required to identify the specific opportunities at a disaggregated level. At the heart of the challenge, is to localise more of the battery supply chain in the UK and this is an important policy and strategy for both the public and private sector. Raw materials are needed for all parts of the battery including the cathode powder, graphite for the anode, separators and other key chemicals that are used in the manufacturing process. An efficient and effective UK supply chain will improve availability and affordability of key chemicals, materials and components.

The clearest supply chain opportunity is in securing and generating jobs through the development of a EV and battery manufacturing industry and battery supply chain. The Faraday Institution forecasts that UK EV battery demand would reach 137 GWh per annum in 2040, which is equivalent to 7 gigafactories generating 20 GWh per annum each.[7] At present, the AESC Envision plant is the only large-scale EV battery factory operating in the UK. Britishvolt intends to build a gigafactory in Blythe and plans for a West Midlands gigafactory at Coventry Airport has been announced.

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[5] How clean are electric cars? www.transportenvironment.org/what-we-do/electric-cars/how-clean-are-electric-cars

[6] Ricardo (July 2020). Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, for the European Commission, DG Climate Action. (See Figure ES5 for country comparisons).

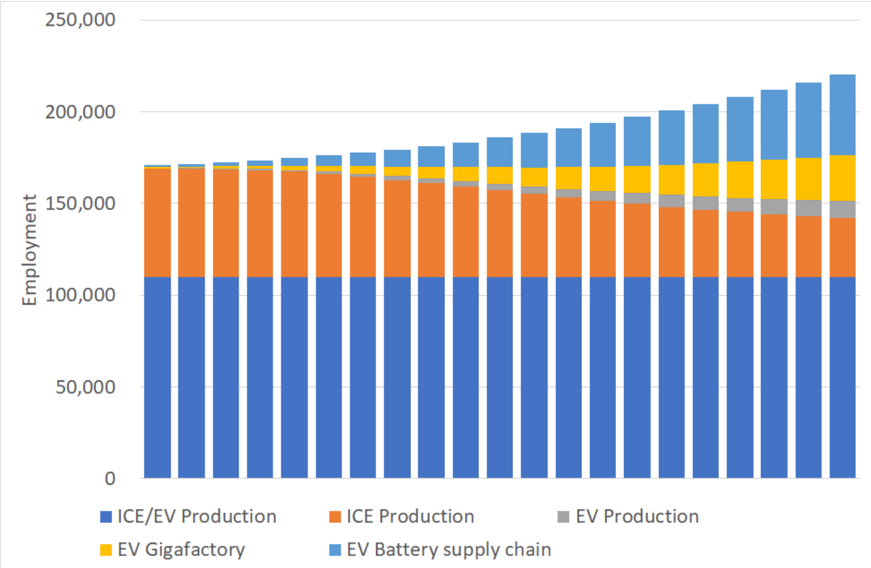
[7] "UK EV and battery production potential to 2040"

Securing the gigafactory opportunity, would increase the UK workforce in the automotive and EV battery ecosystem (including the battery supply chain) by 29% from 170,000 in 2020 to 220,000 employees by 2040. Employment (Figure 1) is split by the following:

- 78,000 jobs created in the new UK battery gigafactories and battery supply chains;
- 32,000 jobs remaining in ICE vehicle production; and
- 110,000 jobs remaining in powertrain manufacturing serving both ICE and EV production.

Of the 78,000 jobs in the gigafactory and battery supply chain industry, 24,500 jobs would be in battery manufacturing, 43,500 jobs in the battery supply chain and around 10,000 would be created in EV manufacturing. Securing the supply chain opportunities will require the attraction of cell component (cathode, anode, electrolyte, etc.) suppliers to the UK.

Figure 1: UK ICE and EV automotive and battery manufacturing 2020 to 2040



The UK is facing a supply chain scale-up challenge given the acceleration of EV demand expected from 2025, with the challenge focused on the chemical industry, mineral imports and the supply chain rather than mineral extraction. The Advanced Propulsion Centre (APC) has identified an opportunity of £4.8 billion per annum for the UK chemicals sector by 2030 for the lithium-ion battery supply chain. The UK already has significant capability including:

- the world's largest producer of speciality graphite cokes;
- Europe's second largest nickel refinery;
- a large, hydropowered aluminium smelter producing suitable grade aluminium; and
- pilot manufacturing for one of the world's leading cathode materials suppliers.

Global production of lithium and cobalt will need to sharply increase, and we estimate by a factor of 5 times and 3 times respectively from now to 2035. The UK is exploring some domestic supplies of key raw minerals, but it does not have abundant reserves available. The UK does, however, have some important commercial strengths such as the second biggest nickel factory in the EU, Cornish Lithium (currently investigating Cornwall's mineral potential) and Johnson Matthey (a global leader in battery material production).

One of the biggest economic value and jobs opportunities for the UK is to become a leader in the manufacturing of next generation battery technology, particularly solid-state, sodium-ion and lithium-sulfur batteries. Currently, no country manufactures these batteries at significant commercial scale. The UK has world-leading expertise in these technologies and could gain a first-mover advantage provided the lessons have been learned from the failure to commercialise lithium-ion batteries in the UK in the 1980s.

Q5) What action is needed to support investment and establishment of UK gigafactories?

The action required to support investment and establishment of UK gigafactories is wide ranging. The UK Government should continue to provide a coordinated, ambitious and centralised leadership on this issue. Key actions include:

- The DIT, FCDO and others should continue to communicate the attractiveness of the UK as a global and regional battery manufacturing location.
- Development of a coherent waste hierarchy strategy for lithium-ion batteries, which addresses end-of-life management and covers recycling, re-use and repurposing of the batteries.
- A strategy to create the conditions for a new lithium-ion battery recycling industry in the UK to flourish.
- New efforts to de-risk the business case by undertaking prospective site selection, the pre-approval of relevant permissions, the construction of basic on-site physical (especially energy) infrastructure.
- The development of the requisite EV battery skills and training infrastructure.

The UK Government should also continue to support the UK research ecosystem, with continued long-term investment in the Advanced Propulsion Centre, the Faraday Institution, Faraday Battery Challenge, and the UK Battery Industrialisation Centre. Domestic battery manufacturing capability is strongly correlated with world class R&D and the generation of valuable intellectual property. China, Japan and Korea currently dominate battery research. Companies and research institutions based in these countries own the majority of battery patents and critical intellectual property for current generation lithium-ion battery technology.

An ongoing strong Faraday Institution research programme aligned with the requirements of the automotive sector with associated training of the next wave of leading battery scientists and engineers able to support battery R&D would significantly strengthen the UK's attractiveness to inward investment in gigafactories. The FI has already been successful in strengthening the academic battery research community in the UK and its links into industry.

The UK should also learn the lessons from the past and particularly the historical failures where the UK did not capture the value generated by battery research into lithium batteries. The lithium-ion battery was invented in the UK but commercialised overseas. Factors for this included a historic lack of strategic planning for national economic impact, lack of risk bearing capital for scale up activities, lack of understanding that battery research needs long-term projects (5-10 years) and close engagement between academia and industry, and the lack of demand from end user applications due to the absence of consumer electronics manufacturing. In recent years the UK has addressed these historical weaknesses. For example, the creation of the Faraday Institution has greatly strengthened the UK's ability for capturing the value of battery research.

Action also has to accept the realities of the market. Existing lithium-ion battery manufacturers have spent 30 years optimising the manufacturing processes and the underlying cell chemistries. Establishing complete inhouse technology for lithium-ion battery manufacturing is impossible for new market entrants and the intellectual property for the newer generation technology is fiercely protected. Therefore, new entrants are unlikely to gain access to the most competitive technology without partnering with leading established Asian companies. For example, Tesla partnered with Panasonic to develop Gigafactory 1 and CATL for Giga Shanghai. Given the anticipated demand for batteries by large automotive companies, competition for access to both expertise and IP is considerable. Furthermore, manufacturing at this scale requires a highly developed supply chain.

Q9) The £1 billion Net Zero Innovation Portfolio will focus on research into low carbon technologies. What proportion of this funding should be directed towards battery electric vehicle research? What areas should ARIA target in distributing funding for high-risk, high-reward research into battery electric vehicles?

A significant proportion of the Net Zero Innovation Portfolio funding should be directed towards battery research in lithium-ion batteries and next generation battery technology.

The Faraday Institution have been established to undertake battery research, strategically convene the UK battery community and ensure commercialisation is accelerated for the benefit of the UK economy. The FI currently has 10 major research projects across 20+ UK universities with more than 50 industrial partners across the UK.[8] This portfolio covers both current generation Li-ion batteries and higher risk, higher reward projects in next-generation chemistries. As the FI model to drive application-inspired research toward early-stage commercial is unique, there will be an opportunity for ARIA to sit alongside the FI to learn from us as it establishes its other programmes. We can particularly offer examples of case studies in higher risk, higher reward research that should be of interest when establishing ARIA.

This Faraday Institution's programme of research also brings an opportunity for the UK to become a leader next generation battery technology such as particularly solid-state, sodium-ion and lithium-sulfur batteries. The UK is amongst the leaders and probably world leading in developing battery systems with high energy lithium-sulfur battery packs. In the development of next generation sodium-ion batteries as a lower-cost alternative to lithium ion, the UK is also amongst the leaders.

The UK has strengths in the next generation technologies (sodium-ion, solid-state and lithium-sulfur batteries) and there are opportunities to commercialise these technologies and capture significant economic benefits for the UK (worth £ billions). This will require a highly coordinated strategy with industry, continuation / acceleration of research and a willingness to engage in higher risk scale-up and industrialisation efforts, and a willingness to fail whilst trying. If strategic bets are placed, with sufficient backing and continued research, the UK could become a leader in these technologies.

[8] The Faraday Institution Annual Report 2019/2020

Capturing and developing next generation battery and fuel cell technology in the UK will be critical to the competitiveness and health of the automotive industry and the associated supply chains.

However, there is a significant amount of discovery research to be undertaken requiring long-term research funding. New manufacturing methods will be needed for these next-generation batteries, which will require government funding to be comfortable with committing long-term capital to high-risk research and manufacturing scale-up activities. A willingness to try and fail and then iterate quickly is critical to developing the manufacturing capability and securing the IP necessary to guarantee UK manufacturing. These activities are often too risky for the private sector and will always rely on government financing as a catalyst.

Q10) What steps should be taken to ensure the UK workforce has the necessary skills to staff gigafactories and their supporting supply chains?

The Auto Council working through the Advanced Propulsion Centre (APC) has identified an Electrical Energy Storage Technology Roadmap, which details the technological transformation needed across the supply chain to strengthen the UK's battery cell production capability. A similar approach toward a comprehensive and unified national plan for battery cell production training is required to ensure a consistent delivery of skills across the UK and will increase interest in inward investment in UK gigafactories by leveraging the workforce pipeline as an investment risk-reducer.

Toward this end, in 2020, the FI began work with the Warwick Manufacturing Group (WMG) to model the workforce, roles and skills required in the automotive sector and in a representative gigafactory by reference to global examples. From this effort, it was recognised that training plans to develop such a workforce could be generally understood and made, though any detailed training plans would need to be timed with and tailored to a particular facility and its location. This is similarly true for the elements of gigafactory supply chains to be based in the UK.

The FI engagement with WMG and the High Value Manufacturing Catapult (HVMC) has led to a more focused effort to develop a national electrification skills plan for the UK, targeting sector impacts to both automotive manufacture and the battery production industry. To fully understand the skilled workforce needed to meet the needs of this emergent sector a community-wide effort is required whereby technologists, educators, accrediting bodies and training providers work together to ensure that quality training is delivered at the time when jobs are available.

The plan will launch in 2021 and will provide a modular approach to the transition to green jobs so that skilled workers can be re-skilled, upskilled, or "new skilled" depending on their level of expertise and capability. Founded on examples of international good practice, a 'Skills Value Chain' (SVC) process has been developed by the HVMC to convene the technologists developing future industrial applications and processes, the educators and trainers who will develop the knowledge and skills in the workforce, and the employers who understand changing roles and duties and who can prioritise pipeline activities.

At time of writing, a systematic skills 'foresighting' approach has begun to be applied to electrification technologies with initial support from the Gatsby Foundation and the FI that is now being further piloted by the Department for Education funded 'Emerging Skills Pilot Project' that was announced in the Skills for Jobs policy paper[9] in January 2021. The pilot project will develop shared course structures and content and will train future trainers. It is being delivered by a partnership of the HVMC, WMG, and the national group of 12 Institutes of Technology.

The impact of this approach is to conquer the considerable lag in delivery of future skills (often seen as current market failure when it occurs) as well as increase the value of investment by preparing for need in a highly scalable manner such that skills may be developed locally at the time of need using a foundation of common resources across a growing and supportive network of providers which continue to remain connected with sources of specialist technology and expertise. This effort aims to reset the reactive nature of training provision toward a longer-term national collaborative effort.

A current focus of the effort is to address how to best adopt digital solutions to increase the efficiency and responsiveness of education and training providers and widen access to skills using the concept of 'cyber - physical' learning factory networks. This would support a distributed and connected delivery model across the whole supply chain with particular relevance to smaller businesses who may be remote from early training opportunities.

Q11) What measures should the Government take to ensure that minerals for battery electric vehicles are sourced in a responsible way?

Substantial amounts of raw materials, particularly lithium, cobalt and nickel are needed to manufacture the quantities of batteries required for BEVs. Other minerals used in BEVs are graphite for the anode, as well as neodymium and dysprosium for the magnets used in electric motors. Key measures the Government should take include the following:

- Continued funding of UK battery research to reduce the dependence on cobalt where social and ethical issues are more prominent;
- Develop a UK recycling industry to supply a substantive proportion of the raw material required for EV batteries;
- Develop a strategy to diversify the UK supply chain away from a reliance on the Democratic of Congo (DRC) for cobalt and South America for lithium;
- Improve transparency, traceability and accountability throughout the mining supply chain through multi-lateral policy development and reduce the reliance on China;
- Support policy development by trade bodies and interested organisation on the ethical sourcing and responsible mining of raw materials; [10]
- Multi-lateral engagement with other countries and NGOs to develop a global approach to ethical sourcing of minerals including traceability.

Continued research is needed to improve to lithium-ion battery technologies and specifically to develop new cathode chemistries to replace or reduce the amount of cobalt in the EV battery without impacting on EV performance. Near-term research is looking to tackle resource pressure and social issues with cobalt through innovations in battery cell technology, such as the move to high nickel batteries such as NMC 811 and the successful development of alternatives such as solid-state and lithium-sulfur batteries.

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[9] Skills for jobs: lifelong learning for opportunity and growth, 21 January 2021. https://www.gov.uk/government/publications/skills-for-jobs-lifelong-learning-for-opportunity-and-growth

[10] Faraday Insight 7: Building a responsible cobalt supply chain. www.faraday.ac.uk/get/insight-7/

Current end-of-life battery processing techniques do not optimise or maximise the recovery of all of the materials contained in EV batteries. There is therefore an urgent imperative to reduce the raw materials that need to be sourced to manufacture batteries for future EV production by increasing the amount of battery materials that are recycled, so making better use of ethical resources. A government strategy is needed to create the conditions for a new lithium-ion battery recycling industry in the UK to flourish. The UK's Faraday Battery Challenge is playing a leading role in promoting the reuse and recycling of battery components. One of the eight technical challenges set for the Faraday Battery Challenge by industry is to be able to recycle 95% of an EV battery pack by 2035.

A government supply chain strategy is needed to develop a more diversified supply chain. Lithium, cobalt and nickel are predominately found in a small number of countries. The DRC is the biggest producer of cobalt, supplying more than 60% of the world's cobalt while key quantities of lithium are found in Chile, Australia and Argentina.

Improving transparency, traceability and accountability can be accomplished through building trust at all levels and between all stakeholders. Reducing the dependence on materials sourced through China's battery supply chain will also help improve traceability, which is currently difficult as most minerals required for EV batteries pass through the China mineral refining industry. China has a strong influence if not control of the global supply chain of many critical materials used in EV batteries.

The Government should continue to engage with UK trade bodies and organisations developing policy on the responsible mining of battery materials. Examples include the LME responsible sourcing programme[11] and the Cobalt Industry Responsible Assessment Framework (CIRAF) led by the Cobalt Institute. A cross-government approach to develop policy is required including the FCDO and DIT for example.

As well as supply chain and security issues, cobalt mining in DRC has the added concerns around social and human rights issues due to artisanal mining industry (ASM), which is low-tech and labour intensive. However, the political and socioeconomic challenges in reforming ASM are highly complex. Any international action should aim to avoid causing harm, which is challenging given that ASM is an important source of income for the DRC population on the extreme end of the poverty line. Examples of international action include the Faraday Institution participation in the Global Battery Alliance, which is a World Economic Forum initiative seeking to address the human, health and environmental challenges of batteries. Other initiatives such as Delve, Pact's Mines to Markets, Fair Cobalt Alliance and Responsible Minerals Initiative are set out in Faraday Insight 7 published in May 2020.

Q12) What steps should be taken to ensure that EV batteries are recycled at the end of their lives and not simply sent to landfill?

Current regulations ensure that EV batteries are not sent to landfill. At present there are no facilities for recycling EV batteries in the UK. Batteries at end of life are collected and exported for processing.

[11] Overview of London Metal Exchange responsible sourcing (2019).

This will increase as the volume of EV sales continues to rise, so now is the time for action to establish the optimum systems and processes for the recycling EV batteries. Key steps that should be undertaking include the following:

- Ensure that EV batteries are designed in a way that enhances recycling;
- Ensure that EV batteries are designed with second life applications in mind;
- Use of policy and regulation to help to manage environmental impacts;
- Encourage investment in the infrastructure for recycling lithium-ion batteries from EVs; and
- Consider government support to help develop a UK recycling industry.

One step is to ensure that EV batteries are recycled is to design batteries in a way that enhances the re-use of components and the eventual recycling of materials at end-of-useful life. Design for recycling would enhance the potential for efficient recovery of the materials required to produce new batteries and hence mitigate against increased demand for primary resources. Large improvements will be necessary if the end-of-life processing of EV batteries is to be economic for most battery chemistries.

Another step is to ensure that new batteries are designed not just with the ability to be recycled effectively, but also with second life applications in mind. Some batteries are already being designed this way, but much more needs to be done. For example, there is a growing interest in second-life applications for grid-based energy storage systems in a stationary environment, including for load-shifting, peak-shaving and energy backup. Retired batteries from EVs can also be reused as part of a strategy to integrate wind power to minimise grid outage impacts and coupling with photovoltaic generation has also been examined.

Policy and regulation could be used to influence business models in favour of those that promote re-use and safe and effective end-of-life management. This will require a mix of carrot and stick within an extended producer responsibility (EPR) model. Targets could be set for recycling and other second life use. For example, there could be allowances for OEMs exceeding the target to trade with those lagging behind (the carrot) alongside strict waste controls on disposal (the stick).

Using regulation or incentives to change the model of ownership of EV batteries could be another step. Currently, the most common form of ownership is that an individual owns the vehicle and all the components. This means that the battery state of health is not something that the manufacturer can understand or influence before the used battery is returned. There is therefore a risk that the owner continues to use the battery well below 70-80% capacity, which is the optimal time for batteries to be re-used or repurposed. An overall regulatory framework to address recycling issues across the EV battery lifecycle would require:

- A coherent waste hierarchy strategy for lithium-ion batteries, which addresses end-of-life management and covers recycling, re-use and repurposing of the batteries in the UK.
- Clear regulation and policy on re-use and re-purposing, including the influencing of contractual and ownership models (e.g. battery leasing schemes) for EV batteries to facilitate recycling and second use.
- Internalised social and environmental costs of mineral extraction in the market price, which encourages recycling, minimises supply chain vulnerabilities and supports self-sufficiency in critical material supplies.

- Extended producer responsibility (EPR) regulations that support a move to a circular economy model, ensuring safe and effective re-use of EV batteries and increasingly robust recycling targets are imposed.
- Eco-design criteria for recycling and remanufacturing, including restrictions on the use of hazardous substances and promoting designs that allow easy separation of parts.
- Smart regulation techniques to facilitate the transportation of waste to support recycling while ensuring that safety is prioritised in any policy for EV battery management.
- Chemistry labelling requirements introduced (e.g. through the review of the Waste Battery and Accumulators Regulations) for lithium-ion batteries to enable end-of-life lithium batteries to be easily and safely sorted and separated, then recycled in specific groups.

There is currently a lack of substantial EV battery recycling facilities in the UK or indeed a pipeline of investments. Many UK manufacturers currently export used lithium-ion batteries to European facilities for recycling, such as the Umicore facility in Belgium. This is expensive, logistically challenging and only viable in the short term while the numbers of EV batteries reaching their end-of-life is relatively small. Without the early development of UK waste recycling facilities, a serious waste problem will be created as waste volumes build up.

Government support to help develop a UK recycling industry should be considered, as the industry may not otherwise develop at the required pace to tackle the substantial levels of battery waste. Investments required include a battery dismantling and pre-processing facility and a processing facility for recovered material. The FI's ReLiB research programme led by the University of Birmingham has recently published a study examining the most promising locations in the UK for a recycling facility.[12]

May 2021

[12] "An Economic, Environmental and Geospatial Analysis of Recycling Electric-vehicle Lithium-ion Batteries" (forthcoming 2021).