CENTS: A Research Network for the Sustainable Transport Community

Circular Economy Network+ in Transportation Systems

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CENTS Feasibility Funding Case Study Template

Title of Feasibility Study: Map the gap – quantifying the circularity of the UK lithium-ion battery sector to 2050

1. Project Team

Pierre Josso (PI – early career researcher): Minerals Geoscientist, BGS Eimear Deady (early career researcher): Minerals Geoscientist, BGS Hannah Grant (early career researcher): Marine Geoscientist, BGS Paul Lusty: Principal Economic Geologist and BGS Critical Raw Materials Topic Lead, BGS

2. Executive summary (max 200 words)

1-2 sentences to highlight main findings and how they can be used by industry and the wider sustainable transport research community

- In 2022 UK battery electric vehicle production will demand < 1 per cent of total global production of cathode materials. Based on projected market growth by 2032 the UK will consume the following proportions of global production (relative to 2020 production levels): 4–9 per cent of nickel, 20–55 per cent of lithium and 12–37 per cent for cobalt.
- Based on current projected infrastructure development, even in the longer-term the UK will not have the recycling capacity for the quantity of batteries that are expected to reach their end-of-life. In order to comply with future mandated requirements for minimum levels of recycled content in batteries entering the EU market, the UK will either have to import recycled metals for domestic battery production or ensure significant expansion of its battery recycling capacity.

The problem (max 200 words)

2-3 sentences to set the scene, including scope, challenges, opportunities

Growth in the global electric vehicle (EV) fleet will lead to increased demand for key battery raw materials, such as lithium, cobalt, nickel and manganese, and may result in associated price volatility and security of supply concerns. Battery raw material recycling could help to mitigate against these risks, particularly in countries such as the UK that have no or limited primary production of these metals. Furthermore, it appears likely that the UK will implement regulations to ensure that batteries entering the market are sustainable and circular. This is likely to include minimum levels of recycled content (e.g. 12% cobalt, 4% lithium and 4% nickel by 2030, increasing in 2035 to 20% cobalt, 10% lithium and 12% nickel), as proposed in the new European Union Batteries Regulation [1]. Access to supplies of recycled battery raw materials may become essential for UK manufacturers to ensure compliance. These ambitious targets and dates broadly define the timescales required for establishing a major battery recycling industry in the UK; and it is important to understand the future temporal availability of stocks of battery raw materials for different applications, such as EVs and secondary storage. A feasibility study, considering current government targets for recycling, will provide an indication of the necessary timescales for establishing an end-of-life battery recycling sector in the UK and the necessary scale of this ambition.

The approach (max 100 words)

1-2 sentences to summarise research question and methodology

Projections for the uptake of battery electric vehicles (BEV) in the UK up to 2050 form the basis for modelling the fleet in-and-out stocks. Consideration of multiple scenarios for future battery chemistries, their relative market shares and evolution of energy capacity through time, permits the future metal requirements for manufacturing of the battery cathodes to be estimated. Similarly, the stocks and flows of metal available annually to be recycled can be estimated by assessing literature and data on the projected life span of batteries in BEV, potential secondary storage applications, UK requirements for renewable energy storage, and recycling capacity and efficiency. Comparing these two datasets permits an evaluation of the potential contribution that recycling can make to meeting future UK demand for cathode raw materials

Novelty (max 100 words)

Understanding future raw material demand related to the energy transition is vital for improving security of supply, identifying strategies to mitigate risk and guide strategic investment in primary and secondary resource development and industry. This project is the first to model stocks and flows of recycled materials from the UK BEV fleet and major secondary storage applications, and consider its potential contribution to meeting raw material demand for domestic battery manufacturing.

Results (max 500 words)

Compilation of available scenarios and data selection

Modelling of cathode metals stocks and flows for the UK EV fleet followed the stages shown in Figure 1. For each input data set (green boxes) published or publicly available scenarios and data sets were compiled and reviewed. Details of the input source data, selection criterion, caveats and limits of the model are presented in the supplementary information. Three scenarios for both BEV fleet evolution and future battery market shares have been considered, resulting in nine models. Selected data and results are briefly presented below.

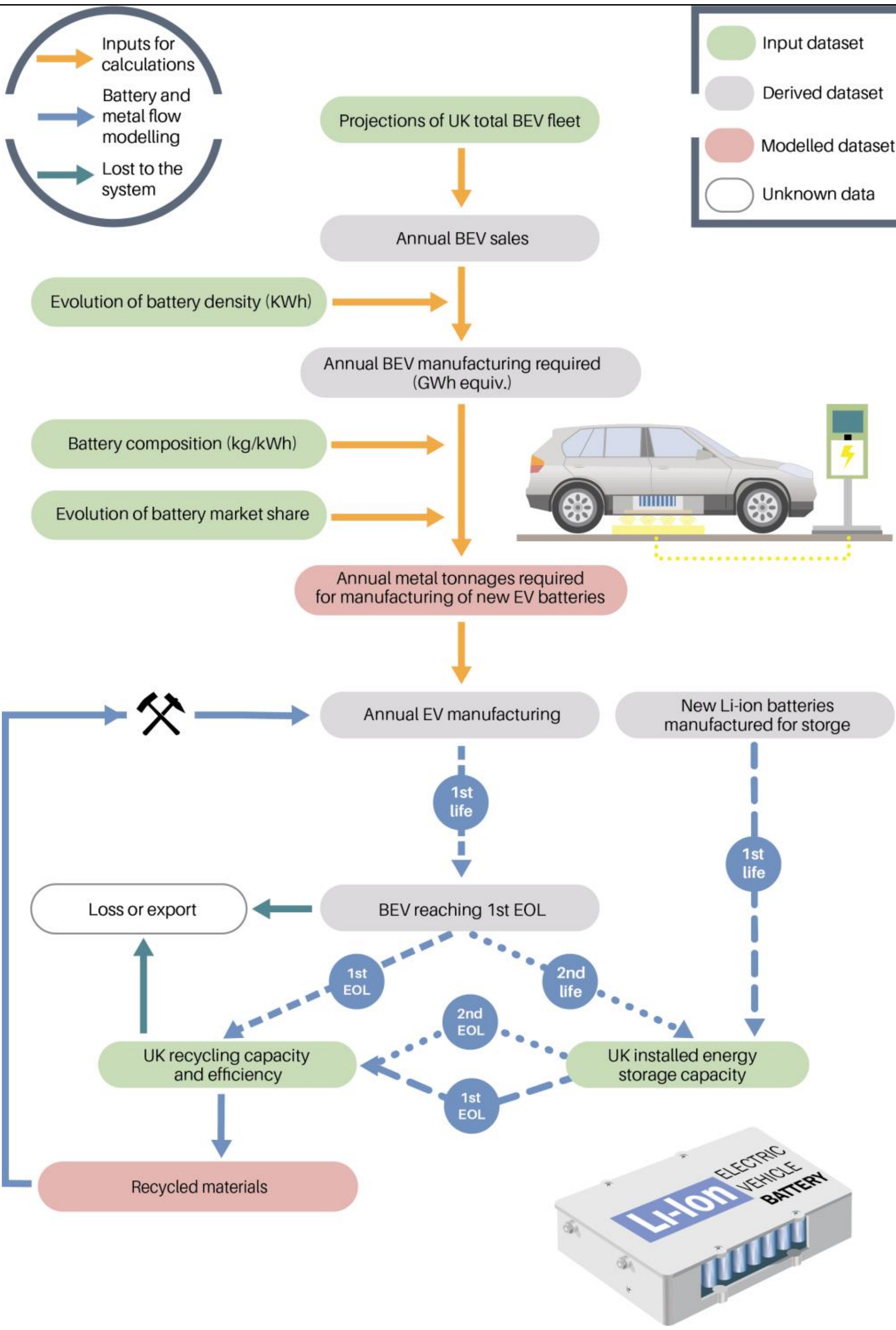

Figure 1: The calculation stages, input data and flow of material used for the modelling of the metals required for the annual production of batteries for UK battery electric vehicles and the amount of potentially recycled metal produced from the batteries.

1. **The National Grid scenarios for the UK BEV fleet evolution**:

Three scenarios from the National Grid (NG) Future Energy Scenarios [2] considering the total projected BEV fleet to 2050 were used as the input data (Figure 2). The selected scenarios reflect differences in consumer behaviour, policy, infrastructure, and the relative speed of decarbonisation. Each scenario shows a rapid uptake in BEV from 2025 and market saturation between 2039 ('Leading the Way' and 'Consumer Transformation' scenarios) and 2045 ('Steady Progression' scenario), at which point the total fleet in two of the three scenarios plateau. Conversely, the 'Consumer Transformation' scenario represents a marked decline in total parc from 2039 and a shift away from car ownership.

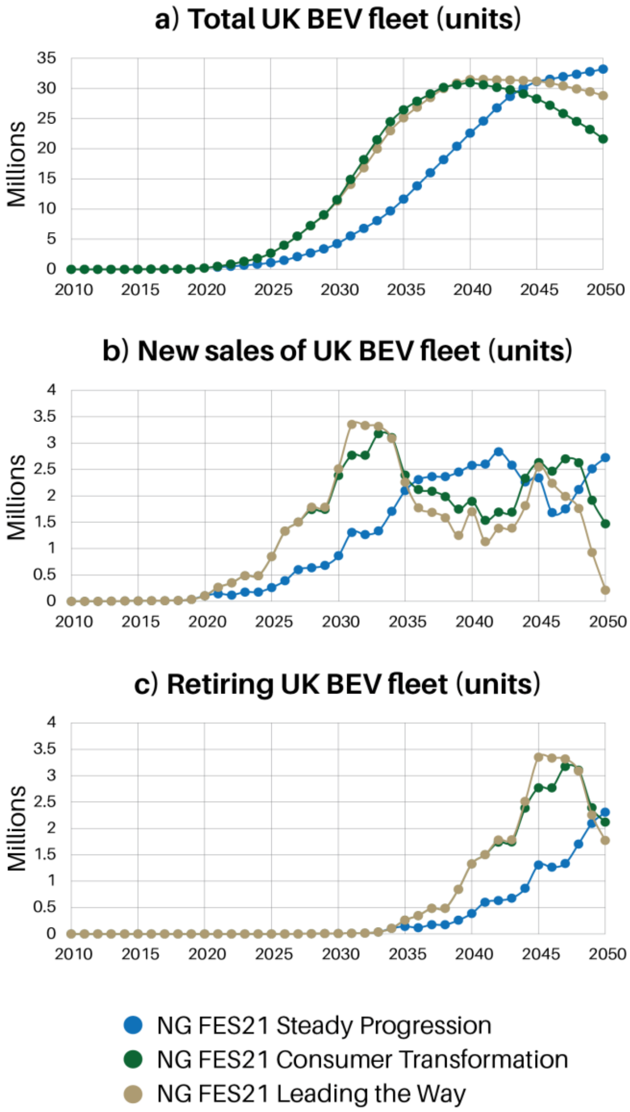

Figure 2: a) Total UK battery electric vehicle fleet until 2050 [2]; b) Annual sales of new battery electric vehicles required to match total fleet projection and including renewal of vehicles after a first life of 14 years; c) battery electric vehicles retiring from the fleet. Data in graphs 2b and 2c were calculated using data [2] shown in graph 2a.

2. Evolution of battery energy density

Compilation of data on battery pack energy density for the last 50 years shows an increase from 10–15 kWh in the period from 1980–2000 to an average of 50–60 kWh in 2020 (Supplementary information) [3, 4]. Most projections converge towards a rapid increase in energy density, reaching an energy capacity of 100 kWh in 2030, which will level off to 120 kWh in 2050.

3. Battery composition

The material intensity of key cathode chemistries used for calculating the tonnages required for battery manufacturing under each scenario is presented in Table 1.

Table 1: Compilation of metal composition of major battery packs (kg/kWh) [5, 6]

Cathode	kg(Li)/kWh	kg(Ni)/kWh	kg(Mn)/kWh	kg(Co)/kWh
LFP	0.1	0	0	0
NCA	0.112	0.759	0	0.143
NMC-111	0.139	0.392	0.367	0.394
NMC-622	0.126	0.641	0.2	0.214
NMC-811	0.11	0.75	0.088	0.094
NMC-955	0.137	0.82	0.046	0.05

4. The battery market share scenarios

Nickel-Manganese-Cobalt (NMC) chemistries currently dominate the EU and UK market and are expected to remain dominant during the next 30 years [8]. Research and industrial trends all highlight a shift towards lower Co and higher Ni chemistries (Figure 3) [7]. The NMC-dominant scenario is considered to be most reflective of the future UK market [8]. The two other scenarios are representative of a breakthrough in LFP and solid-state Li-Air/S batteries, and their appearance on the market by 2030, based on the expected levels of market penetration estimated by Xu et al., 2020 [9].

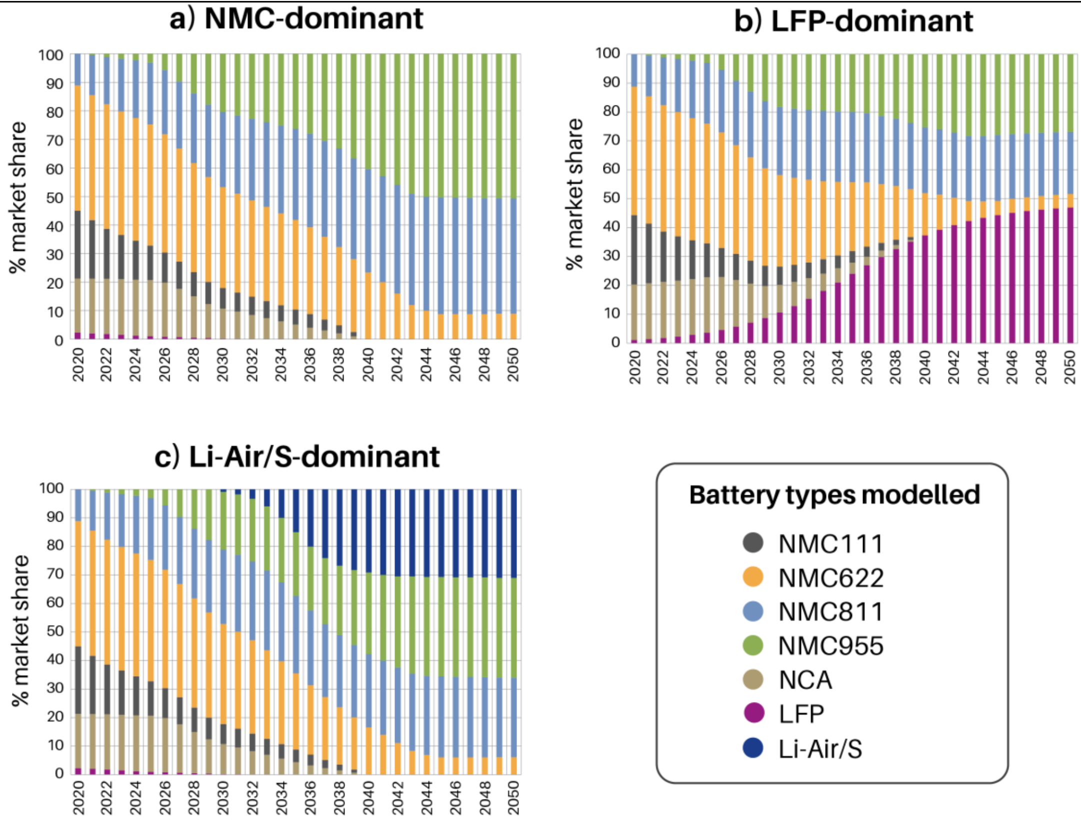

Figure 3: Evolution of the market share of different battery types considered in the modelling under three scenarios in which the following battery chemistries dominate: a) Nickel-Manganese-Cobalt (NMC); b) Lithium-Iron-Phosphate (LFP); c) and solid-state Li-Air/Sulphur [5, 6].

5. UK electricity storage capacity

Once the capacity of an EV battery decreases to 80 per cent it is considered too inefficient for continued use in an EV. Many different applications for the reuse of batteries, in their so-called 'second life' exist or are under development. The lifetimes of batteries in second life energy storage applications range between 3.8 and 29 years [10]. An average life time of 11 years was used for the purpose of the modelling. The use of second life batteries in storage applications is a nascent industry in the UK, however, there is significant potential for their use in battery grid storage in the UK. The NG scenarios [2] consider a range of projections for grid storage requirements, principally driven by current plans for large-scale deployment of wind turbines in the UK. Existing energy storage capacity is lower than the predicted starting capacity of 3.5 GW (2021) for each scenario, but capacity is expected to increase significantly under all scenarios by 2025.

6. Recycling capacity and efficiency

The UK currently has no EV battery recycling capacity. Indications of potential future recycling capacity in the UK are evident from media reports on the development of pilot-scale recycling plants and planned developments, along with information on their predicted GW equivalent recycling capacity. Future recycling capacity was calculated based on a stepwise increase, rising to 2 GW by 2025 and increasing further to 8 GW in 2050. Data for the estimated recovery of metals are derived from the published literature [11], reaching a maximum level of 95 per cent by 2025.

Results

The model generates two key outputs: (i) an estimate of the annual metal demand for the manufacturing of EV batteries to be sold in the UK market (Figure 4); and (ii) an estimate of the amount of recycled metal that can potentially be recovered annually from retired batteries (Table 2), and is available for remanufacturing (Figure 5). The implications of these results are discussed in the key findings and impact section.

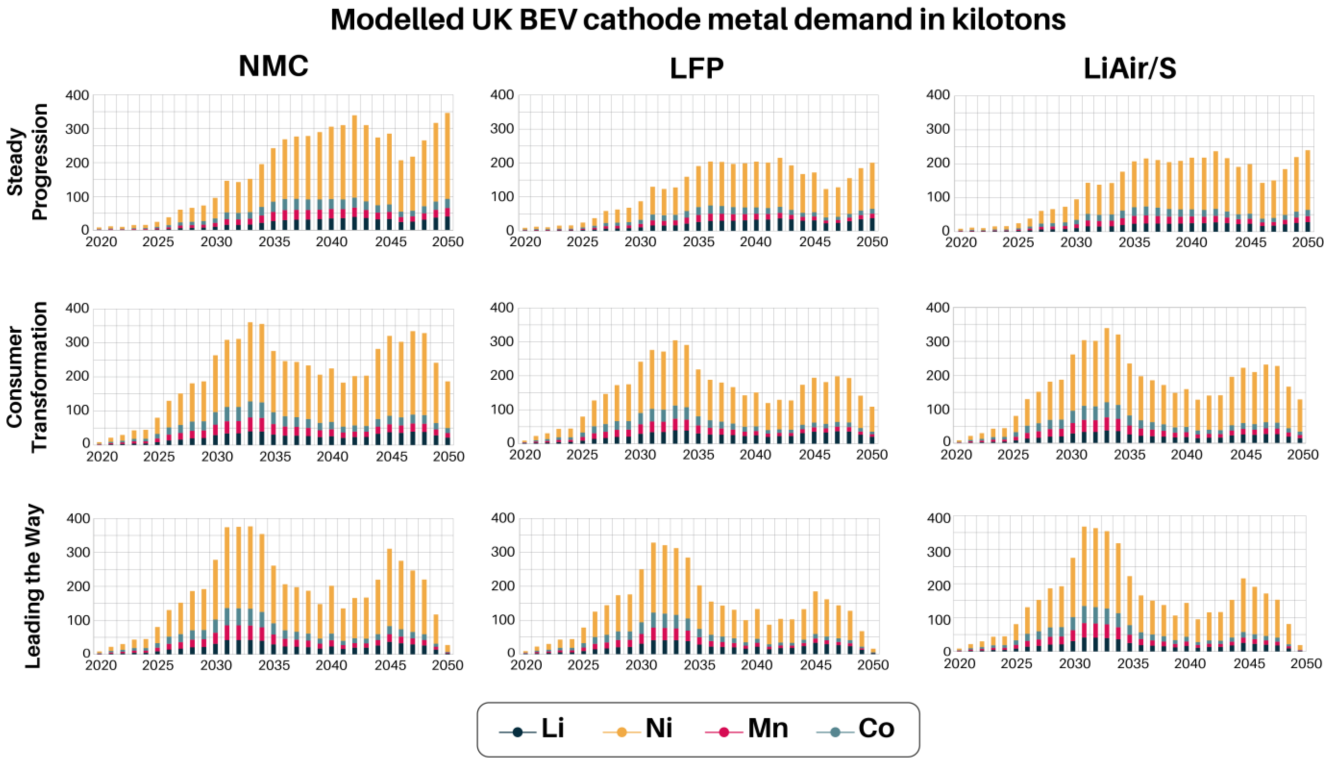

Figure 4: Projections of metal requirements for the manufacturing of cathodes for new UK battery electric vehicles until 2050 under nine scenarios.

Table 2: Projected quantities of recycled metals (tonnes) available under the nine scenarios.

	2030 – 2035	2035 – 2040	2040 – 2045	2045 – 2050
Li	460 – 470	680 – 700	910 – 940	810 – 940
Ni	2,290 – 2,450	3,610 – 3,850	4,700 – 5,250	4,300 – 5,300
Mn	600 – 700	770 – 940	980 – 1,130	820 – 1,030
Co	750 – 850	940 – 1,170	1,200 – 1,400	950 – 1,280

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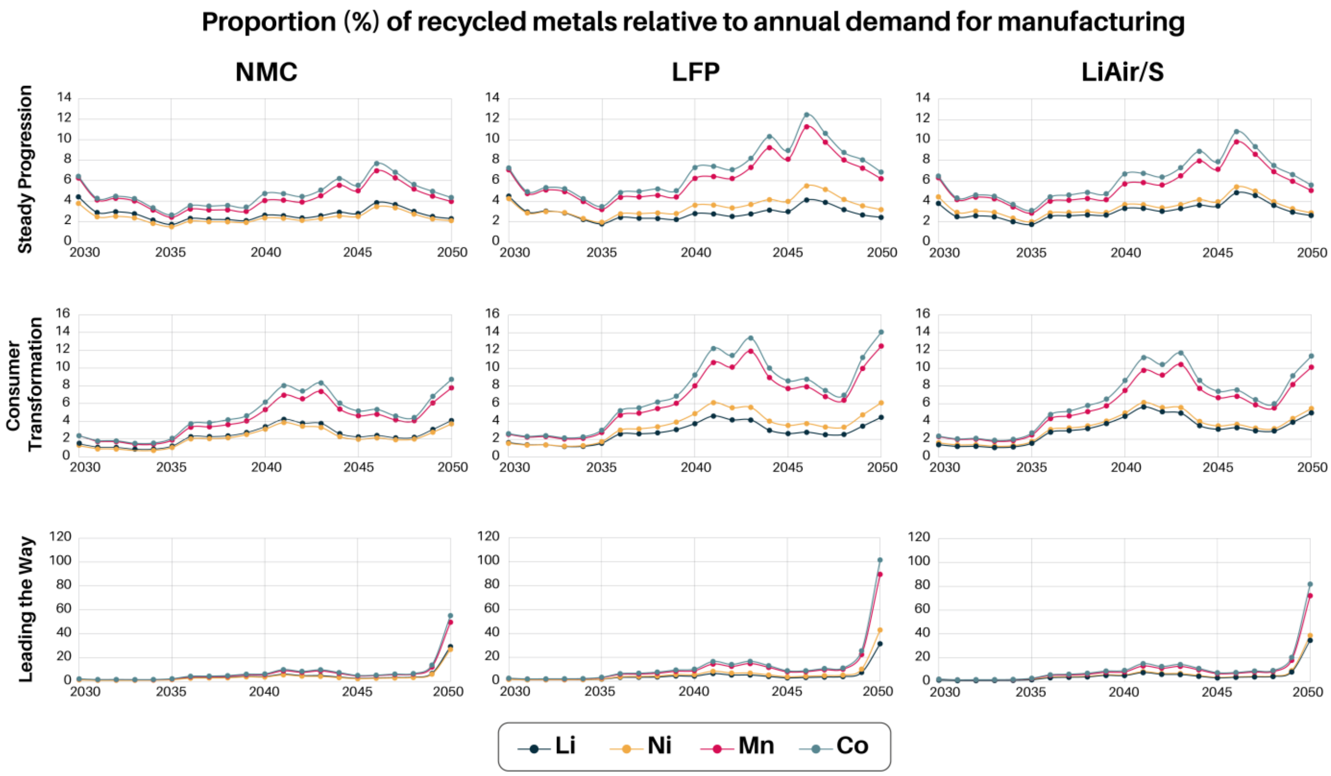

Figure 5: Projections of recycled metals contribution to the total amount required metal for battery manufacturing under each of the nine projected scenarios considered in this study.

References:

References:
[1]https://ec.europa.eu/environment/pdf/waste/batteries/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf
[2] National Grid ESO, 2021. Future Energy Scenarios. Digital version accessible via https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021
[3] https://energysavingtrust.org.uk/wp-content/uploads/2020/10/EST0018-001-EV-Guide-for-Fleet-Manager-WEB.pdf
[4] https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets
[5] https://faraday.ac.uk/wp-content/uploads/2020/10/Reuse-and-Recycling-Environmental-Sustainability-of-Lithium-Ion-Battery-Energy-Storage-Systems-1.pdf
[6] Olivetti, E.A., Ceder, G., Gaustad, G.G. and Fu, X. (2017) Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. Joule 1, 229-243.
[7] Zhao, Y.; Pohl, O.; Bhatt, A.I.; Collis, G.E.; Mahon, P.J.; Rüther, T.; Hollenkamp, A.F. (2021) A Review on Battery Market Trends, Second-Life Reuse, and Recycling. Sustain. Chem. 2, 167–205. https://doi.org/10.3390/suschem2010011
[8] https://faraday.ac.uk/wp-content/uploads/2020/12/Faraday_Insights_6_Updated_Dec2020.pdf

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[10] Casals, L.C., Amante García, B. and Canal, C. (2019) Second life batteries lifespan: Rest of useful life and environmental analysis. Journal of Environmental Management 232, 354-363.
[11] Zhuang, L., Sun, C., Zhou, T., Li, H. and Dai, A. (2019) Recovery of valuable metals from $LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$ cathode materials of spent Li-ion batteries using mild mixed acid as leachant. Waste Management 85, 175-185.

Key finding 1 (max 50 words)

All BEV fleet scenarios result in two peaks in battery raw material demand. All the scenarios result in similar levels of total material demand but at different times, owing to variation in BEV uptake rate, fleet saturation and BEV renewal rate across the scenarios.
Notwithstanding the significant uncertainty in the modelling, the trend towards lower Co content in NMC batteries, the potential for the emergence of new disruptive technologies and major breakthroughs in LFP and Li-Air/S batteries in the coming decades; projected UK demand for cathode materials in 2022 increases from < 1 per cent of 2020 global metal production to 4–9% for Ni, 20–55% for Li, and 12–37% for Co in 2031, as a percentage of 2020 world production, highlighting the major increase in primary raw material production that is required to underpin the clean energy transition.

Key finding 2 (max 50 words)

By 2033, batteries reaching their first end-of-life (EOL) in EV will vastly exceed annual requirements for secondary applications (e.g. grid storage), and overwhelm projected domestic recycling capacity. The amount of secondary metal available is primarily limited by the recycling capacity in the UK, with very little limited influence from other variables considered in the scenarios before 2040 (Supplementary information). Based on current estimates of demand from secondary applications and the recycling capacity that will exist in the UK, after 2040, only 10 per cent of batteries reaching their first EOL in EV will transition to the secondary market or be recycled. The rest will have to be stored or exported.

Testimonial from ECR/project team (max 500 words)

How has the project and involvement in CENTS impacted your skills and aspirations?
The knowledge and skills of the ECRs have been greatly enhanced by participation in this CENTS project. Detailed investigation of the stocks and flows of batteries in EV is a relatively new research area for the ECRs, and they have developed knowledge and recognise the research potential associated with an almost entirely new subject area. Furthermore, although they have worked in the broad field of economic geology for some time this work has provided them with additional context to the strategic importance of their role. The research has required the ECRs to familiarise themselves with national energy data sets, battery chemistries and other relevant time-series datasets. As the feasibility study was led by an ECR, it has provided an excellent opportunity to develop research proposal writing skills, and undertake project and team management.

Testimonial from Industry partner(s) (max 500 words)

Have the project and its findings had a beneficial impact?
NA

Impact (max 200 words)

Wider applications and beneficiaries
Despite limitations due to the granularity of the data used and assumptions of the model, this feasibility project demonstrates that the demand for metals essentials for the transition to BEV will increase rapidly over the next 10-20 years. Projected raw materials demand to 2050, for battery manufacturing to deliver the UK EV fleet, indicates the need for significant expansion of global primary production of Li, Co and Ni, supported by mineral exploration, mine development and general investment in supply chains. Given current UK Government interest in critical minerals, as highlighted in the recent 'Net Zero Strategy: Build Back Greener', this research enhances our ability to advise on this and related topics.

Assuming that the adoption of circular economy principles permits maximisation of the secondary use of end-of-life batteries, the predicted flows of used batteries largely exceed the secondary application capacity in the UK. As a result, flows of recycled metal are not affected by batteries having long life times, owing to two stages of use. The modelling shows that currently planned levels of recycling capacity in the UK are a limiting factor in terms of the secondary supply of metals. This is because it can only accommodate between 2 and 21 per cent of the projected annual flow of end-of-life batteries by 2040, highlighting a major business opportunity. However, the scale of the opportunity will be determined by the economics of battery recycling relative to supply from primary sources and policy drivers, influenced by the interplay between economic, technological, societal and environmental factors along the entire value chain for battery raw materials.

Next steps (max 200 words)

*Future research directions, publications, follow on funding achieved**
The results provided in this brief summary will form the basis for a more detailed Science Briefing Paper. These aim to allow BGS scientists to demonstrate and communicate their science in a succinct way to other experts, policymakers and the public. There is also potential for a peer-reviewed publication based on this study

*CENTS team will be in touch towards the completion of the CENTS project (end of 2022) to update the impact section