# Written evidence from Jeff Townsend, Founder, Critical Minerals Association

The Critical Minerals Association (CMA) is pleased to have the opportunity to provide evidence for the discussion around electrical waste, or waste electrical and electronic equipment (WEEE) and the Circular Economy.

Among the activities being undertaken by the CMA is engagement on sustainability through a Circular Economy Working Group. The working group is populated by representatives from CMA member organisations including mining enterprises, manufacturing, recycling, consultancy, and investment groups.

The working group provide the following written evidence for consideration by the committee.

## CMA Overview - Critical Minerals as a Resource

The Critical Minerals Association (CMA) (www.criticalmineral.org) was established in January 2020 after discussions between UK Civil Service and the UK's critical mineral industry recognised the lack of a national critical minerals strategy. This lack of critical minerals strategy put the UK behind Australia, Canada, Japan, Europe and America who had already spotted the growing threat of China's dominance on the sector and this international vulnerabilities' potential to undermine the green growth agenda.

The CMA is an industry led organisation with experts developing thought leadership papers on specific topics as a means of informing society, media and the political arena about the need for a critical mineral strategy and the role critical minerals play as the building blocks of the future economy.

The founders of the Critical Mineral Association felt that the UK government was failing to recognise the complexity of the industrial change they had set themselves on and that there needed to be an industry body that could help explain the requirement for the UK to secure its supply of necessary critical minerals, offer support in understanding how the government's economic transition can be a catalyst for the creation of a new industry in the UK (by leaning on the UK's known comparative advantage in the mining industry) and the potential for the UK to become a world leader in the circular economy industry.

In 2017 the UK Government set out an ambitious industrial strategy that outlined how the UK would transition from its current economy to a future economy based around green growth, the electrification of mobility and advanced AI and data economy. The industrial strategy sets the country on a path away from being fossil fuel centric to one based on critical minerals.

Despite the new industrial strategy being dependant on a secure supply of critical minerals, it failed to mention any plan to develop such a supply chain other than purchasing from the international market (that is dominated by China. Even the London Metal Exchange is owned by Hong Kong Exchanges and Clearing). However, the white paper does mention the circular economy as a means of fuelling this transition from fossil fuels to green energy although lacks any clarity of how this can be done.

The UK's domestic critical mineral capacity is growing. However as a nation we will never be capable of domestically producing all that is required to build the new economy outlined in the industrial strategy. A 3MW wind turbine requires 2000kg of rare earths to operate. 75% of the value of an electric car battery is in its minerals. As an importer of critical minerals it should be a core objective to keep these critical minerals in the UK's economy through circular economy practices; improving the UK's drive to net zero and reducing our reliance on vulnerable international supply chains.

The CMA believes that the re-use of critical minerals is essential to the delivery of the future, green economy we all want to see in the UK. However, the drive towards a greener economy is more complex than the UK government seems to or wants to understand. If we are to deliver a net zero carbon economy by 2050 the industrial complexity of recycling lithium-ion magnets or rare earth magnets needed for electric vehicles and wind turbines must be addressed. Many of the legislation relating to the circular economy of critical minerals puts the UK at a disadvantage to our European or Western competitors. If the regulatory landscape is not amended, the UK and its future economy companies will be dependent on foreign providers of recycled critical minerals, most likely from the European Union as our nearest market.

Below we have set out some of the industrial issues and provided an overview on the legislation that will need to be amended if the UK is to take advantage of its natural global comparative advantage in the circular economy sector.

## Lithium-ion Battery Recycling Technology

### End-of-Life Lithium Ion Batteries Are a Problem

Lithium-ion (Li-ion) batteries are well established as part of modern life, having been developed in the 1980's for general consumer use and now a pervasive part of our interconnected, automated, and electrified society.  Unfortunately, most of us in the UK are not recycling our Li-ion batteries – the Royal Society of Chemistry commissioned an Ipsos MORI survey which found that 51% of UK households have at least one unused electronic device – such as mobile phones, computers, smart TVs, MP3 players or e-readers – and 45% have up to five, but that of these **82% have no plans to recycle or sell on their devices after they fall out of use**.

This lack of reuse/recycling of Li-ion batteries is problematic for a number of reasons: 1) An expired Li-ion battery can be dangerous. Unlike traditional lead-acid or alkaline batteries, Li-ion batteries can be a fire or explosion hazard if defective or damaged; 2) they contain hazardous and potentially polluting material and chemicals; and 3) they contain high value critical minerals for which the UK currently relies solely on imports.

### The Scale of the Problem is Increasing Rapidly

The adoption of Li-ion batteries in the home continues to grow: The Royal Society Chemistry's Ipsos MORI survey found that while 30% of 55-75 year old have 10 or more devices, among 16-24 year olds that figure is 52%.

With the rise of Li-ion powered electric vehicles, the scale of end-of-life ("EOL") Li-ion batteries in the UK is set to change dramatically.

The UK is currently the second largest market in Europe for new auto sales and is moving rapidly towards electrification. In September 2020, EVs were 10.5% of total passenger auto sales which is an astounding rise from just 3.7% in September 2019(1). Current legislation is such that all new vehicles will have to be non-polluting by 2035 (with proposals to bring this forward to 2030), so this acceleration to electrification is expected to continue at pace and with it the rapid consumption of large Li-ion batteries.

As EVs sold and used in the UK come to the end of their life, they will generate staggering amounts for Li-ion batteries that will be available for recycling in the UK. The University of Warwick estimates that by 2040, there will be 339,000 tonnes a year available for recycling(2) which would represent approximately $1bn of revenue at current prices.

1) https://cleantechnica.com/2020/10/07/uk-september-ev-market-share-hits-10-5-up-3x-year-on-year/

2) Catapult/APC/WMG report September 2020: Automotive Lithium ion Battery Recycling in the UK:

**Why Are We Not Recycling Li-ion Batteries Right Now?**

Current legislation makes no differentiation for Li-ion batteries within electronic waste and therefore they are captured under the general WEEE rules and regulations for waste management. This is not fit for purpose and as the volume of Li-ion batteries within WEEE increases, the issue of potentially highly hazardous Li-ion batteries within household and commercial waste will increase.

Without specific legislation for Li-ion batteries, there has been no incentive up to this point for any producer or waste handler to separate Li-ion batteries from the accompanying WEEE.

Insofar as consumer-led recycling efforts, without an incentive (other than the feeling of having 'done the right thing') consumer recycling of Li-ion batteries has been almost non-existent. For some (37% according the Ipsos MORI survey), there are concerns over personal data contained on the device, and 29% said that they didn't know where to recycle old tech.

A large part of the reason for this lack of action to recycle Li-ion batteries is that at present there is simply no UK-based solution to recycle this Li-ion battery waste. If Li-ion batteries are collected at all (most remain in consumers' cupboards, drawers, lofts etc), and it is not able to be refurbished, the majority of it is sent to Europe for treatment by inefficient, polluting, pyrometallurgical waste treatment facilities. This is very costly, and the cost is required by law to be borne by the producers of the devices. When considering this, one begins to understand how producers of electronics and their Li-ion batteries may not be properly incentivised to recycle.

**TechMet's Recycling Strategy**

TechMet is proposing to build a lithium-ion (Li-on) battery recycling facility in the UK. We currently have a working commercial facility in Ontario, Canada with a second commercial facility under construction in Rochester, New York, USA which combined will make us the largest recycler of Li-ion batteries in North America. We have developed and validated a unique and sustainable process for recycling all types of Li-ion batteries used in electronic devices, electrified transport, electric passenger vehicles and energy storage. We aim to bring our proven technology and capabilities to the UK with an initial facility that will have the capacity to treat up to 5,000 tonnes of Li-ion batteries a year.

Our patented and commercially proven technology is less energy-intensive, cleaner, and offers the opportunity to recover almost all the valuable critical materials, unlike the incumbent pyrometallurgical facilities that have no way to recover any lithium. Our recycling plant will provide the UK's Li-ion industry with a more cost effective and far less polluting solution, as well as keeping these critical materials within the UK and available for reuse in the burgeoning Li-ion automotive battery sector.

Our closed loop lithium-ion battery resource recovery technology consists of a two-part process:

The first is a Safe Size Reduction where we take all types of Li-ion batteries from a charged state, in a safe and secure way, to an inert product. Our technology allows us to process Li-ion battery pack formats including cylindrical, prismatic, and pouch cells, in any state of charge, regardless of the battery chemistry. This process produces shredded materials such as aluminium, copper and steel, and a high-grade concentrate containing the high-value cathode materials (Black Mass).

The second part of our process is a Hydrometallurgical Hub facility that takes the Black Mass and refines the recovered electrode materials to produce battery grade end-products for reuse in Li-ion battery production or for use in the broader economy. Recoveries of all material through this process are in excess of 80%, and as a closed-loop process it is highly environmentally friendly with energy consumption levels and greenhouse gas emissions that are a fraction of the current incumbent technologies.

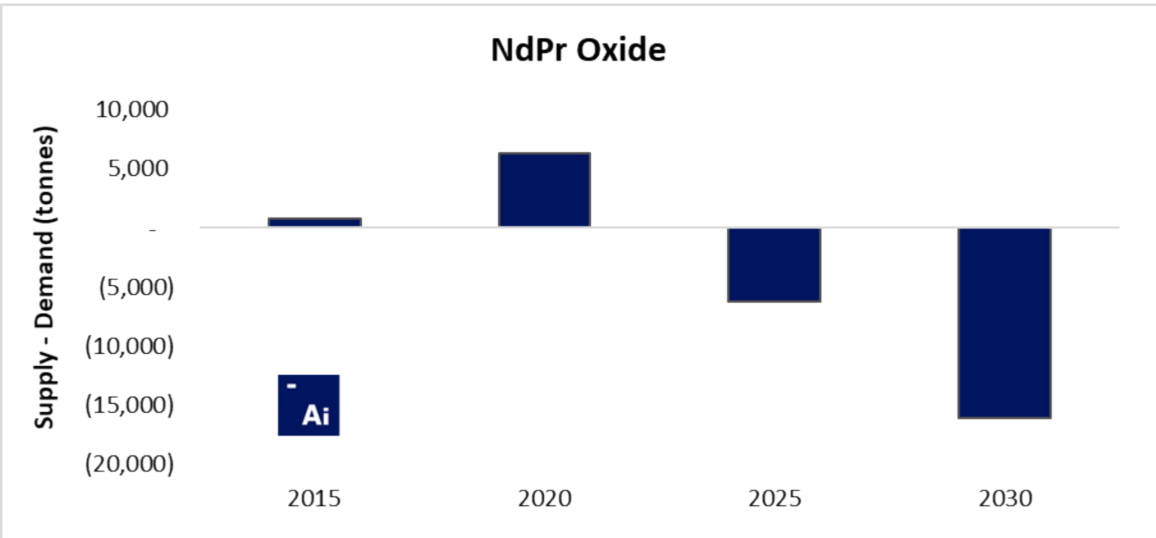
Our proposal is to make an initial investment in a number of regional Safe Size Reduction facilities and send the Black Mass produced to our hydrometallurgical facility that is under construction in Rochester, USA. When the market reaches sufficient size, we will look to build a hydrometallurgical facility in the UK.

## Rare Earth Magnet Recycling Technology

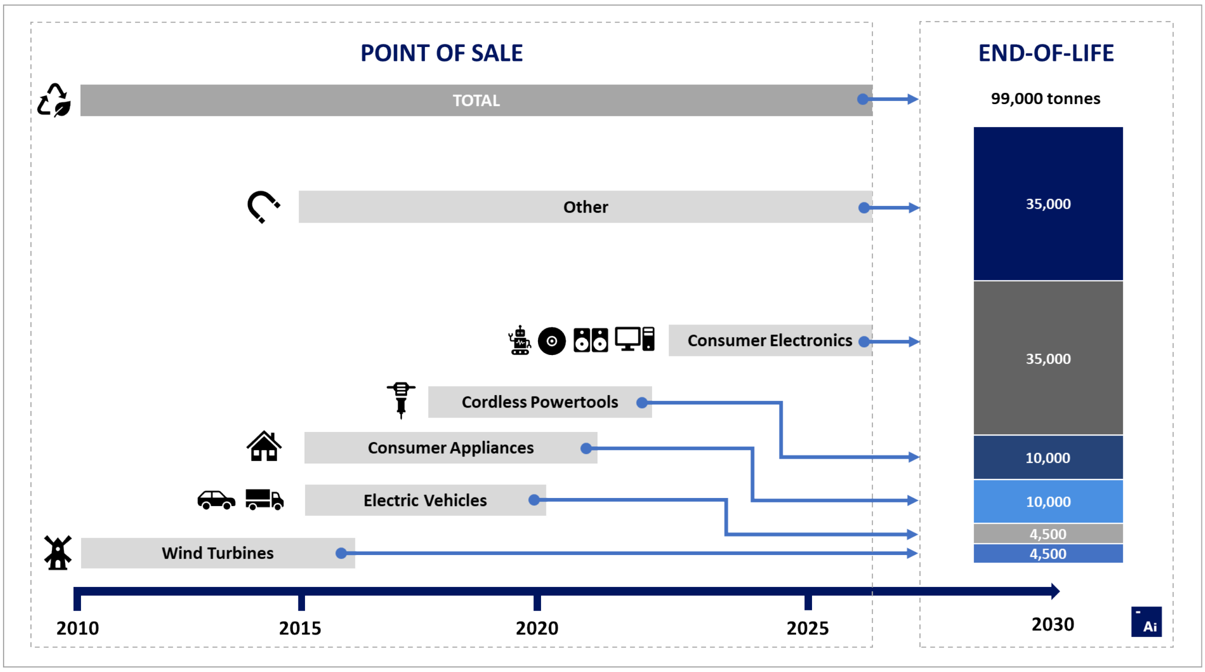
Production of Rare Earth (NdFeB) magnets requires the use of REEs, including neodymium, praseodymium, to a lesser extent dysprosium, and terbium, (the “magnet REOs”) which make up around 30% of their composition. Adamas Intelligence reports that in 2019 rare earth permanent magnets were responsible for over 90% of the value of global total rare earth oxide (TREO) consumption and most of the current stock of redundant material is assumed to be held in electronic waste. The mining and subsequent processing of REEs is costly and energy intensive, and the waste streams from primary production have the potential to damage the environment if not properly treated. China dominates the upstream and downstream rare earth market, including that for NdFeB magnets. This concentration of supply, and the criticality of NdFeB magnets for many applications place certain rare earths, in particular neodymium, praseodymium and dysprosium at risk of supply bottlenecks. Furthermore, the transition to clean technologies such as electric vehicles and wind power, is catalysing the accelerating demand for neodymium, praseodymium and dysprosium, and will place further strain on the rare earths supply chain.

From 2019 through 2030, Adamas Intelligence forecasts that global annual production of neodymium oxide and praseodymium oxide (or oxide equivalents) will increase at a slower rate than global demand, resulting in the draw-down of producer inventories and, ultimately, shortages of these materials if supply is not increased beyond what is currently anticipated.

Even with substantial production increases in China in the years ahead, and the development of 55,000 tonnes-per-annum of new rare earth oxide production capacity outside China, Adamas Intelligence forecasts that global annual demand for neodymium oxide and praseodymium oxide (combined) will exceed global annual production by upwards of 16,000 tonnes in 2030 – equal to the amount of material needed for production of approximately 20 million EV traction motors.




Market analysis from Adamas Intelligence indicates that in 2030 alone greater than 90,000 tonnes of NdFeB magnets will be entering waste streams globally, with approximately one third from consumer electronics, with annual NdFeB shortages of 48,000 tonnes. With a projected CAGR increase of 9.7% for REO demand, a greater global effort to recover and recycle magnet rare earths from end-of-life devices will play a meaningful role in helping to satisfy this demand and reduce waste streams and the associated environmental implications. If just 5 to 10% of the NdFeB magnets entering waste streams globally each year by 2030 could be viably recovered and recycled, it would make a substantial contribution to global supply.




With a steady and rising flow of NdFeB magnets entering waste streams globally, Adamas Intelligence believes there is a growing opportunity for innovative recycling companies to capitalize on in the years ahead.

Analysis from Adamas Intelligence suggests that certain “high-volume” and “high-value” end-of-life devices offer near-term opportunities that forward-looking recyclers should consider. As shown in the following figure, “high-value” end-of-life devices are those that enter waste streams in relatively small unit numbers per annum but contain a large mass of NdFeB per unit, such as wind turbine generators and MRI machines. Conversely, “high-volume” end-of-life devices are those that enter waste streams in relatively large unit numbers per annum but contain a small mass of NdFeB per unit, such as car speakers, laptop and tablet speakers, hard disk drives (“HDDs”), and others.


As global electric vehicle sales continue to rise in the years ahead, and an increasing number of end-of-life electric vehicles are scrapped each year, Adamas foresees a broadening of the opportunity available to NdFeB recyclers to also include EV traction motors and other micromotors and sensors located throughout the vehicle.

## Challenges in NdFeB Magnet Recycling

Shredded magnet components - University of Birmingham / HyProMag

Magnet recycling requires the identification of products containing magnet materials. These are often very small components embedded in complex electronic devices such as mobile phones, for example, which generally contain only 300mg of NdFeB. Additionally, the composition of these magnets may vary significantly between devices, making repeatable processing of this material difficult. Embedded NdFeB magnets usually have a protective coating, which requires removal and processing. Short loop recycled magnets may have a higher oxygen content than primary material, so the addition of primary REEs may be required to maintain favourable magnetic properties for the recycled magnet. If the component is shredded for recycle, the NdFeB material remains magnetised and will stick to ferrous scrap, proving more difficult to separate. Shredding may be necessary if products are not designed for disassembly or recycle, thereby enabling access to the embedded components at scale. If the magnet has not been completely isolated prior to shredding, this will inevitably result in impurities from the device that must be dealt with in addition to the NdFeB material, increasing downstream processing requirements, reagent use and costs.

The HPMS (Hydrogen Processing of Magnet Scrap) process developed at the Magnetic Materials Group at the University of Birmingham and licenced by HyProMag provides a solution for these challenges.

## Hydrogen Decrepitation - Hydrogen Processing of Magnet Scrap (HPMS)

Hydrogen decrepitation (HD) is the process by which NdFeB is exposed to hydrogen gas at atmospheric pressure and room temperature causing it to break apart. The HD process was used to create the first hydrogen based sintered magnet in 1986, which revolutionised magnet production and laid the groundwork for future development of HPMS which is at the core of HyProMag's (a UK company) magnet recycling technology. Professor Rex Harris, a founding Director of HyProMag, pioneered the work on hydrogen decrepitation, currently used worldwide to produce magnets, and co-authored the 1986 paper on the world's first hydrogen based sintered magnet. Today, almost all magnet production and recycling methods take advantage of the HD process to some degree for processing of the NdFeB material.

The hydrogen is first absorbed into the NdFeB alloy or magnet by the Nd-rich phase through an exothermic reaction, promoting the $Nd_2Fe_{14}B$ matrix phase to absorb hydrogen, forming neodymium-hydride. These reactions are both accompanied by a lattice expansion and due to the material being brittle causes it to break apart and become demagnetised. The resulting material is highly friable allowing additional milling to refine the powder to the desired particle size, with demagnetisation preventing unwanted commingling with other metallic parts of the component being processed.

Liberating the NdFeB magnet material via HPMS has several advantages:

- The Nd-hydride material is very brittle, allowing for easy downstream refining and milling
- Nd-hydride is relatively stable, so will oxidise less during processing before the final alloy is formed (oxidation negatively impacts magnetic properties), enabling direct short-loop recycling of the obtained powder
- Complete demagnetisation of the material overcomes complications relating to the separation of the NdFeB and other metallic material; easier handling of the material is achieved
- Surface expansion of the magnet due to HD enhances the kinetics of solid-state hydrogen diffusion in the neodymium rich phase, speeding up the decrepitation process significantly
- Less energy input required to break down the magnet relative to crushing; sintered magnets have high mechanical strength

A limitation of this processing route, however, is that the NdFeB surface must be exposed to the hydrogen gas for the material to undergo decrepitation. If the magnet is deeply embedded in the component, this will impede hydrogen accessing the magnet. Likewise, prior processing of the material will depend on not only if there is a coating layer on the magnet, but the thickness of the oxidised surface layer if there is no coating. This will all determine the extent and type of prior processing required, and therefore impact repeatability and reliability of the HD process.

## HyProMag

HyProMag has licenced the patented HPMS process for extracting and demagnetising NdFeB alloy powders from magnets embedded in scrap and redundant equipment, originally developed within the Magnetic Materials Group (MMG) at the University of Birmingham, as discussed above.

HyProMag is 25% owned and backed by Maginito Limited, a cleantech growth company established by UK/Canada listed Mkango Resources and Noble Group subsidiary, Talaxis, to invest in downstream technology opportunities in the rare earths supply chain and circular economy.

The founding directors of HyProMag, comprising Professor Emeritus Rex Harris, former Head of the MMG, Professor Allan Walton, current Head of the MMG, and two Honorary Fellows, Dr John Speight and Mr David Kennedy, are leading world experts in the field of rare earth magnetic materials, alloys and hydrogen technology, and have significant industry experience.

The Magnetic Materials Group (MMG) within the School of Metallurgy and Materials at the University of Birmingham has been active in the field of rare earth alloys and processing of permanent magnets using hydrogen for over 40 years. Originated by Professor Rex Harris, who co-authored the first paper on hydrogen based sintered magnet production, the hydrogen decrepitation method, which is used to reduce NdFeB alloys to a powder, is now ubiquitously employed in worldwide magnet processing. In a further development, the MMG patented a process for extracting and demagnetising NdFeB powders from magnets embedded in redundant equipment using hydrogen in a process called HPMS (Hydrogen Processing of Magnet Scrap). This patent and related intellectual property is at the core of HyProMag. The MMG continues to develop new research and development opportunities, cooperates widely in Europe, and has been involved in a number of significant EU projects, including Remanence, MagDrive, REProMag, and most recently SusMagPro and the Innovate UK funded RaRE Project. The directors of HyProMag all provide their expertise to the MMG and there is potential for HyProMag to gain possible future access to new intellectual property.

Hydrogen reaction vessel – source: University of Birmingham / HyProMag

HyProMag's strategy is to establish a recycling facility for NdFeB magnets at Tyseley in Birmingham to provide a sustainable solution for the supply of NdFeB magnets and alloy powders for a wide range of markets including, for example, automotive and electronics. A number of product options are being evaluated including hydrogen decrepitated demagnetised powders suitable for magnet producers, alloy ingot remelted from HD powders suitable for alloy feed or magnet production, anisotropic alloy powders (HDDR) for bonded magnets and sintered NdFeB magnets as required by the RaRE project for automotive applications.

HyProMag benefits from impressive capabilities, experience, and industrial connections within the industry, all significant factors in the successful development of feasible and competitive magnet recycling. Previous research into optimising the HD process has enabled HyProMag to develop a technique where the HD process is applied directly to electronic components after minor alterations. This effectively bypasses the use of complex robotics and/or crushing and shredding stages necessary to isolate the REE rich phase, establishing a short loop recycle path for magnets in components such as, but not limited to, HDDs. Assemblies of components are first mechanically processed to expose the magnet and enable a pathway for hydrogen access. In the case of hard disk drives, this would envisage robotic alignment and cropping the corner of the hard disk drive containing the magnet. Further piercing of the protective magnet coating or oxide layer may be required to allow hydrogen to encounter the NdFeB surface. The assembly is placed into an airtight vessel and exposed to hydrogen gas at either standard conditions or elevated temperatures and pressures. Following the HD process, the Nd-hydride powder contained within the vessel is separated using processes such as sieving or centrifuge. HyProMag's development of a simple and scalable technology to isolate NdFeB powder directly from electronic assemblies facilitates the efficient recycling of magnets with a range of potential products, including short loop to produce sintered magnets, HDDR powder, remelting into alloys and optional further chemical processing, purification and separation. To get the full benefits of HyProMag's short-loop recycling process, the magnet powder should be free of defect causing impurities such as oxygen, in which case HyProMag is able to feed its product into magnet making processes without significant additional processing.

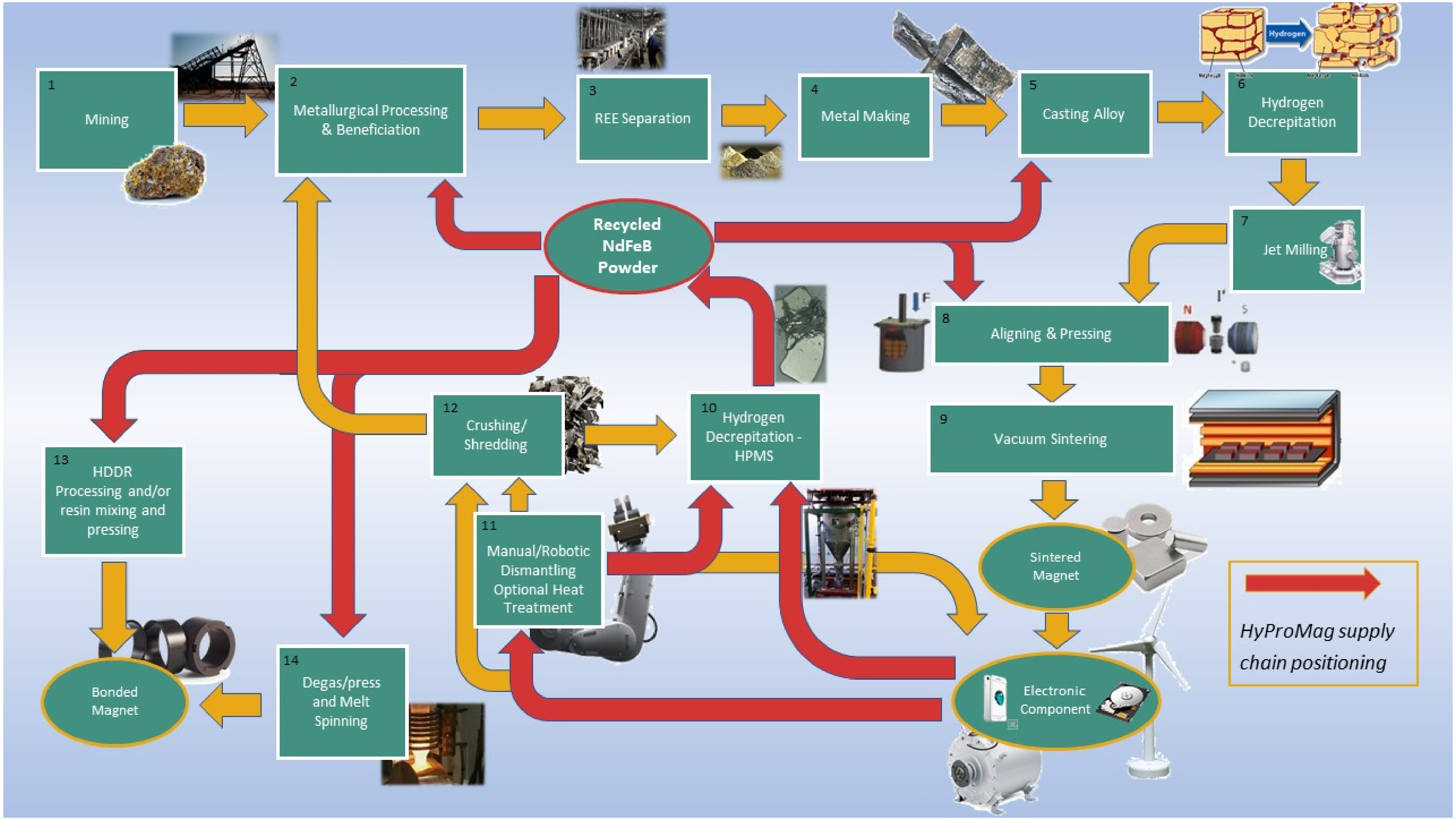
### HyProMag's strategic position

HyProMag's innovative HPMS process not only enables short loop recycling to be integrated within the existing rare earths supply chain, but will also be a key enabler for other downstream technologies and process routes being developed including novel chemical processing and separation methods, and other product options such as HDDR powder for bonded magnets and rare earth alloys.

It effectively unlocks the magnet circular economy and overcomes many of the challenges of alternative magnet liberation and recycling methods. HPMS allows for efficient separation of NdFeB powder from the component, bypassing the impurities and mechanical limitations associated with shredding or crushing. The HPMS process also limits oxygen from entering the powder, an impurity which causes defects in magnets. A combination of HPMS and short loop magnet recycling has a significantly lower environmental impact than alternative flow sheets, such as shredding, chemical processing and separation to produce rare earth oxides, followed by metal, alloy and then magnet making.

An overview of HyProMag's strategic position is illustrated overleaf.

## HyProMag's Strategic Position



1. **Mining**: Mining of ores containing rare earth elements. This provides primary rare earth elements to the supply chain and is currently the source for almost all rare earth containing products and components due to current lack of end-of-life recycling in the supply chain.

2. **Metallurgical Processing and Beneficiation**: In the case of material sourced from mining, this step is necessary to process the ore, removing minerals containing no rare earth elements and other impurities before separation of the individual rare earths. This step also encompasses processing technologies to remove impurities from recycled magnet scrap, for example commingled metal from shredding, iron and boron. This usually involves extraction technologies such as hydrometallurgy or other alternative processes such as electrolysis and bioleaching.

3. **REE Separation**: Conventional hydrometallurgy using nitric or hydrochloric acids with appropriate extractants are used in all commercial RE separation plants. This separates individual REEs from a mixed RE-rich phase. Other technologies such as ionic liquid solvents, electrowinning, chromatography, and electrophoresis are being researched and piloted for integration into the supply chain.

4. **Metal Making**: Rare earth metals are prepared from their respective oxides through processes such as calciothermic or electrolytic processes. In these methods, the oxides are reduced to form the metal at high purity. The exact method undertaken depends on the lanthanide being processed and the required purity of the metal.

5. **Casting Alloy**: To produce NdFeB magnet alloys, neodymium is alloyed directly with iron in an electrolytic process using a pure cast iron cathode. Neodymium reacts with the iron cathode to produce molten alloy which drips into a crucible. Other alloys such as Dy-Fe and Nd-Dy-Fe are made in a similar way. The exact composition of the alloy will depend on the downstream application of the material. Recycled NdFeB powder can also be used as a feed to this process as well as primary material.

6. **Hydrogen Decrepitation**: Passing hydrogen over the rare earth alloy material causes it to demagnetise and decrepitate into a friable powder. The metal-hydride powder formed can then be processed further with ease.

7. **Jet Milling**: Jet milling is employed following hydrogen decrepitation to further reduce the grain size of the material by using high speed jets of compressed air. Small grain sizes allow for better magnetic properties of the formed magnet downstream

8. **Aligning & Pressing**: The milled, fine NdFeB powder is aligned in a magnetic field whilst being mechanically compressed into the required shape for the application. Recycled NdFeB as well as primary material can be combined as a feed to this processing step

9. **Vacuum Sintering**: High temperature sintering causes the density of the pressed NdFeB material to increase significantly, forming the sintered magnet. This is performed in a vacuum to prevent oxidation of the material which would cause defects in the structure of the magnet, negatively impacting magnet properties. Appropriate cutting can then shape the magnet into its required dimensions.

10. **Hydrogen Decrepitation - HPMS**: Hydrogen processing of magnet scrap (HPMS), developed at the University of Birmingham and licenced by HyProMag, can be applied directly, or after appropriate dismantling, to electronic waste components to produce recycled, demagnetised, fine NdFeB powder. This facilitates short loop magnet recycling as this powder can be used as a feed in various parts of the life cycle: sintered and bonded magnet making, REE separation, alloy making and blending.

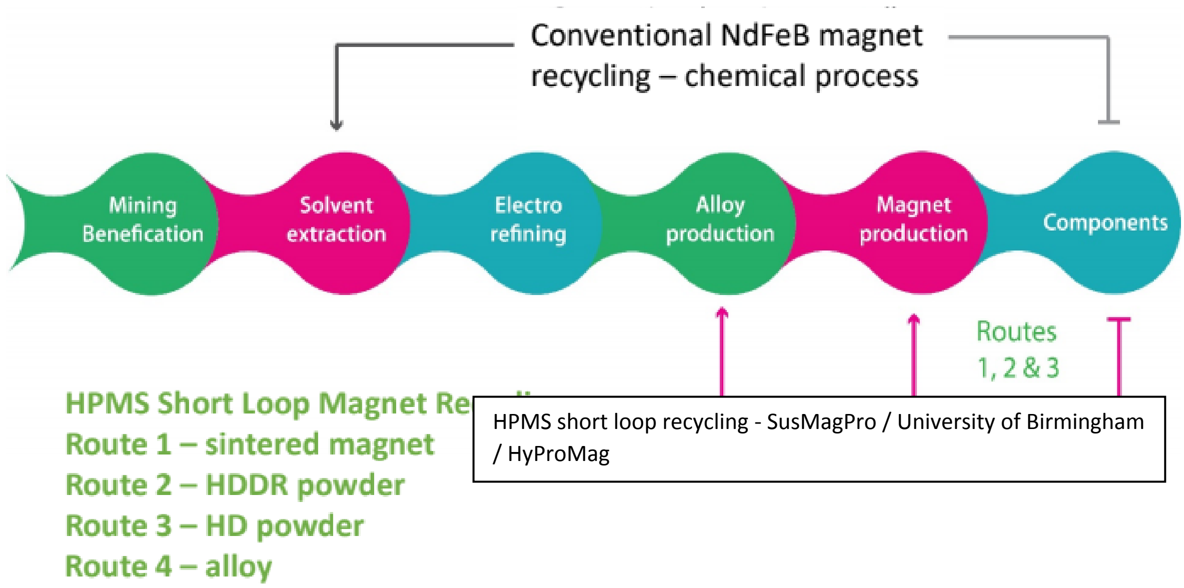
11. **Manual/Robotic Dismantling** with **Optional Heat Treatment**: Manual or automated dismantling enables the magnet to be fully or partially isolated from a component where it may be deeply embedded and difficult to access. Depending on the component, heat treatment can be used in this step to demagnetise the magnet and facilitating its removal from the device. The isolated magnet can then be further processed with fewer impurities compared to if the whole device was to be shredded/crushed for recycle.

12. **Crushing/Shredding**: Crushing and/or shredding of electronic waste is used to both decrease the size of the magnet material and to gain access to embedded magnets. This material often contains impurities from the component, so requires further processing to isolate the NdFeB material.

13. **HDDR Processing and/or resin mixing and pressing**: The hydrogen decrepitation process can be used in conjunction with the hydrogen, disproportionation, desorption, and recombination (HDDR) process with appropriate mixing with polymer resins for the formation of bonded magnets. This provides a potential short loop recycling route for recycled NdFeB powder.

14. **Degas/press and melt spinning**: A route for recycled NdFeB powder is degassing and pressing for the formation of bonded magnets. Melt spinning with suitable resin binders can be used to produce the bonded magnet.

*Two projects, RaRE and SusMagPro showcase HyProMag's strategic positioning in the supply chain and will significantly de-risk and scale up implementation of the HPMS technology. The following figure demonstrates how the HPMS process enables short loop recycling of sintered NdFeB magnets***RaRE Project**




HPMS short loop recycling - SusMagPro / University of Birmingham / HyProMag

HyProMag is a partner in the Innovate UK grant funded project "Rare-Earth Recycling for E-Machines" ("RaRE"). RaRE will for the first time establish an end to end supply chain to incorporate recycled rare earth magnets into electric vehicles, whereby recycled magnets will be built into an ancillary electric motor to ultimately support the development of a commercial ancillary motor suite. The HPMS process is fundamental to the project.

In addition to HyProMag and UoB, the Project features a strong set of partners with complementary expertise:

- Advanced Electric Machines Research Limited - extensive experience in designing motors for customers including Airbus and Tevva Motors
- Bentley Motors Limited - an iconic automotive brand and part of the VW Group, one of the world's largest car manufacturers
- Intelligent Lifecycle Solutions Limited - a global leader in the processing of electronics waste working with Fortune 500 companies and UK government agencies
- Unipart Powertrain Applications Limited - one of the largest UK based Tier 1 automotive partners and a recognised volume automotive supplier able to supply globally

Building on work completed at the University of Birmingham to devise a method to extract magnets from waste electronics, HyProMag will scale up the HPMS process and re-process the product back into new magnetic materials at pilot scale to demonstrate the quality of material which can be produced in terms of its magnetic behaviour, mechanical performance and corrosion resistance, all of which are key to the end user application. Intelligent Lifecycle Solutions will establish the scrap sorting process to maximise process efficiency and rare earth material volumes.

The recycled magnets will be built into an ancillary electric motor designed by Advanced Electric Machines Research to a Bentley Motors specification and focused on reducing the overall complexity of electrical systems in electric vehicles and designed with recycling in mind. This will be the first time that such a recycled motor will have been demonstrated. Unipart will take this motor design and use it as the core focus for the design of a flexible volume motor assembly line suitable for production volumes of 100,000 units per year.

Innovate UK will fund £1.9 million of the £2.6 million total Project costs with the balance funded by the Project partners. In the case of HyProMag, Innovate UK will contribute £657,717 and HyProMag will contribute £281,879. HyProMag's contribution will be fully funded from the investment by Maginito in HyProMag announced on January 10, 2020, whereby Maginito invested £300,000 for a 25% equity interest in HyProMag and provided a £200,000 convertible loan facility, now fully drawn.

*Recycling of rare earth magnets will play a key role in the development of robust supply chains to catalyse and support growth in the electric vehicle sector and in other clean technologies. With the increasing need for sustainably sourced commodities, the RaRE project highlights the role that closed loops chains can play in rare earths supply to meet the environmental and economic demands of the growing electric vehicle market.*

SusMagPro (Production of recycled sintered NdFeB magnet, bonded magnet, HDDR powder, alloys)

SusMagPro is focused on establishing a sustainable magnet supply chain in the EU through recovery and recycling of REEs from magnetic waste materials. By introducing a reliable source of raw materials at scale, SusMagPro will contribute to the future growth of the magnet recycling industry. This will be enabled by SusMagPro's current strategic partnership with 19 companies and institutes, allowing for synergies and collaboration between different points of the magnet life cycle. The project's goal of producing a total of 110 tonnes per year of NdFeB powders will facilitate the adoption of recycled REEs into a range of new magnetic products. This will provide an eco-friendly and sustainable supply of magnet materials,reducing imports and the associated environmental implications of obtaining these materials; SusMagPro has a goal of a 75% reduction in energy consumed from isolating magnet materials relative to obtaining them from primary sources. SusMagPro's objective of contributing significantly to the EU's supply of NdFeB products demonstrates the project's importance in advancing the development of a cost-efficient and renewable integrated supply chain. Through raising awareness of the importance of NdFeB materials and the challenges relating to their supply, the project ultimately aims to raise confidence and trust in a circular economy for rare earth magnets.

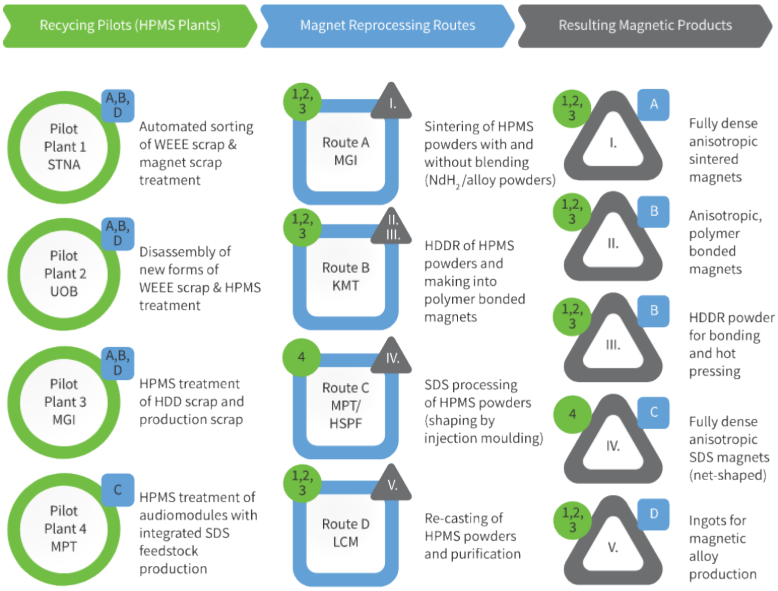



Figure 20: SusMagPro processes overview - https://www.susmagpro.eu/about/about-susmagpro-solutions

SusMagPro partners are researching and developing a variety of technologies necessary to facilitate a sustainable magnet supply chain, both recycling and recovery processes, and reprocessing routes to form recycled magnets. New sensing and robotic sorting lines identify and extract materials from waste components efficiently. Piloted HPMS technology at the University of Birmingham directly extracts NdFeB powders from magnets embedded in electrical components. This treatment can used in conjunction with SDS (shaping-debinding-sintering) processing for the formation of new magnets. Sintering of HPMS powders with optional blending with neodymium-hydride or alloy powders is a processing route for magnet production which SusMagPro utilises. Pyrometallurgical processes, purification and shaping magnets through pressing and injection moulding are further technologies which are used by SusMagPro's partners. SusMagPro is therefore involved in the production of fully dense anisotropic sintered magnets, HDDR powder for bonding and hot pressing, polymer bonded magnets, and ingots for magnetic alloy production. This provides a diverse range of end-user-ready magnets for a variety of products such as electric car motors, headphones, and loudspeakers. With 4 pilot plants in Germany, Slovenia, Belgium, and the UK, SusMagPro is working to achieve its objective of integrating sustainable magnet recycling for the development of a circular magnet supply chain in Europe.

The SusMagPro project covers a wide spectrum of potential products, underpinned by supply of recycled NdFeB powder from HPMS pilot plant production, technology licenced by HyProMag from University of Birmingham, which will result in significant further derisking of the technology. Apart from production of sintered magnets (in common with the RaRE project), the project will also produce HDDR powder, which may represent another potential product opportunity for HyProMag.

## Legislative Barriers

The waste legislation within the UK has evolved over time as issues have arisen, both at UK domestic level and at the EU level. Legislation has been applied to loop-holes and issues as they have arisen over the life of the EU, with a spider-web of cross-referencing between Directives and Regulations at EU level and Acts and Regulations at national level. The result is a highly thorough, yet highly complex statute book. This description can be applied to other areas of environmental legislation, not just the waste industry.

The CMA understands that this EU statute book as it stands is to effectively be duplicated in order to enable all the current high standards of environmental management to continue following the end of the transition period for leaving the European Union.

Ensuring the continuation of high environmental standards is essential. The CMA does not propose to remove any of the requirements for the protection and net improvement of the environment; but exiting of the EU does provide an opportunity, through consultation with stakeholders in the waste sector, NGOs, and industry, to consolidate the framework and remove unnecessary barriers. One of the primary aims of the CMA is to facilitate the re-introduction of critical minerals required to transition to a green economy into the supply chain. This means a crucial part of the Associations' work is to ensure the minerals already within the UK borders, captive in electrical devices, batteries and other equipment is available to the UK's Green Economy going forward; essentially the re-use and recycle stages of the waste hierarchy.

The following legislation applies to waste containing critical minerals:

- The Waste Framework Directive
- The Waste Electrical and Electronic Equipment Directive
- The Industrial Emissions Directive
- The Water Framework Directive
- The Landfill Directive
- The Batteries Directive
- The Waste (Duty of Care) Regulations
- The Hazardous Waste Regulations
- The Fluorinated Greenhouse Gas Regulations
- The Transfrontier Shipment of Waste Regulations
- The Waste Acceptance Criteria rules
- The Environmental Permitting Regulations

- The List of Wastes Regulations

Key among the above, and for many in industry the beginning of the sequential barriers to re-use and recycling is the Waste Framework Directive. This directive imparts the title of "waste" onto anything that is either discarded or is intended to be discarded. Whether a substance is a waste or not a waste changes the dynamics of how it is managed, and the avenues available for its re-introduction into the supply chain.

Consider a lithium ion battery from a power tool. These batteries are not interchangeable between manufacturers, and occasionally a manufacturer will cease making a particular type of battery and the accompanying tool, meaning any future malfunction renders the tool or the battery (often both) unusable. There is no other option then but to discard it at end of life.

Once it meets the criteria of a waste, the subsequent options for the conservation of the lithium, cobalt, nickel and graphite therein are limited.

An irresponsible owner may put the battery in domestic general waste. In most council areas general waste bins are directly discharged into the rear of compaction lorries with no manual sorting; this as much as anything ensures the safety of the waste collection operatives from potentially harmful substances or sharp objects in the waste. These lorries then either directly discharge into bulk shredding and incineration facilities or directly into a landfill site.

In the event the batteries are deposited into the landfill intact, but so interspersed with other household waste that it is effectively impossible (and or dangerous) to remove, an offence is being committed under the Batteries Directive, which specifies these batteries must not be landfilled.

If the batteries are shredded with other household waste and incinerated, the minerals will most likely be captured in waste flue gas bags or ash, both of which are landfilled. To landfill this ash or residue the substance must meet the Waste Acceptance Requirements outlined in the Landfill Directive for the relevant list of waste code defined in the List of Wastes Regulations. Heavy metals in the waste may cause an exceedance of thresholds for acceptance into stable non-reactive landfills, requiring that they be landfilled instead in expensive hazardous waste cells.

In both instances these minerals may form part of landfill leachate that can be harmful to the environment. Leachate must be regularly tested, and if exceeding water quality criteria laid out in the landfill site environmental permit, must be conveyed to another waste treatment facility via a licenced hazardous waste carrier for neutralisation or further treatment to reduce it's hazardous properties.

As is hopefully evident, for the local authority this is a complex, expensive, environmentally damaging and often accidentally illegal route.

The original battery owner may be committing an offence using general waste in this way, but firstly they may not be aware that it is illegal, and secondly may not know there are other options available to them, but critically for small businesses operating close to the margin this is undoubtedly the cheapest route.

A more responsible owner may call the manufacturer and request collection in line with the requirements placed on them by the Waste Electrical and Electronic Equipment Directive, the best available workable alternative. WEEE legislation establishes the requirement for manufacturers to take waste electricals back free of charge. They can discharge this requirement by joining a compliance scheme. Arrangements can be made by a compliance scheme to collect the battery free of charge, however compliance schemes are not in themselves battery recyclers, but rather transition services. Once collected the scheme must ensure that any onward transport of the waste is done in line with the Waste (Duty of Care) Regulations and the Hazardous Waste Regulations. This means the compliance scheme must first identify the waste using a 6 digit code from the Government List of Wastes (LOW). LOW codes for batteries are as below:

- 16 06 batteries and accumulators
- 16 06 01* lead batteries
- 16 06 02* Ni-Cd batteries
- 16 06 03* mercury-containing batteries
- 16 06 04 alkaline batteries (except 16 06 03)
- 16 06 05 other batteries and accumulators
- 16 06 06* separately collected electrolyte from batteries and accumulators

Note, Lithium Ion batteries would be considered 16 06 05 – other batteries. They are defined by the Batteries Directive as industrial batteries.

The Duty of Care regulations specify that the waste remains that of the source until it is no longer a waste, either in landfill or recycled. Producers of hazardous wastes such as WEEE must be Registered as such with the Competent Authority, the Environment Agency in England, Natural Resources Wales in Wales, the Scottish Environmental Protection Agency in Scotland and the Northern Ireland Environment Agency in Northern Ireland. There are also variations in regulations between these devolved administrations, for example the Duty of Care Regulations are subtly different in Scotland compared to Wales.

The compliance scheme must arrange transport of the waste by a licenced Waste Carrier registered with the Competent Authority (CA). This Waste Carrier must transport the waste to a Waste Broker again registered with the Competent Authority to an Approved Authorised Treatment Facility (AATF). These facilities can then issue evidence notes to the compliance scheme that the requirements for recycling have been discharged.

These facilities must hold a permit in order to operate, again issued by the CA or local authority depending on the size of the facility. The Permit is granted in accordance with the Environmental Permitting Regulations 2016 in England and Wales and similar legislation in

Scotland and Northern Ireland. In order to be granted a permit the facility must demonstrate that they meet Best Available Treatment Recycling and Recovery Techniques (BATRRT). BATRRT for other processes is defined at a European level in best available techniques reference notes (BRef notes), however no such BRef note exists for electrical waste installations, rather the Waste Treatment BRef must be applied. This BRef however is focussed on ensuring hazardous contents of batteries such as lead from car batteries and mercury are managed effectively and so do not cause pollution to the environment.

BATRRT is however described at a domestic UK level. Within the UK an operator of a waste treatment installation may apply to become an Approved Battery Treatment Operator (ABTO) in order to issue evidence notes, but you must already have an environmental permit to apply, and this is only available to those that issue evidence notes to compliance schemes or those that treat more than 150 tonnes of automotive batteries a year. As mentioned above, automotive batteries are lead-acid used for internal combustion engines, rather than the Lithium batteries used for electric vehicles or hybrids. These are rather considered industrial batteries.

In order to legally recycle batteries, an operator requires a waste permit under the Environmental Permitting Regulations 2016 (other similar legislation applies in Scotland and Northern Ireland). Adding waste codes to a permit involves a check from the CA to ensure that the operator has an environmental management system and the technologies to capture some emissions (under legislation geared to protect the environment) but is not an onerous task. Landfilling or incinerating automotive batteries and industrial batteries is illegal, however sending them overseas is not (with authorisation from the CA).

In light of this the CMA proposes that a specific sector guidance note for batteries be written by the UK Competent Authorities (normally authored by the Environment Agency in England) setting out the requirements of a waste battery treatment installation.

The issue is wider than batteries. Waste electrical and electronic equipment as described above, contain numerous critical minerals that will be essential in a low-carbon economy, as will waste electric vehicles going forward. These minerals are most effectively recovered from the waste equipment when uncontaminated, and intact. To meet all the regulatory requirements to comply with waste legislation as it currently stands is expensive and time-consuming, leading to waste producers taking any viable steps to avoid the material being classified as waste in the first place. Products and bi-products can be easily sold and purchased without application of any of the requirements of waste legislation, therefore conserving value.

The unique situation the UK finds itself in post-EU membership allows for consolidation of the statute book and enabling of measures to facilitate a circular economy in critical minerals; as long as this can be achieved with net increase in environment and social responsibility.

## Recommendations

- Establish a working group or committee to review waste legislation in the UK as a country no longer part of the EU against countries in and beyond the EU, and produce a report with recommendations for consolidation and augmentation the UK waste statute book.
- Review the Transfrontier Shipment of Waste legislation in light of the UK's new situation, and add more granularity to enable recyclates to be responsibly exported to treatment facilities overseas following a thorough and transparent due diligence process.
- Establish a framework similar to the Streamlined Energy and Carbon Reporting scheme to require UK registered large undertakings to disclose the quantities and types of wastes generated by the organisation annually. This will facilitate cross pollination of waste producers with recycling or re-processing facilities.
- Establish a Critical Minerals Forum to bring together critical minerals producers, manufacturers, waste operators and funding agencies such as Innovate UK to discuss circular opportunities for retaining critical minerals in the UK economy.
- Produce a Sector Guidance Note for battery production and battery recycling facilities, including consolidation of existing environmental controls.
- Produce a Sector Guidance Note for electrical and electronic equipment production and recycling facilities, including consolidation of existing environmental controls.
- Review the procedure and criteria for evaluation of the "end of waste" (EoW) classification for electrical and electronic equipment, batteries and other critical mineral containing waste streams, to enable more materials to achieve EoW quicker and cheaper, retaining the materials' value.

*October 2020*