A Study of the Recycling and Recovery Infrastructure for Materials Critical to the UK

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<u>NOTE</u>

This draft report has been produced on the basis of the information available to the author at the time of preparation. If you are aware of any inaccuracies or omissions I would welcome your input for inclusion into the final report.

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CONTENTS

1. INTRODUCTION

There is a finite amount of all elements on the Earth, and their exploitation depends upon the ability to recover them economically in sufficient quantities, from locations where they occur in excess of the natural concentration in the crust.

With today's greater demand many elements that were mined in the UK are no longer economic to recover. A situation that has been caused by the increasing cost of manpower leading to greater automation and different mining techniques.

A recent study by the Raw Materials Supply Group for the EU highlighted the dependence of the EU on imports for many raw materials for its modern industrial activity as well as the infrastructure and products used in daily-life. It recognised that these imports were being increasingly affected by growing demand pressure from emerging economies and by an increasing number of national policy measures that disrupt the normal operation of global markets. The current production of many materials is concentrated in a small number of countries, with more than 90% of the rare earths and 80 % of antimony produced in China, 90% of niobium by Brazil and 77% of the platinum group metals by South Africa. In addition, high tec metals are often by-products of the mining and processing of major industrial metals such as copper, zinc and aluminium.

The working group qualitatively analysed 41 metals and minerals, and assessed the stability of the producing country, the diversity of supply, the substitutability and recycling as key factors. From this analysis a group of 14 critical materials were identified, comprised mainly of speciality metals which exhibit a combination of high economic importance to the EU and a high risk of potential disruption to or interference in supply.

A similar exercise, initiated by UNEP DTIE (United Nations Environment Programme-Division of Technology, Industry and Economics) and conducted by the Oko-Institut, identified a number of materials critical for future sustainable technologies. The materials identified were encompassed within the listing generated in the Raw Materials Supply Group report.

The Materials KTN ran a workshop last year specifically to assess the scale of the problem for the aerospace and energy sectors, and this was followed up by an evaluation of the impact on alloying materials for the metals industry. The Materials KTN have identified the importance of materials recovery and waste recycling as one option for addressing this issue. In addition to those materials identified in the above reports, the Materials KTN also considered carbon fibre, lithium and titanium to be of specific importance to UK industry.

The following materials have therefore been evaluated in terms of their major producing countries, their applications and the extent to which recycling is possible and carried out both in the UK and, where not available, on mainland Europe:

Antimony	Beryllium	Carbon Fibre	Cobalt	Fluorspar	Gallium
Germanium	Indium	Lithium	Magnesium	Niobium	Phosphorus
PGMs	Rare Earths	Tantalum	Titanium	Tungsten	

2. Analysis of Critical Materials

2.1 Antimony

Background

Antimony is a silvery-white, very brittle semi-conductor metal. Metallic antimony is rarely used alone, due to its poor mechanical properties, and it is usually alloyed with other metals such as lead, tin, copper and zinc (A). The major use of antimony is as the chemical compound antimony trioxide (E).

China is the major producer of antimony ore with in excess of 80% of the world's production in 2010 (B).

Applications

Metallic antimony

Antimony metal is used extensively to harden and increase the mechanical strength of lead alloy particularly for the use in wet-cell batteries (A). It is also used in the production of solders, machine bearings, ammunition and pewter.

Chemical antimony

Antimony trioxide is used as a catalyst in the production of PET. Early problems of a yellow tinge to the product associated with the use of titanium compounds as an alternative have now been overcome and titanium compounds are now likely to dominate PET production (F).

Antimony trioxide is predominantly used as a flame retardant synergistic in plastics, paints, adhesives, sealants, rubber and textile back coatings where it is co-used with appropriate halogenated compounds usually based on chlorine or bromine (J). The inclusion of low levels of antimony trioxide allows a significant reduction in the amount of brominated compounds in order to achieve a similar effectiveness of flame retardancy. In 2000 approximately 50% of the total antimony production was used in flame retardant applications.

Recycling UK & Europe

Wet-cell batteries

Historically lead-acid batteries manufacturers alloyed lead with antimony for certain parts of the battery that require corrosion resistance, creep resistant, and good strength. The current 'low maintenance' and 'maintenance free' batteries now use calcium-lead plates, but antimony lead is still used for the posts and cell connectors, and for the plates in heavy duty batteries. It is estimated that between 70 - 90% of lead-acid batteries in the UK are recycled. Antimony is recovered during the recycling/refining process and is sold as high antimony-lead ingots (G).

Flame retardant

Flame retardancy is often an essential requirement of plastic materials used in applications subject to the Waste Electrical and Electronic Equipment (WEEE) legislation in order to meet the higher fire safety standards required. Brominated plastics with antimony trioxide additions do not cause any notable processing problems when the material is recycled (K). However more recent legislation has limited the use of the more mobile bromine compounds although they may still be present in material returned under the WEEE directive.

In certain instances, where the full history of the plastic material returned under the WEEE directive is known, flame retarded ABS can be recycled to the required safety standard without the need for addition of further flame retardants (H).

Potential recycling options

UK research has successfully identified a process route for fire retardant plastics disposed of under the WEEE legislation that can produce halogen-free oil, using a pyrolysis-catalysis route (D). The oil would be suitable for use as a high grade fuel or as a source of chemicals. The antimony component is isolated as antimony bromide allowing for the potential recovery of both the bromine and the antimony.

Other information

Sony Ericsson, in the manufacture of their branded mobile phones, have recently phased out brominated flame retardants (and by implication, antimony trioxide) used in the cables, casings and circuit boards (C).

2.2 Beryllium

Background

Beryllium is a low atomic number metal with a density similar to that of magnesium but a surprisingly high melting point (in excess of 1200 °C). It has excellent thermal conductivity and is strong, stiff and fundamentally stable over a wide temperature range. It is also highly permeable to X-rays. Although in final solid form the metal and its alloys are unlikely to cause any ill effects beryllium does however have toxicity issues if handled incorrectly and hence is only used where it is essential (L).

The most important use for beryllium is in alloys- in the US this equates to 75% of consumption, with approximately 15% being used for ceramics incorporating beryllium oxide. Similar proportions apply to the UK. The metal itself accounts for 10% of demand. These specific values are for 2000 (L) but are considered to be valid for 2010 (J).

The USA is the predominant source of beryllium ore and refined material, supplying more than 80% of the world demand, with China and Mozambique making up the remainder (B).

Applications

Copper-beryllium alloys

Beryllium-copper alloys represent the greatest use of beryllium. Although the high strength variant with 1.6-2% Be, and the high conductivity variant with 0.3% Be contain relatively small proportions of the metal these alloys are used widely where it is important to have high electrical and or thermal conductivity, high strength and hardness combined with non-magnetic properties (L). Typical applications include electrical contacts, springs, and plastic moulds. In 2000 it was estimated that a typical computer contains 2.1 grams of beryllium (M).

Nickel-beryllium alloy

Nickel-beryllium alloy with 2% Be retains its good spring properties at elevated temperatures and is used in applications such as thermostats, bellows, diaphragms and sockets (L).

Beryllium- aluminium alloy

Beryllium-aluminium alloys are more accurately metal matrix composites since the two metals do not combine and remain as separate phases. The two principal beryllium-aluminium alloys contain 62 and 40% beryllium. Their low density, high specific stiffness, and high thermal conductivity characteristics are suited to applications in the avionic sector where increasing electronic packaging densities and growing thermal loads are a particular challenge (M).

Beryllium metal

Beryllium metal is used in the defence and aerospace sectors as a lightweight structural material in high-speed aircraft, helicopters, missiles, spacecraft and satellites. It is also the standard material for optics in space (M). Beryllium is also used widely in nuclear reactors and weapons (M).

Beryllium oxide

Beryllium oxide can be formed into a lightweight rigid ceramic combining good electrical resistance with greater thermal conductivity than any other oxide. It is used as a substrate for electrical circuits that generate significant quantities of heat (L).

Recycling UK & Europe

Beryllium-copper and other alloys

Materion Brush Ltd (formerly Brush Wellman) is the major supplier of copper-beryllium alloys in the UK and will take back new scrap(N). This is returned to the US for reprocessing.

There is no mechanism in place for the recovery of beryllium from post consumer waste. Although copper is recovered during the recycling of electronic scrap the beryllium is lost in the current recovery process (N). It is estimated that in 2000 there was approximately 2 g of beryllium, as copper-beryllium alloy, in every personal computer present (M). Gartner estimated that more than 12 million desk-based and mobile PCs were sold in the UK (O) (*figure obtained by multiplying first-quarter sales by four).*

Materion Brush Ltd is the major supplier of nickel-beryllium and beryllium-aluminium alloys in the UK and will take back new scrap (N).

Beryllium metal

Little beryllium is recovered from old scrap, the majority of which is nuclear contaminated (M). Materion Brush Ltd will accept new beryllium scrap (N)

Beryllium oxide

Materion Brush Ltd will purchase clean, segregated beryllium oxide scrap (routine amounts of lubricant are not a problem) for recycling (O).

Other information

Sony Ericsson has phased out the use of beryllium-copper contacts and all their new products now longer contain beryllium (I).

2.3 Carbon Fibre

Background

Carbon fibre is a material consisting of extremely thin fibres with a diameter of 0.005-0.010 mm and composed mostly of carbon atoms, made by either the thermal carbonisation of polyacrylonitrile (PAN) or pitch. Although the structure of the carbon fibre is not clearly defined, the carbon atoms have a linear arrangement that gives the fibres excellent stiffness and strength (X). In order to make use of the high stiffness and strength of carbon fibres they must be combined with a plastic or resin matrix. Carbon fibres are mainly used as continuous fibre reinforcement for epoxy resins which offers the highest stiffness and strength to weight ratios of any material, or more recently in thermoplastic resins such as PEEK (T). The predominant source of carbon fibre is Japan with greater than 75% of world production (Y).

For construction of a carbon fibre composite it is necessary to incorporate the resin matrix. This can be carried out either at an early stage of manufacture where the individual fibres are supplied ready coated with adhesive, or the adhesive is applied during construction.

Some chopped fibres are also used in injection moulded thermoplastics such as polyamide 66 (T).

Applications

Aerospace

Carbon fibre composites found early aerospace application by the developers of military aircraft in the late 1960s. These new stiff, high-strength lightweight reinforcement materials found initial use in wingtips, nose cones trailing edges of wings and air inlet ducts. More recently the commercial aircraft industry has followed aerospace's lead, and the Airbus A350 scheduled for introduction in 2013 will have both fuselage and wing structure made from carbon-fibre composite. The main driving force is a significant reduction in aircraft mass with its impact on fuel consumption (AB).

Wind energy

Carbon fibre composites are currently used in the manufacture of many of the components in wind turbines, including spar/shear web, shell, root and the nacelle (GG).

Automotive

Carbon fibre reinforced polymer is used extensively in high-end automobile racing and finds particular application where high stiffness/strength is required in specific directions. It is used widely in the body shell and other components of performance cars. More recently companies such as BMW and Mercedes-Benz and Daimler are looking to increase the proportion of carbon fibre composite in order to achieve significant weight reductions (U).

Marine

The high strength and stiffness to weight ratio of carbon fibre composites, together with the ability to construct a vessel in which the individual components can be tailored to the required form, has led to their extensive use in the manufacture of high-performance marine craft, including racing dinghies and ocean-going racing yachts (W).

Industrial

As an example large, single-span carbon fibre driveshafts have eliminated the need for intermediate bearing support and offered greater speed for large boats, such as fast ferries. This technology has now been transferred to other applications where long carbon fibre driveshafts provide an effective and safe alternative (W).

Recycling UK & Europe

For many applications, such as wind turbines, the durability of carbon fibre composite means that recycling is not an immediate issue, but is likely to become increasingly so in the near future (Z).

Recycled Carbon Fibre Ltd (Coseley, West Midlands) is the world's first commercial scale continuous carbon fibre recycling facility (AA) and has the capacity to take all the UK’s cured carbon fibre composite waste for several years. The company requires that the product is delivered to their site but can recycle most forms of composite waste such as dry fibre, pre-preg and laminates. At present they cannot accept aerospace and marine wastes that contain honeycomb material. The carbon fibre is recovered in a pyrolysis process; it is milled, chopped and pelletised and is used mainly for electrostatic applications, and reinforcement in polymers, with the recovered carbon fibre retaining greater than 90% of its original mechanical properties (FJ).

A number of other recycling processes are being researched. Nottingham University are investigating the use of supercritical fluids to extract the carbon fibres with minimal damage (V). The technique has the added benefit that it will also extract the chemicals of the polymer resin so that there will be less waste.

2.4 Cobalt

Background

Cobalt is ferromagnetic material. Its industrial importance is related to its ability to form alloys with many other metals, imparting strength at high temperatures and to maintain magnetic properties at elevated temperatures (ES).

Cobalt is almost always extracted as a by-product of other minerals, usually copper or nickel, with only approximately 15% recovered from cobalt ores (ET). Although the major deposits of cobalt mineral are to be found primarily in the Democratic Republic of the Congo and Canada, which accounts for in excess of 50% of total production, the major producers of refined cobalt metal are China (25%), Finland (15%) and Canada (10%). These values are for the period 2003-2007 (ET).

Applications

Superalloys

Cobalt can be combined with chromium, aluminium and certain other metals to produce materials (superalloys) which are capable of withstanding severe mechanical stresses at elevated temperatures. Cobalt also enhances the high temperature strength and corrosion resistance of nickel-based superalloys.

Cobalt-based and superalloys with cobalt additions are used in jet engines and other turbines where its high operating temperature capability is accompanied by increased efficiency (EU).

Magnetic alloys

Cobalt is alloyed with a number of other metals to produce specialised magnets for use in high-performance electrical equipment. Aluminium-nickel-cobalt alloys (Alnico) have high mechanical strength and retain their magnetic properties up to 550 °C. Cobalt is also allied with samarium to produce a powerful magnet with operating temperatures up to 350 °C.

Magnetic cobalt alloys are used in electric motors and generators, microphones, automotive sensors, loudspeakers and computer hard drives (EV).

Other cobalt alloys

High-specification, high-carbon steel cutting tools have cobalt additions to increase cutting speed and efficiency of material removal (EW).

Hard facing materials are coatings which are abrasion and corrosion resistant, and contain up to 17% cobalt with carbides as the balance (EW).

Prosthetic hips and new joints are made from cobalt-chromium-molybdenum alloys which exhibit high strength and good biocompatibility (EW).

Low expansion alloys (cobalt-nickel-iron) are used in the electronic packaging industries for glass/metal seals (EW).

Maraging steels, which are used primarily for aerospace and military applications, contain up to 12% cobalt.

Hardmetals, based on tungsten carbide can contain up to 9% cobalt with additions of other carbides such as tantalum carbide (EX).

Batteries and electronics

Cobalt is an important component of the three main rechargeable battery technologies: nickel-cadmium, nickel-metal hydride and lithium-ion (EY). The environmental problem associated with nickel-cadmium rechargeable batteries has led to their withdrawal in the UK for consumer use although they are still used in special industrial applications (EZ).

In nickel-metal hydride batteries the cathode, a nickel alloy material, contains up to 15% cobalt which enhances the life of the battery (EY).

The cathode active material of lithium-ion batteries contains up to 60% of cobalt in the form of lithium-cobalt oxide. This type of battery is both lighter and more powerful than the others and is dominant in the consumer marketplace (EY). Lithium-ion batteries are used as the power source in electric powered vehicles such as those produced by Nissan.

Chemicals

Cobalt, in various forms, is used widely as a catalyst. In the petrochemical industry a cobalt oxide compound is used to remove sulphur from crude oil during refining. Cobalt base catalysts are also employed in gas-to-liquid technology where natural gas is converted to synthetic diesel fuel. Cobalt-based catalysts are also used in the production of plastics (ET).

Other uses

Cobalt compounds are widely used as a paint pigment.

Recycling UK & Europe

Superalloys

Caledonian Alloys (Livingston Scotland) processes excess alloy material arising from high-performance component manufacturer, from decommissioned parts and the melting process, into material that can be remelted to produce new cobalt alloys. They also process nickel and titanium alloys. They operate a number of facilities including Hereford, Derby and Sheffield, close to the aerospace and other industries. They also offer fully processed revert material to major vacuum and high temperature melters worldwide (FA).

Select Alloy Materials Ltd deal in scrap wrought and cast cobalt alloy products as well as nickel and titanium-based materials. In addition to supplying the UK's domestic casting industry they also export material (FB).

Ireland Alloys, based in Scotland, buy and sell a range of cobalt alloys in addition to tungsten and titanium alloys (FC).

Magnetic alloys

The only reference to recycling of cobalt-based magnetic alloys is from Arnold Magnetic Technologies who have manufacturing capability in the USA, UK – where they as Swift Levick Magnets, Europe and China. Swift Levick Magnets can recycle Arnold Magnetic Technologies samarium-cobalt and AlNiCo magnets but place restrictions on accepting other manufacturers' products depending on level of contaminants (FD).

Other cobalt alloys

No companies have been identified that offer specific recycling of other cobalt alloys, although there are a number of general scrap merchants, primarily collectors of material, which accept cobalt base material.

Batteries and Electronics

Local authority recycling centres accept consumer batteries and many retail premises also have in-house collection facility. The disposed batteries are primarily ZnC/alkaline type but there are facilities in the EU (Germany, France, Sweden and Belgian) for the treatment of nickel-cadmium, nickel-metal hydride and lithium ion batteries (FE). In the UK the recycling system relies on the consumer separating batteries from the general waste.

G & P Batteries Ltd offer a collection and recycling service for both industry and local authorities, dealing with a wide range of batteries including nickel-cadmium, nickel-metal hydride and lithium ion. These are sorted in their Darlaston facility. The company offered a UK-based recovery process for lithium-ion batteries (FF).

Umicore (Belgium) have developed a closed loop solution for lithium ion batteries by which the cobalt, lithium and nickel components can be recycled, refined and transformed into lithium cobalt dioxide for manufacturer of new lithium-ion batteries (FG).

Hardmetals

Contaminated carbide scrap can be recycled to recover both the cobalt content and the various carbide metals by oxidising and chemically processing. Clean cemented carbide inserts and compacts are converted to powder by the zinc process which dissolves the cobalt phase and can then be distilled off (DX).

Chemicals

Catalyst Recycling Ltd (Burton upon Trent) specialise in the collection of cobalt and other metal bearing catalysts and residues. The collected material is sent to the recycling facilities which are based in OECD countries, the majority to Nickelhutte Aue (Germany). The choice of recyclers is dependent on the nature of the catalyst and contaminants (FH).

2.5 FLUORSPAR

Background

Fluorspar is a commercial term for the mineral fluorite (calcium fluoride, $CaF2$). Commercial fluorspar is graded according to quality and specification with the grade determining its end use. The three grades are acid, metallurgical and ceramic (Q).

China is the dominant supplier of fluorspar with over 50% of world production in 2003. Other producers include Mexico and South Africa (Q). Until recently (2010) fluorspar was mined in the Peak District with the production of acid-grade fluorspar accounting for almost all of the fluorspar consumed. UK imports of acid-grade fluorspar are now principally from Spain whilst imports of metallurgical fluorspar are chiefly from Mexico and China.

Applications

Acid-grade fluorspar

Acid-grade fluorspar is used in the manufacture of hydrogen fluoride (HF), which, in addition to being an important product in its own right, is the key intermediate for the manufacture of all speciality fluorine-bearing chemicals notably fluorocarbons. Just over 50% of worldwide fluorspar consumption is used as the starting material for the production of HF (Q).

The chlorine-free hydrofluorocarbons, which have no impact on the ozone layer, have two main applications: foam blowing of plastics and heat transfer processes, including domestic and industrial refrigeration and air conditioning. Fluorocarbons are also used as a feedstock for fluoropolymer production. In addition HF is a critical chemical for the electronics industry in the manufacture of semiconductors (R).

Metallurgical-grade fluorspar

Metallurgical-grade fluorspar is used as a flux along with lime to improve the fluidity of slag in steel making and subsequent ladle metallurgy processing, and for the same purpose in iron foundries. It is also used in electric slag refining of aluminium to form a conductive slag with the required melting point. Metallurgical-grade fluorspar is added to the mix of cement raw materials before introduction to the rotary kiln (S).

Ceramic-grade fluorspar

In the ceramic industries, ceramic-grade fluorspar is used to make flint glass, white or coloured opal glasses and enamels. Many types of welding rod coatings incorporate fluorspar or fluorspar mixtures. It is also used in the manufacture of fibreglass insulation (S)

Recycling UK

Acid-grade fluorspar

As fluorspar is consumed in the HF and subsequent chemical manufacturing processes recycling of the mineral is not possible (Q).

Metallurgical-grade fluorspar

The fluorspar additions to the flux used in the manufacture of steel are consumed during the conversion to slag and are therefore not available for recycling (R).

Ceramic-grade fluorspar

The nature of the products manufactured from or containing ceramic-grade fluorspar means that recycling of post consumer waste is currently not a practical option due to the wide dispersion of the material.

2.6 Gallium

Background

Gallium is a relatively common metallic element with a low melting point (30 °C) with a density similar to iron. Economic deposits of gallium-rich mineral rarely occur, and production of primary material is almost entirely as a by-product of alumina production from bauxite, in which gallium is essentially a contaminant (AE). Gallium is also recovered from the by-products of zinc refining. Coal can contain up to 1.5% gallium and limited amounts of gallium are recovered from coal ash (AH).

In 2008 the main producing nations of primary gallium were China (32%), Germany (19%), Kazakhstan (14%) and Russia (10%) (FZ).

Applications

Metallic gallium

The low melting point of gallium combined with its high melting point (in excess of 2000 °C) is reported to lead to the very limited use of metallic gallium use as a high temperature thermometer (AG). No UK suppliers of gallium thermometers have been identified.

Gallium arsenide and gallium nitride

The gallium arsenide and nitride compounds display both significant opto-electronic and semiconductor properties. In the US these two compounds consume in the order of 98% of domestic consumption. They are used in integrated circuits (especially for mobile phones), LEDs, laser diodes photodetectors and solar cells (AF). Solar cells containing gallium indium arsenide currently exhibit the highest solar cell efficiency in excess of 40%, whilst copper-indium-gallium-(di)selenide (CIGS) semiconductor material is used in thin-film solar cells (AK). There is a rapidly increasing demand for high brightness LEDs based on gallium arsenide and gallium nitride (AI).

Gallium nitride is used in amplifiers for cable TV and wireless communications base stations, advanced transistors, specialised chips and in blue laser diodes (AL).

Recycling UK & Europe

Metallic gallium

Mining & Chemical Products Ltd will accept metallic gallium for refining (FK).

Gallium arsenide and gallium nitride

Recycled gallium is a significant source of material for the market from new (process scrap) (AF). During electronics manufacture only 15% of a gallium arsenide ingot is actually used, and the remaining 85% can be recycled. The UK, together with the US, Japan and Germany, are reported to be one of the leading recyclers of gallium (AF).

At their Wellingborough plant Mining & Chemical Products Ltd recycle/ reprocess gallium compounds scrap from UK customers and materials obtained from other group locations in Europe. The principal sources are electronic waste and material that fails quality testing prior to manufacture of targets. MCP also refines indium, germanium and other metals (FK).

The Umicore Group based in Belgium recycle production waste from producers of CIGS, recovering gallium in addition to the other component materials. Recapture Metals Ltd, a Canadian company but with a European plant in Stade, Germany also recycle production waste from gallium compounds.

At present, no common post-consumer recycling is known. As almost all gallium applications are in the field of electronics, with its associated applications at high dilutions rates, the most promising recycling technology is considered to be the recovery of gallium in WEE smelting plants if they are able to extend their output range to include gallium (AE)

2.7 Germanium

Background

Germanium is a relatively common metalloid element similar to silicon metal, having the properties of both metals and non-metals (AM).

Germanium is mostly produced as a by-product of zinc and copper-zinc smelting where it is recovered from flu dust, but it is also recovered from germanium-bearing coal from certain regional deposits (AN, AO). In 2007 the contribution from coal to the worldwide supply of germanium was estimated in the range 20 to 30% but many of the suppliers struggled with the economics as well as the presence of many other, heavy and undesirable metallic elements (AO).

Although the information related to the mining of germanium is regarded as propriety and hence is very limited, the major producers are reported to be a China, Canada and Chile. It is estimated by some sources that China produces 80% of the global germanium supply (AQ)

Applications

Polymerisation catalysts

Germanium dioxide is used as a catalyst in the industrial production of polymers, mainly PET, consuming approximately 30% of the world's germanium annual production in 2004 (AM). This is decreasing as a number of key manufacturers of PET are currently exploring and licensing the use of other catalysts based on aluminium and titanium that like germanium do not result in undesirable colouring of the plastic product (AS, AR).

Infrared optics

Germanium and its oxide are transparent to the infrared spectrum. The glass can be manufactured into infrared windows and lenses used for night-vision technology in the military and luxury vehicles. Germanium oxide is preferred over other IR transparent glasses because of its mechanical strength and is therefore more suited to rugged military usage (AT).

Fibre optics

Germanium tetrachloride is used as a doping agent in the core of a silica glass optical fibre to increase its refraction index, allowing optical data transmission through the fibre. Fibre optic communications are replacing copper wires as the technology is immune to electrical interference (cross talk), the data carrying capacity is greatly increased and only a single fibre is required compared with the two-way circuit required to complete copper wire-based communications (AS).

Electronics and solar applications

Germanium is also finding application in the photovoltaic industry in the form of so-called multi-junction solar cells. These are up to twice as efficient as conventional single-junction silicon solar cells with each layer of thin-film capturing a different part of the solar spectrum. Although originally designed for the space industry, their high efficiency means that they are finding increasing demand for ground applications (AU).

Recycling UK & Europe

Chemical and Technical Developments Ltd of Salisbury, Wiltshire recycle geranium bearing material including germanium metal, germanium dioxide and other germanium compounds. The majority of the scrap (95%) is from obsolete optical sources with the balance from the machining of infra-red lenses and other infra-red system components. The company also purchases and processes powders and pastes containing germanium dioxide (BH).

MCP recycle germanium from electronic scrap targets (FK).

PPM Pure (Germany) and Umicore (Belgium) also reprocess germanium containing components (BI,BJ) returned from the optical fibre manufacturing industries.

2.8 INDIUM

Background

Indium is a rare, very soft, silvery-white malleable metal with a relatively low melting point (156° C). Indium does not occur in mineral form in concentrations sufficient to warrant its exploitation in isolation but is produced from the by-product residues generated during processing of zinc ore (AW). It is also found in iron, lead, tin and copper ores but most of the deposits of these materials are currently not economic for extraction of indium (AZ) with the exception of Russian tin ores (BA).

The major producer of indium is China which in 2010 accounted for just over half of the world total output (AX, AZ). Republic of Korea, Japan and Canada are also producers of indium, with smaller amounts produced in a number of European countries (AZ).

Applications

Metallic indium

Metallic indium retains its malleability at temperatures approaching absolute zero, making it ideal for sealing in cryogenic and vacuum applications. It is commonly used in lead-free and in other specialist applications where advantage is taken of the ability of oxide-free indium to cold weld to itself and other metals (AX).

Indium-tin-oxide (ITO)

ITO is both transparent and colourless in thin layers. The oxide, which is a stable ceramic-like material and insoluble in water, is also conducting and can act as an infrared reflector (AX).

The oxide is used widely in the number of consumer electronics applications including liquid crystal displays, flat panel displays, touch panels, solar cells and organic light-emitting diodes. The thin-films of ITO are most commonly deposited by electron beam evaporation, physical vapour deposition, or a range of sputtering deposition techniques (AX).

It is estimated that ITO thin-film coatings account for between 50-80% of global indium consumption (AZ, AW, BB).

Other indium compounds

The semiconductor compound copper-indium/gallium-diselenide is finding increased application in thin-film solar cells as a consequence of its photovoltaic properties. Solar cells containing gallium-indium-arsenide exhibit high solar efficiency combined with low manufacturing cost (AX). The use of indium in such applications although still in its infancy is increasing.

Recycling UK & Europe

Metallic indium

AWA Refiners Ltd chemically refine and melt a variety of precious metals specialising in the refining of gold, silver, platinum, palladium, chromium, indium and ruthenium, but they process a number of other metals

Recapture Metals Ltd, a Canadian company with a German office, recycles indium alloys and solders.

ITO and other Indium compounds

The deposition of ITO by any of the currently available techniques is highly inefficient. It is estimated that only approximately 15% of an ITO target is deposited onto the substrate, the remainder is scrap. Typically end-users, such as flat panel display manufacturers establish contacts directly with the recyclers: the end-user supplying the recycler with scrap indium compound which is then purified and returned.

At present Umicore Ltd (Belgium) (AV) and Recapture Metals recover indium from spent targets used in the manufacture of solar cells.

The dissipative and widespread application of indium in post-consumer waste electronic equipment and solar cells means that its recovery is not currently economic. However Umicore Ltd (Belgium) is currently looking at the recycling of complete reject or end-of-life solar panels.

MCP Ltd (Wellingborough) recycles indium, sourced primarily from waste material from the deposition of ITO film (FK).

2.9 LITHIUM

Background

Lithium, a very reactive alkali metal with the lowest density of all solids at room temperature, is a relatively abundant element. It is silvery shining, soft and tough.

Originally produced from lithium-containing mineral ores, it is now extracted at lower energy cost from brines in salt lakes, which are becoming increasingly important as a commercial source of lithium. The dominant producer of lithium resource is Chile, with Australia, Argentina and China making significant contributions (BD). Small amounts of lithium are also sourced from Portugal and Spain (BC).

Applications

Lithium is used in a wide range of applications, with glass and ceramics currently dominating at just under 40% with batteries at 20% (BF), although other sources suggest 25% for batteries and 18% for ceramic glasses (BE). Worldwide lithium batteries are reported to power more than 60% of cellphones and 90% of laptop computers (BG).

Other applications include lubricating grease, air conditioning plant (as lithium chloride solution), pharmaceuticals, aluminium-lithium alloys, and aluminium smelting. With the ever-increasing interest in electric-powered vehicles the uses of lithium in batteries is likely to increase progressively in the coming years and will probably become dominant (BC).

Glasses and ceramics

Lithium is considered to be the ideal flux in glassmaking, and its use with other alkali fluxes allows producers to take advantage of the mixed-alkali effect to reduce fuel consumption and emissions, whilst improving glass quality (BL).

Lithium aluminosilicate glass ceramics are extremely resistant thermal shock and find application where this property is important, including cooker hobs, cooking ware, windows the gas or coal files, mirror substrates for astronomical telescopes, and missile nose cones. An essential feature of the glass is that it does not contain crystals. However by deliberately stimulating crystal growth in glass it is possible to produce the type of glass with a controlled amount of crystallisation that can combine many of the best features of both ceramics and glass (BK).

Batteries

Lithium is used in advanced primary (non-rechargeable) batteries where their high energy density, long shelf-life and ability to operate a temperature extremes makes them ideal for portable electronic equipment. The lithium, in metallic form, is used for the anode with a conductive organic electrolyte and manganese dioxide for the cathode (BO).

In the rechargeable lithium-ion batteries most designs use graphite for the anode. The cathode is made from either lithium manganese oxide, lithium iron phosphate, or lithium cobalt oxide. Lithium ions of a charged particle moving between them in an electrolyte that is often solid lithium salts plus an organic solvent (BP). In addition to the consumer market, a rapidly growing end-use is in electric cars where lithium batteries are expected to replace alternative hydrogen storage devices as the power source. At their UK plant in Sunderland Nissan manufacture lithium-ion batteries for their new electric vehicles which were launched earlier this year (BM).

Aluminium smelting

Numerous aluminium smelters in the world add lithium carbonate (1-3%) to the flux cryolite (Na3AlF6) bath to realize several benefits: reduction of the bath temperature as well as energy savings through higher conductivity and lower viscosity (BQ). The production capacity of a smelter can be slightly increased at the same operating conditions. The more modern facilities use a more acidic bath (high AlF3) composition instead and better scrubbing systems. These facilities do not require the addition of lithium (BQ).

Aluminium-lithium alloys

Aluminium-lithium alloys were developed primarily as direct replacements for existing aluminium alloys to reduce the weight of aircraft and aerospace structures. It has been realized that the most efficient way of doing this is to develop low density materials, since weight reduction through reduced component size often leads to low stiffness parts and reduced fatigue life. Typical components that benefit from low density alloys include structural members in airframes, aerospace vehicle skins, and liquid oxygen and hydrogen fuel-tanks in spacecraft. The addition of up to 2.5% lithium in commercial alloys gives limited but significant reductions in density (GB).

Recycling UK

Batteries

At present only lead acid batteries are fully treated in the UK. For portable batteries only part-treatment facilities are available and they are then sent mainly to Western Europe, but also to North America, for further treatment (BM). It is suggested that any new facility in the UK for treating lithium-ion batteries would currently find it difficult to source sufficient quantities of these batteries to feed a pilot plant facility (BM).

It should be borne in mind that approximately only 3% of portable batteries are treated in the UK (BM). Recent regulations have introduced targets for collecting 25% portable batteries by 2012 and 45% by 2016 (BN). This will require a significant increase in the collection and recycling of these batteries.

A mixed input of both nickel-metal hydride and lithium batteries is recycled at an Umicore owned Swedish plant. The pyro-metallurgical process is designed for the production of an alloy containing copper, iron, manganese, nickel and cobalt which is treated for the recovery of the main products nickel sulphate cobalt oxide. The lithium and aluminium contents of the batteries move into the slag phase as oxide, but are uneconomical to recover (BS)

Chemetall Lithium (Germany) has recently referred received government funding for the development of a pilot plant for the recycling of lithium-ion automotive batteries for electric cars (BT). In contrast to the pyro-metallurgical processes where lithium remains in the ash or slag residues and is not economical to extract, hydro-metallurgical processes will be used to facilitate very high recovery rates of lithium. A collection of approaching 100% of hybrid electric vehicle and electric vehicle batteries is anticipated as a consequence of the End of Legislation (BT).

In America a recycling company has produced a small quantity of lithium carbonate from solutions recovered during the recycling of lithium-ion batteries (BD). In addition a US company has recycled lithium metal and lithium-ion batteries since 1992 and was recently awarded a grant to construct the first US recycling facility for lithium ion batteries (BV)

Glasses and ceramics

The dissipative nature of the products in which lithium aluminosilicate glasses and ceramics combined with the low economic incentive for lithium recycling would account for the absence of any evidence of post consumer recycling of the products for their lithium content.

Aluminium smelting

It is currently not economic to recover lithium from the slag produced as a by product in the extraction of aluminium metal.

Aluminium-lithium alloys

The recovery of finished aluminium-lithium products from semi-fabrication facilities is generally somewhat lower than that of conventional aluminium alloy products. Some of the scrap produced by these processes is heavy, relatively easily segregated, and can be taken back for direct recycling into aluminium-lithium ingots. However the bulk is in the form of machining swarf, which is unsuitable for direct recycling because it is contaminated with other aluminium alloys.

2.10 MAGNESIUM

Background

Magnesium metal is relatively soft, silvery-white in colour and is the lightest of the metals in general use (BV). Magnesium finds widespread application where weight saving is at a premium, particularly associated with the ambition of car manufacturers to reduce the vehicles weight and CO_2 emissions according to EU policy.

Magnesium is one of the more common elements in the Earth's crust and, until recently, seawater provided almost 50% of the magnesium produced in the Western world. It remains a major source of magnesium oxide in many countries. Nowadays however, the production of magnesium metal is dominated by mineral resources (BV). In 2009 China produced over 80% of the world's production of magnesium (BW), but it is considered that the world reserve of magnesium-rich minerals, from which the metal can be refined, ranges from large to virtually unlimited, and are globally widespread.

The extraction of magnesium from the ore is however energy intensive and remelting of magnesium scrap saves more than 95% of the energy for primary production (BW).

Applications

Alloying with aluminium

Alloying with aluminium is the major principle use of magnesium in an industrial context, utilising over 40% of the refined metal. The 5000 series of aluminium alloys, used widely in marine applications because of their excellent corrosion resistance, may contain up to 5.5% magnesium. The body of the aluminium beverage can contains 1% magnesium, whilst the lid contains 4.5% magnesium (BW).

Structural metal

Magnesium-alloy products are manufactured both by conventional sand casting and die casting processes and are used mainly for automotive parts. Although pure magnesium is usually specified as a minimum of 99.8% Mg, it has been found that some of the early problems with accelerated corrosion of magnesium components, particularly in automotive under-body applications, were the result of impurities (GC). Thus since the early 80s corrosion-resistant, high-purity alloys have been favoured in the die casting industry, and have led to a dramatic increase in this method of magnesium alloy production.

Desulphurisation

Sulphur is generally considered as an undesirable element in steel and adversely affects a number of mechanical properties such as transverse toughness. Magnesium has a high chemical affinity for sulphur and also dissolves in the iron-carbon melt with the result that its reaction with sulphur is homogeneous. As a consequence addition of magnesium is the preferred option for desulphurisation of steel (CB).

Recycling UK & Europe

Alloying with aluminium

There is a well-established recovery chain in the UK for aluminium beverage cans, and as a consequence the magnesium content is recovered and used again for the manufacture of aluminium beverage cans. It should be noted however that in 2008 only 48% of the cans manufactured were recovered for recycling, and that only two thirds of those returned found their way back for direct recycling into can body stock (BX).

Structural metal

During the manufacture of magnesium sand and die castings a high proportion of the melt, typically 40 to 60% is scrap. This is in the form of runners which feed the castings. The foundry can sell the material on the open market, recycle material internally, or recycle the material externally (CC).

The demand for high-purity magnesium alloys for the majority of new applications suggest that unlike other materials, a two tier system of alloys i.e. primary and secondary, is unlikely to evolve. It is currently not possible to remove elements such as nickel and copper, which if present in small amounts can have a detrimental impact on the corrosion resistance of magnesium alloy (CD). Since the first stage of vehicle disposal is likely to be shredding rather than being dismantled and separated according to their alloy, this can pose a particular problem. As the use of magnesium casting increases and the end-of-life vehicle directive takes effect, second-generation components will begin to play an important role supply of magnesium. Up to 2007 however post consumer scrap had not been used for structural parts (BZ).

Magnesium Elektron UK (Manchester) will recycle high-grade processings and have recently developed technology to process lower grade material such as magnesium swarf and dross (CB).

At their plants in Bottrop (Germany) and Porsgrunn (Norway) Norsk Hydro provide the largest volume of remelt magnesium to the European market, - 35,000 t per annum in 2004 (BY).

Desulphurisation

In desulphurisation of steel the magnesium sulphide which is formed is dissolved within the slag and is not recovered.

2.11 NIOBIUM

Background

Niobium - a relatively light, ductile metal - is one of the five major refractory metals with a melting point in excess of 2000°C. Although it is found in niobium-rich complex minerals (CI), which are the most important for the production of niobium metal, the element is very similar to tantalum, and they often occur together in nature. In this case they are processed directly into ferro-niobium-tantalum master alloy (CG).

Over three quarters of the world's niobium production currently come from Brazil, with most of the remainder coming from eastern Canada (CI).

Applications

High-strength, low-alloy (HSLA) steels

The main use of niobium, over 80%, is in the steel industry where it is added as ferro-niobium to produce high-strength, low-alloy (HSLA) steels (CF, CI). HSLA steel is used in many applications where weldability and strength to weight ratio is important. HSLA steels are typically 20 to 30% stronger than the equivalent carbon steel. HSLA steels vary from other steels in that they are not made to meet specific chemical composition but rather to specific mechanical properties (CJ). Niobium is a small (typically 0.1%) but essential addition (CG).

HSLA steels are widely used for large pipelines for the transmission of oil and natural gas, in the automotive industry and also for structural applications such as bridges and cranes (CG).

Stainless steels

Small amounts of niobium may be added to certain stainless steels to lower the carbon content of the material to a level below which corrosion problems associated with subsequent welding of the steel are avoided. Titanium is more commonly used in the UK as alternative to niobium for this application and the levels employed are typically less than 0.4%

Nickel-based superalloys

Small amounts of niobium are added to selected nickel-based superalloys to improve high-temperature strength (CG). However it is estimated that this application makes up no more than 5% of the total use of niobium metal (CF).

Other applications

A number of niobium alloys exhibit superconductivity at cryogenic temperatures and are used in magnetic applications (CG, CI). Biocompatible titanium-niobium alloys are used as implants. Niobium is also added to hardmetals made from tungsten carbide/cobalt to improve their hot hardness and diffusion resistance against iron alloys (CI).

Niobium complexes are used as catalysts for producing bio-fuels from vegetable crops (CG, CI).

Recycling UK & Europe

No evidence for the recycling of niobium in either the UK or Europe has been identified. This is probably a consequence of the large volume of reserves to be found in Brazil, which is estimated to be up to supply current world demand for about 500 years (CG).

A method of recovering niobium from unclassified hardmetal scrap, along with other elements such as cobalt, tantalum and titanium has been developed (CH). It is not known whether it is employed in Europe.

2.12 PHOSPHORUS

Background

Phosphorus is a non-metal that when refined can exist in several different forms or allotropes. The largest source is phosphate rock (minerals containing high levels phosphors, typically tri-calcium phosphate) which is found in deposits of sedimentary origin, laid down originally in beds on the ocean floor. Some use is also made of phosphatic iron ore, from which the phosphorus is obtained as a by-product from the slag (FQ).

China is the major supplier of phosphate rock (35%) with the USA (15%), Morocco and Western Sahara (15%), and Russia (6%) contributing to the total extracted. The balance is made up from numerous other countries (FP).

Applications

Fertiliser

It is estimated that some 80% of phosphorus use is in agriculture, mainly as fertilisers. Phosphorus is one of the essential nutrients for plants, animals and humans, and its use as a fertiliser contributed to the green revolution in enabling food production at levels to meet the demands of the dramatically increasing population growth of the 20^{th} Century (FX). Low phosphorus levels in soils can reduce crop yields by well over 50% (FW)

Detergents

A Scottish report suggests that in 2008 domestic laundry cleaning products accounted for 25% of the phosphate entering waste water treatment works (FS). An EC Environment Directorate report recommends that there is a general ban on the use of phosphate-containing detergents and that this should be combined with implementation of the Urban Wastewater Treatment Directive (FT).

Metallurgical

The primary use of phosphorus in metallurgical applications is as additions to tin bronze as a de-oxidant of the molten material. A typical phosphor bronze can contain up to 1% phosphorus (FU).

Other applications include phosphate coating of steel for corrosion protection, electroless plating of nickel, and zinc and copper electroplating (FU).

Catalysts

Phosphors, as phosphoric acid is used as a catalyst in the production of propylene and pewter in polymers and ethyl benzene (FU).

Fire Retardants

Phosphorus-containing flame retardants cover a wide range of inorganic and organic compounds and include both reactive products which are chemically bound into the polymer material, as well as additive products which are integrated into the material by physical mixing only. Phosphorus-containing flame retardants are widely used in standard and engineering plastics, polyurethane foams, thermosets, coatings, and textiles (FR).

Recycling UK & Europe

The limited amount of addition to and the dispersive use of phosphorus-containing materials generally precludes recycling of phosphorus from original material.

Thames Water and Ostora Nutrient Recovery Technologies (Canada) have built and are operating Europe's first wastewater treatment facility that removes phosphorus, as well as nitrogen, and converts it into commercial fertiliser. A similar facility is under consideration in the Netherlands (FN).

It is also suggested that processing of organic waste through anaerobic digestion plants could be increasingly employed to recover the high levels of phosphorus, potassium and nitrogen, which improves soil fertility. The biogas captured during this process can also be converted into electricity and heat (FO).

Since 1999 sewage phosphates have been recovered at a plant near Edam, Netherlands for recycling into industrial products. Legislation regulating the discharge of phosphorus into surface and groundwater and also regulating the application of waste water sludge to agriculture are typically in place to protect the environment from discharges associated with sewage treatment works. This will become stricter in the future and will lead to a greater emphasis on the removal of phosphates from waste water and sludge (FM).

ASH DEC Umwelt AG (Austria) has developed a process that extracts phosphorus fertiliser from ash that is generated as a by-product of the incineration of biomass/sludge (FU).

2.13 Platinum-Group Metals

Background

The platinum-group metals comprise six closely related metals: platinum, palladium, rhodium, ruthenium, iridium, and osmium, all of which are very rare metals in the Earth's crust. They commonly occur together in nature and are among the scarcest of the metallic materials. Of these, ruthenium, rhodium and palladium are known as the light platinum metals. All of the platinum-group metals have similar chemical and physical properties, such as high melting point, low vapour pressure, high temperature coefficient of electrical resistivity, and low coefficient of thermal expansion. In addition the platinum-group metals exhibit strong catalytic activity (CK, CL).

Platinum-group metals occur and are mined together as coupled elements with platinum and palladium as the major metals, with rhodium and ruthenium making up approximately 10% of the recovered metal, and iridium and osmium markedly lower. The platinum-group metals are also extracted as a by-product from the mining of nickel.

The major producers of the platinum-group metals are South Africa with approximately 70% of world production and where their production now exceeds that of gold, and Russia (CY, CT).

Applications

Automotive catalytic converters

An auto catalytic converter reduces the emission of harmful gases, such as carbon monoxide, hydrocarbons and nitrogen oxides. During the catalytic process these gases are transformed into carbon dioxide, water and nitrogen. For efficient working a large active surface of catalytic converter is essential. This surface is created by use of a carrier with a honeycomb structure. The carrier consists of the ceramic or metallic substrate coated with aluminium oxide wash coat in which the platinum-group metals are suspended (CU). A typical automotive converter contains approximate 1.5 g of platinum or palladium. Either metal is an effective catalyst and the selection will depend on economic factors.

In 2010 there were 2.2 million new vehicle registrations in the UK (GD) and the requirement for the fitting of a catalytic converter has been in place since the early 1990s (GE). Worldwide, catalytic converters account for in excess of 50% of the main end use markets for platinum group metals. Catalysts for diesels use platinum rather than mixtures of platinum and palladium commonly used in petrol catalysts.

Jewellery

Platinum-group metals are used in jewellery, coinage and other investment applications, where they make up approximately 20% of the end use market. The jewellery is typically a minimum of 85% platinum with additions of palladium, ruthenium and iridium together with cobalt and copper to optimise the working characteristics and wear properties (CS).

Petroleum and chemical catalysts

Platinum-group metals are used widely as a catalyst for the production of many products. Examples include naphtha reforming for the production of petrol, the production of hydrogen peroxide and the manufacture of many chemicals, including vitamins, dyes and scents, as well as fertiliser for food production (CT).

Electronics and electrics

The platinum-group metal palladium is widely used in electronic applications on account of its electrical conductivity and its durability. Palladium-containing components are used in virtually every type of electronic device, from basic consumer products to complex military hardware. The largest volume of palladium use in electronics sector is in multi-layer ceramic capacitors. Smaller amounts of palladium are used in conductive tracks in hybrid integrated-circuits and for plating connectors and lead frames used to connect integrated circuits to other electronic devices. In addition, components inside computers are linked by connectors plated with a conductive layer of precious metal. Palladium is used as an alternative plating material to gold for connectors as it has a low density so less weight of metal is required for a coating similar thickness (DB).

The vast majority of computer hard disks use platinum additions to the cobalt magnetic alloy used in the manufacture of the discs (CV).

Dental alloys

Platinum and to a much greater extent palladium are the principal platinum-group metals used in dental restorations. The metals are usually mixed with gold or silver as well as copper and zinc in varying ratios to produce alloys suitable for dental inlays, crowns and bridges. Small amounts of ruthenium or iridium are also sometimes added (DA).

Recycling UK & Europe

Automotive catalytic converters

Automotive catalysts converters are a particular important source for recycled platinum-group metals, and quantities continue to rise as the number of end-of-life vehicles with catalytic converters steadily increases. The mandatory removal of autocatalysts from end-of-life vehicles supports the recycling of the platinum-group metals but does not affect those cars which are exported from the EU. The ceramic or metallic automotive catalysts are removed from their steel special cutting devices, and the steel is then sorted by quality and sold as secondary scrap to steel plants. The catalyst with the precious metal is subsequently processed at precious metal refineries (CM).

In the UK Johnson Matthey recycles platinum-group metals from pre-processed automotive catalyst converters, with Platinum Recoveries Ltd specialising in recovering and recycling the platinum from the converter (CO), which is sent for refining in the UK, Japan and USA depending on market prices (FL).

A number of other companies will accept used converters but just sell them on.

More recently attention has been focused on the platinum-group metals that are lost from vehicle catalytic converters during everyday driving. Much of this ends up as road dust, which is collected but not currently recycled and often ends up in landfill sites. Options for recovering the platinum-group materials are being explored currently by Birmingham University (CN, CW).

Jewellery

Relatively little metal is returned by consumers for recycling in Europe, North America or the Rest of the World regions (CR).

Petroleum and chemical catalysts

In most applications, more than 90% of the platinum-group metals used as industrial process catalysts is recycled. Most industrial users keep property of the platinum-group metals throughout their life-cycle returning the waste catalysts for refining and receiving equivalent material in return. Material is brought only to cover life-cycle losses or market growth.

Johnson Matthey and Engelhard Sales refine spent catalytic material (CP, CZ). In addition Tetronics Ltd (Swindon) use patented plasma waste recovery technology for the design of plants to smelt and preferentially separate the precious metals from the less valuable material, which is vitrified into an inert, safe, disposable, non-hazardous material in a single processing step (CX).

JBR Recovery Ltd (West Bromwich) also accept gold and platinum-group metal bearing ceramic substrates for refining.

Electronics and electrics

Johnson Matthey offer a general refining service for electronic waste containing platinum-group metals (CR). A service specifically for scrap computer boards is offered by AWA Refiners Ltd (Harlow) who chemically refine and melt process (CQ).

There is disagreement as to whether the EU WEEE directive currently provides incentive for the recovery of platinum group metals as they are mass-based recycling targets. This limits the optimum access to platinum-group metal containing components for subsequent recovery of these metals. Nevertheless Europe remains the largest market for recovery of platinum and palladium from scrap electronics (CR)

Dental alloys

Johnson Matthey accept scrap material from the production of dental alloys returned for recycling by the manufacturers (CP).

2.14 Rare Earth Elements

Background

The rare earth elements (REE) are a group of 17 chemically similar metallic elements, including the non-lanthanides scandium and yttrium. They can be divided into two groups: the light REE e.g. neodymium, lanthanum, cerium) and the heavy REE (dysprosium, terbium). Scandium and yttrium are considered as rare earths as they have similar chemical and physical properties (DH). The light REE are more abundant in many deposits and are typically easier to extract, nevertheless all rare earth elements are cost intensive to produce in pure form (DC).

The term rare earth is a misnomer arising from the rarity of the minerals from which they were originally isolated from. The REEs are relatively plentiful in the Earth's crust having an overall crustal abundance greater than silver with the more abundant having a similar crustal abundance to copper, although the crustal abundance of individual REE varies considerably (DC).

Currently China produces approximately 97% of world supply of the REEs (DL) but is reducing exports, and increasing prices to foreign consumers, although there are currently no Chinese export quotas on downstream goods. Imports to the UK are very limited as it has only a small rare earth processing industry (DD).

Applications

Although widely used, many applications of rare earths require relatively small amounts of material.

Permanent Magnets

An increasingly important use of REE is in high strength permanent magnets, accounting for just over 21%. This is likely to increase significantly in the future with the emphasis on power generation from wind turbines, which currently use 250-600 kg of neodymium magnets per megawatt (DM). Neodymium magnets are also considered essential for hybrid cars with the electric motor in a previous requiring 1 kg of neodymium. In addition there are numerous small electric powered motors in modern automobiles to operate such equipment as fuel management systems (DH).

Catalysts

Catalysts account for a significant share, approximately 20%, of the uses of REE. Cerium carbonate and cerium oxide play a critical role in the chemical reactions within the autocatalyst. They also increase the effectiveness and reduce the amount of platinum and other precious metals required (DH).

REE are also important in fluid cracking catalysts which are used in the process of refining crude oil to petrol and other fuels (DH).

Metallurgical alloys

REE have major applications in metallurgical alloys, accounting for 18% of global consumption in 2008. Mischmetal, a mixture of rare earth elements and cerium, is commonly used as minor alloying additives for controlling the shape of inclusions in steels (DI). The addition of REE also enhances the oxidation resistance of certain iron, nickel or cobalt-based superalloys (DH).

REE are used in nickel-metal hydride rechargeable batteries that power many electronic products. A mixed rare earth metal alloy, in which lanthanum dominates, is used as the anode in the nickel-metal hydride battery (DK).

Phosphors

REE are common additions to the phosphors used in televisions, computer screens and any other visual display devices that require cathode ray tube, liquid crystal display or plasma display panel technologies.

Energy efficient lighting is another major application of REE phosphors, and more recently REE phosphors are being used for white LEDs (DH).

Glass and polishing

REE are commonly used in the glass industry, accounting for 22% of total REE consumption in 2008. The addition of cerium to the glass is necessary to counteract the yellow-green colour caused by the ever present iron oxide impurities. Other REE are used to give glass a variety of colours (DH).

Substantial amounts of cerium concentrates and oxide are used to polish glass surfaces. Cerium is especially suitable as a polishing agent as it removes glass by both chemical dissolution and mechanical abrasion (DK).

Ceramics

REE oxides are essential in ceramics, acting as both stabilisers and sintering aids to reduce sintering temperature and production costs. Rare earth oxides are also used in functional ceramics such as semiconductor sensors, microwave dielectric and piezoelectric ceramics (DH).

Recycling UK & Europe

Until recently the recycling of REE was a very uncommon issue. An analysis by the Oko-Institut conducted for United Nations Environment Programme on critical metals reported that only very small quantities of rare earths with pre-consumer origins (permanent magnet scrap), where recycled, although it is estimated that 20-30 % of the rare earth magnets are scrapped during manufacture, with no recovery of the rare earths from the production waste (DJ). No indications of any post-consumer recycling of rare earth containing products were found. Although abundant qualities of rare earth metals already exist above ground in the form of obsolete, consumer technology, with an estimated 30 million computers and laptops containing these metals currently lying unused in the UK, there is no active commercial recycling program in the UK. (DC)

In the UK work at Birmingham University has studied the possibility of using hydrogen decrepitation to turn used neodymium-iron-boron magnets into a powder which can then be reprocessed into sintered magnets with properties comparable to the start material (DG). Other techniques such melt-spinning are also being investigated (DN).

Some work is being carried out in Germany to assess the feasibility of recovering rare earth metals from the slag of the pyro-metallurgical treatment of used nickel-metal hydride batteries. In France the speciality chemical company Rhodia has developed a process to recycle several rare earths from the powders found in fluorescent light bulbs. They plan to have the metal recycling process up and running by 2012 (DF).

In America GreenRock Rare Earth Recovery Corporation expect to have four processing facilities to recover rare earth elements from components found in obsolete and end-of-life electronics by the end of the current year (DE).

2.15 Tantalum

Background

Tantalum is a refractory metal, with a the melting point of about 3000° C, that is ductile, easily fabricated, and a good conductor of heat and electricity. It is also highly resistant to corrosion by many organic and inorganic acids as a consequence of the formation of a thin film of tantalum oxide which rapidly forms on the metal. The tantalum oxide layer is also used as a dielectric substance for electrolytic capacitors (DP).

The principal source of tantalum is a series of minerals that contain niobium, iron, manganese and tantalum oxides. The main producer in 2010, not counting central Africa, was Brazil with 90% of mined production (DO). A key issue is the continuing supply of low-cost columbite-tantalite (coltan) mined in central Africa, and mostly sold illegally to fund rebel militias. The major processors will not knowingly by such material and almost all of it is reported to go to China (DQ).

Tantalum is also produced as a by-product during tin smelting, and refining of tin slags currently accounts for in excess of 10% of total production (DS).

Applications

Capacitors

The miniaturisation of consumer electronics and its components has driven the growing market for the capacitor-grade tantalum powder which comprises about 60% of all tantalum shipments(DP, DV). The use of ‘dry’ tantalum capacitors in electronic circuits is a consequence of the capacitors high reliability, high capacitance in a small volume, and good temperature stability at the temperature range is required by modern electronic applications.

Tantalum capacitors have become the standard in new laptop computers, multifunctional cell phones, wired and wireless infrastructure for mobile telephony, and mobile handheld devices (DP, DU, DV, DY). Tantalum capacitors are made by sintering tantalum powder around a tantalum wire to form an open pore structure. The material is then anodised to form a dielectric oxide coating on the titanium, and a layer of manganese dioxide is then deposited to act cathode. More recently produced tantalum capacitors now incorporate a conductive polymer counter-electrode (DY).

Hardmetals

Tantalum carbide is one of the basic hard materials, along with carbides of tungsten and titanium, employed in cutting and boring tools. It increases thermal shock resistance and reduces high temperature oxidation of the tools. This application consumes approximately 12% of tantalum production (DP, DY).

Superalloys

Tantalum is a component of superalloys, at levels 3-11%, for the high-temperature parts of aero engines and gas turbines. It improves structural integrity and allows higher operating temperatures and hence greater efficiency (DP). Tantalum in superalloys accounts for approximately 14% of the global market (DT).

Industrial equipment

The high corrosion resistance, strength and high thermal conductivity of tantalum has lead to its use in equipment for the chemical industry and heat exchangers, and in finished components such as screens and crucibles. The most common alloy employed is tantalum-2.5% tungsten which is stronger than pure tantalum. Approximately 5% of tantalum is used for such applications (DP).

Medical

Tantalum is non-toxic and inert to body fluids and is thus highly compatible with human tissue. It is used for prosthetic implants such as hip joint, plates, suture clips and the mesh for tissue repair (DY).

Recycling UK & Europe

Capacitors

The manufacture of tantalum capacitors involves several stages of production, and at each stage the product is tested for electronic characteristics. The rejection rate varies with the type of capacitor but is typically 20%. Any tantalum material that is rejected from capacitor production is fully recycled (DS). It should be noted however that there is no manufacture of tantalum capacitors in the UK, although Germany has a number of plants.

Recycling from discarded tantalum-containing electronic equipment has not been developed to a significant degree. The ongoing miniaturisation of electrical capacitor in electronic devices leads to dissipative problems. Each capacitor contains less tantalum, but the number of manufactured tantalum conductors is progressively increasing. In addition it is technically problematic to recover tantalum from old scrap, and due to its chemical characteristics tantalum oxidises easily and during pyro-metallurgical recycling processes is lost into the slag phases (DR). Umicore do not recover tantalum in their current refining processes of electronic scrap (DR).

The Tantalum-Niobium International Study Centre (ICT) suggest that a significant percentage of tantalum capacitors in finished electronic devices such as cell phones and personal computers are also recycled. These devices are collected in the West and sent to Asia where they are dismantled by hand. The recovered tantalum metal is resold on the open market (DS).

Hardmetals

Clean cemented carbide inserts and compacts are converted to powder by the zinc process which dissolves the cobalt phase, leaving a spongy material which is easily crushed. The crush powder is added back to the manufacture of ready-to-press powder. This process does not only recycles tungsten carbide (the major component of hardmetals), but also titanium carbide together with other carbides and cobalt (DX, EN, EP).

There is currently no tungsten processing plant in the UK (EK) and the majority of scrap from all sources, which would include tantalum carbide bearing material, is exported to other countries for reprocessing.

Superalloys

No information has been found specifically relating to the recycling of tantalum containing superalloys.

Buss & Buss Spezialmetalle Gmbh in Germany recover and upgrade tantalum, although their main business is the recycling of rhenium from superalloys parts and scrap (DZ).

Industrial equipment

No information has been found specifically relating to the recycling of tantalum containing material used in industrial equipment. There are however a number of companies that will purchase scrap tantalum material for export, with HC Stark (Germany) offering a recycling capability (CZ).

Medical

Until recently after cremation it was accepted practice for metal remains, such as implants, to be gathered and disposed of in the grounds of the crematorium. The Institute of Cemetery and Crematorium Management will now collect these metals from participating crematoria for recycling (DW).

2.16 Titanium

Background

Titanium is a relatively low density metal with high mechanical strength, high melting point and high resistance to many chemicals including acids and salt water. The combination of a high strength to weight ratio combined with good corrosion resistance make titanium and titanium alloys important for many applications, for example in the aircraft industry or medicine (GF).

Titanium is the ninth most common element in the Earth's crust with widely distributed ores. The principal sources for titanium minerals are South Africa (44%), Australia (34%) and Canada (12%) (EA). In 2009 the world's capacity for production of titanium dioxide far outweighed that of titanium metal (5.5 million compared with 250,000 tonnes) (EH). The principal suppliers of titanium sponge in 2006 were Japan (31%), Russia (20%), Kazakhstan (18%) and China (11%) (GA).

The extraction of titanium metal is a very energy intensive process (EA), and a number of alternative, low-cost extraction technologies are being evaluated and are expected to be in the pilot-plant stage of development later this year (EB, EE).

Applications

Titanium dioxide

Titanium dioxide is mainly used for white pigments. It is non-toxic and is therefore used in many diverse applications such as cosmetics, food industry, enamels and plastics (EE).

Industrial Applications

Approximately 50% of current demand for titanium metal comes from the offshore, chemical/petrochemical, pharmaceutical, power generation and water treatment sectors. The primary reason for the use of titanium in these sectors is for corrosion resistance, as a consequence of the very tenacious surface oxide layer. For example in power generating plants, where saline, brackish or polluted waters are used as the cooling medium, titanium thin wall condenser tubing will last for the life of the condenser (typically 40 years) and eliminate the need for a corrosion allowance (EF).

Aerospace

As a consequence of its high strength to weight ratio and excellent corrosion resistance, titanium is used in structural airframe applications ranging from massive, highly-stressed, forged wing structures and landing gear components to springs and hydraulic tubing (ED).

The largest single application of titanium is its use in gas turbine aircraft engines. Titanium is the most common material of choice for engine parts to operate up to 600° C. Titanium-based alloys make up 20 to 30% of the weight of an engine, primarily in the compressor. Specific titanium components in an engine include wide chord fan blades, hubs, inlet guide vanes and cases (EC).

Medical Applications

Titanium is completely inert to human body fluids, making it ideal for medical replacement structures such as hip and knee implants. Titanium also allows bone growth to adhere to the implants, so they last longer than those made of other materials. Reconstructive titanium plates and mesh to support broken bones are commonly used today (EG).

Recycling UK & Europe

Titanium Dioxide

The dissipative use of titanium dioxide in a variety of consumer-based applications means that recycling to recover the material is currently not an option.

Titanium metal

Titanium is not produced within the European Union, and all metal sponge used in the UK is therefore imported - mainly from the USA, Russia and Japan. All primary processing in the UK is carried out at Timet UK in Birmingham, using conventional double and triple melt VAR processing. The UK does not have any production scale cold hearth melting facilities (EA).

There are a number of companies that carry out secondary processing of titanium (the conversion of ingot to billet slab form and further processing into near-finish shape, dominated by forging). Casting the titanium alloys in the UK is only carried out by Castings Technology International in Sheffield (EA)

There are a number of companies in the UK that specialise in the recovery of titanium and other metals from end of life aero engines, such as Caledonian Alloys, SOS Metal UK Ltd (who are working closely with Rolls-Royce), Cronifer UK Ltd and Ireland Alloys Ltd. In addition there are numerous scrap metal facilities that will accept titanium from other sources as well as many other metals.

Until recently after cremation it was accepted practice for metal remains, such as implants, to be gathered and disposed of in the grounds of the crematorium. The Institute of Cemetery and Crematorium Management will now collect these metals from participating crematoria for recycling (DW).

2.17 TUNGSTEN

Background

Pure tungsten is a shiny white metal and in its purest form is quite ductile and can be easily processed. However it usually contains small amounts of carbon and oxygen, which give tungsten metal its considerable hardness and brittleness (EI). Tungsten metal has the highest melting point of all the non-alloyed metals, and the second highest of all the elements after carbon. In addition it has a very high density- almost 20 times that of water and one and three-quarter times that of lead (EI).

China is by far the major supplier of tungsten, in the form of refined ammonium paratungstate, with over 85% of world production. Other suppliers include Russia, Bolivia and Austria (EJ, EL). There is currently no tungsten processing plant in the UK (EK).

In the production of tungsten metal, ammonium paratungstate is oxidised to tungsten trioxide which in turn is then reduced in hydrogen furnaces to give tungsten powder. The powder is not smelted directly because of the very high melting point of tungsten but is pressed into piles, which are hammered and rolled at high temperature to compact them and make them ductile (EM).

Applications

Hardmetals

Hardmetals consist of tungsten carbide and cemented carbides, which are formed from tungsten carbide and cobalt and occasionally other metal carbides such as titanium, tantalum and niobium. They are very hard materials that are used for cutting, drilling and wear-resistant parts or coatings, and make up over 50% of the main global use of tungsten (EM).

The main application of hardmetals is in the metal-working, mining and petroleum drilling industries. Cemented carbides are not only very hard abrasion resistance, but also very tough. As a consequence they have widespread applications in high-tech tools, wear parts, and mining and stone-cutting tools (EM).

Steel and other alloys

Specialist steel alloys, with tungsten additions, are largely utilised in metal cutting and specialist engineering applications where hardness and strength are required, particularly over a wide temperature range (EM).

Superalloys

Tungsten is a minor component of a limited number of nickel-based and cobalt-based superalloys. The main effect of its addition is to improve strength at high temperatures (EM).

Tungsten and alloys

The combination of extremely high melting point, good conductivity and ductility of pure metallic tungsten makes it ideal for electrical and electronic applications, most noticeably in incandescent light bulb filaments, vacuum tubes and heating elements. In medical x-ray tubes both the filament and target is usually tungsten or tungsten alloy. Unalloyed tungsten is also used in electronic circuit interconnects, filaments in a vacuum-metallising furnaces, and its high melting point is the basis for the use of tungsten electrodes in tungsten inert gas (TIG) welding.

Heavy metal alloys are mostly tungsten-nickel-iron. The combination of high density, high strength combined with high radiation absorption capability make them well-suited for a variety of defence and civilian applications including x-ray and radiation shields, vibration damping devices, medical devices for radioactive isotope containment amongst many other (EO).

Tungsten-copper alloys are dense, easy machinable materials with excellent thermal and electrical conductivity. They are widely used in electrical and aerospace industries in applications such as electrical contacts, high voltage switches and circuit breakers (EM).

Catalysts

Tungsten has a number of roles as a catalyst including the removal of nitrogen oxides from combustion power plant stack gases, by their conversion to harmless nitrogen and water vapour. Tungsten-based catalysts are also used for hydrocracking, removal of sulphur from, and hydronitrification of mineral oil products, thus maximising recovery of light fuels from heavy crude. In addition the products are made more environmentally friendly by reducing the content of aromatic hydrocarbons, sulphur and nitrogen compounds (ER).

Recycling UK & Europe

Hardmetals

Clean cemented carbide inserts and compacts can be converted to powder by the zinc process. The items are loaded into molten zinc which dissolves the cobalt phase and can then be distilled off. The remaining spongy material is crushed and added back to the manufacture of ready-to-press powder. This process not only allows the recovery of the tungsten carbide, but also the other minor carbide additions such as tantalum carbide (DX).

Contaminated cemented carbide scrap, turnings, grinding is and powder scrap can be oxidised and chemically processed to the start material for the refinement of tungsten metal (ammonium paratungstate) in a method similar to that used for the processing of tungsten ores (DX).

Ceratizit SA (Austria) (EN) recycle both hard carbide scrap and soft carbide scrap (powder scrap, pre-sintered residuals and sludge that contains tungsten carbide), by two different routes. Ticomet Oy (Finland) (EP) also offer a recycling service for solid tungsten carbide scrap.

Steel and other alloys

It is reported that the recycling of tungsten in high-speed steel is high that a typical melt contains 60 to 70% of scrap, including internally generated scrap.

Tungsten and alloys

Major UK suppliers of tungsten and tungsten alloys include MG Sanders and Mallory.

Catalysts

Centaur Metals and Alloys Ltd (EQ) accept spent catalysts containing tungsten, although the market supply is reported to be very limited (FY).

General

There are a number of companies in the UK that specialise in the recycling of tungsten and/or tungsten carbide scrap. These include Centaur Metals, UK Carbide Recycling, Mormet, and Wilbury Metals Ltd.

3. SUMMARY OF PRODUCING COUNTRIES, APPLICATIONS AND RECYCLING

3.1 ANTIMONY

Principal countries of supply	Material form	Applications	Recycling	Scale of Re-cycling in UK	European capability
China (80 %)	Metallic *Lead alloy*	Wet-cell batteries	Recovered as by-product in smelting of lead battery scrap	High (PC)	
	Chemical *Antimony trioxide*	Flame retardant for plastics, etc	Dissipative use of flame retarded plastics generally precludes recycling of antimony but potential recovery process identified. Presence does not interfere with subsequent recycling of plastic	Low (PC)	Low
		Catalyst - used in production of PET but likely to be replaced by titanium		Unknown	Unknown

3.2 BERYLLIUM

PRINCIPAL COUNTRIES OF SUPPLY	MATERIAL FORM	APPLICATIONS	RECYCLING	SCALE OF RE-CYCLING IN UK	EUROPEAN CAPABILITY
USA (80%)	Copper-beryllium	Electrical contacts, springs, plastic moulding tools	New scrap material is returned to USA for recycling. Beryllium is not recovered in the current process for recycling old electronic scrap.	No capability	Unknown
	Nickel-beryllium	High-temperature springs	New scrap material is returned to USA for recycling.		
	Beryllium-aluminium alloy	Electronic applications in the avionic sector	New scrap material is returned to USA for recycling		
	Beryllium	Defence and aerospace sectors including high-speed aircraft, helicopters, missiles, and the nuclear industry.	Non-nuclear new scrap material is returned to USA for recycling		
	Beryllium oxide	High thermal conductivity insulator for electronic applications	Both new and old scrap material is returned to USA for recycling.		

3.3 Carbon fibre

Principal countries of supply	Material form	Applications	Recycling	Scale of Re-cycling in UK	European capability
Japan (.75%)	Carbon fibre for prepeg or thermoset composite	*Aerospace* - fuselage and wing structures	UK facility for manufacture of short fibre by pyrolysis and pelletising. UK university-based investigation in to use of supercritical fluids to extract carbon fibre and recover polymer resin	High (PM)	
		Wind energy - spar, shell, root and nacelle			
		Automotive - Body shell, and suspension of performance cars			
		Marine – Hull and masts of racing dinghies and yachts			
		Industrial – Large, single-span, driveshafts			

3.4 Cobalt

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
Refined cobalt China (25%) Finland (15%) Canada (10%) Cobalt ore Congo (50%) Zambia (15%)	Cobalt alloy	Superalloy	Number of companies closely associated with the aerospace industry recycle cobalt-base superalloys	High (PM)	
		Magnetic alloy	Swift Levick Magnets will accept own cobalt-bearing magnetic material and defined material from other suppliers	High (PM)	
		Prosthetics	Implant material collected from participating crematoria	Unknown	Unknown
		Hardmetal	Ceratizit SA and Ticomet Oy recover cobalt from hardmetal scrap	No capability	High (PM & PC)
		Nickel-metal hydride batteries	Umicore recover cobalt from lithium-ion and nickel-metal hydride batteries	No capability	High (PC)
	Chemical compound	Lithium-ion batteries – cathode contains 60% cobalt oxide			
		Catalysts - sulphur removal in petrochemical refining, conversion of natural gas to diesel fuel, and manufacture of plastics	Spent catalytic material is collected for refinement in OECD countries, primarily Germany	Unknown	High

3.5 Fluorspar

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (50%) Mexico & South Africa	Acid-grade fluorspar	Manufacture of hydrogen fluoride	Fluorspar is consumed, and can not be recycled.	Not applicable	
	Metallurgical-grade fluorspar	Improves fluidity of slag in steel making. Conductive slag for aluminium refining. Manufacture of cement	Fluorspar is consumed, and can not be recycled.		
	Ceramic-grade fluorspar	Manufacture of flint glass, enamels and fibreglass insulation. Coatings on welding rods	Not recycled due to dissipative nature of applications		

3.6 Gallium

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (32%) Germany (19%) Kazakhstan (14%) Russia (10%)	Metal	Very limited	Accepted for recycling in UK	High (PM)	
	Gallium arsenide	High efficiency solar cells, high brightness LEDs	Recovered from post-manufacturing scrap from deposition processes such as sputtering.		
	Gallium nitride	Electronics, blue laser diodes, high brightness LEDs	Recovered from post-manufacturing scrap		

3.7 Germanium

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (80%)	Germanium dioxide	Polymerisation catalysts	Being replaced by aluminium and titanium- based catalysts		
	Metal & oxide	Infrared optics	Recovered in UK from post-manufacturing waste and returned government equipment	High (PM & PC)	
	Compound	Fibre optics	Recovered in Germany and Belgium from post-manufacturing waste	No capability	High (PM)
	Germanium arsenide	High efficiency solar cells	Recovered from post-manufacturing scrap from deposition processes	High (PM)	

3.8 Indium

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (52%) Republic of Korea (14%) Japan (12%) Canada (6%)	Metal	Lead-free solder			
	Indium-tin-oxide	LCDs, touch panels, solar cells, organic LEDs	Recovered in the UK from post-manufacturing waste from deposition process	High (PM)	
	Gallium indium arsenide & copper-indium/ gallium-diselenide	High-efficiency, low-manufacturing cost, solar cells	Umicore (Belgium) are investigating recovery from post-manufacturing reject and post-consumer end-of-life solar panels	Low - no capability	High (PM & PC)

3.9 Lithium

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
Chile (30%) Australia (30%) China (20%) Argentina (10%)	Metal	Batteries (non-rechargeable)	Lithium is currently not recovered in battery recycling operations in Europe	No capability	No capability
		Aluminium-lithium alloys		Unknown	Unknown
	Compound	Batteries (rechargeable)	Lithium is currently not recovered in battery recycling operation in Europe. Chematall Lithium have a hydro-metallurgical pilot plant for recovery of lithium from electric vehicles.	No capability	No capability
		Glass	Dissipative use precludes recycling of lithium	Not applicable	
		Flux for ceramics and aluminium smelting	No evidence for recovery of lithium	No capability	Low - no capability

3.10 MAGNESIUM

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (72%)*	Alloyed with aluminium	Beverage cans	Well-established recovery chain in the UK	High (PC)	
* 2006 figures for primary metal	Magnesium alloy	Automotive industry for weight reduction	Magnesium is recycled from high-grade processings.	High (PM)	
			Magnesium Elektron recently developed technology for recovery of swarf and dross.		
			ELF disposal processes could have serious consequences for recovery of magnesium alloys		
	Metal	Desulphurisatio n in steel making	Metal is lost to slag and can not be recycled.	Not applicable	

3.11 NIOBIUM

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
Brazil (>75%) Canada (rem)	Alloying addition	High strength low alloy steel	No evidence of recycling in UK or Europe, but implant material collected from participating crematoria	Low - no capability	Unknown
		Stainless steels			
		Nickel-based superalloys			
		Medical implants			
	Metal alloy	Superconductin g magnets			
	Metal compound	Catalysts			

3.12 PHOSPHORUS

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (35%) USA (15%) Morocco & Western Sahara (15%) Russia (6%)	Compound	Fertiliser	Recovered from waste water, anaerobic digesters and incinerated green waste and sludge	High	
		Detergent	Not recovered directly but see above	Not applicable	
		Metallurgical	Dissipative use precludes recycling		
		Catalyst			
		Fire retardant	Dissipative use precludes recycling		

3.13 Platinum-Group Metals

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
South Africa (55%) Russia (30%)	Metal	Automotive catalytic converters	Converters removed, processed and material sent for refining in UK and world-wide. Recovery of platinum from road sweepings under investigation	High	
		Petroleum and chemical catalysts	Very high proportion recovered by UK recycling operations. Material refined worldwide.	High	
		Electronics and electrics	General scrap recovered and refined. Scrap computer board material refined in UK	Medium	
	Metal alloy	Jewellery	Little returned for recovery	Not applicable	
		Dental alloys	Recovered from manufacturers' scrap	High	

3.14 Rare Earth Elements

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (>97%)	Metal	High strength permanent magnets	No chain of recycling identified. Birmingham University have demonstrated successful recovery using hydrogen decrepitation	No capability	No capability
		Catalysts (both vehicle and fuel refining)	No chain of recycling identified	No capability	No capability
	Metal	Steel (inclusion modifying) Phosphors in white LEDs Ni-MH Batteries			
	Metal & oxides	Glass polishing			
	Oxides	Functional ceramics (eg piezoelectric)			

3.15 Tantalum

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
Brazil (90%)	Metal	Industrial equipment		No capability	High
	Alloy	Medical	Implant material collected from participating crematoria	Unknown	Unknown
	Alloying addition	Superalloys		Unknown	Unknown
	Metal & compound	Capacitors	Not recovered in Europe from electronic scrap	No capability	No capability
	Carbide	Hardmetals	Recovered as carbide by Ceratizit SA and Ticomet Oy	No capability	High

3.16 TITANIUM

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
Titanium mineral: South Africa (44%) Australia (34%) Canada (12%) Titanium sponge* Japan (31%) Russia (27%) Kazakhstan (18%) China (11%) * 2006 figures	Titanium dioxide	White pigment for cosmetics, food industry, enamels and plastics	Dissipative use of products precludes recycling	Not applicable	Not applicable
	Metal & alloy	Offshore, chemical/ petrochemical, pharmaceutical, power generation and water treatment sectors		Unknown	Unknown
	Titanium alloy	Structural airframe, wing structures, landing gear components, gas turbine engines		Unknown	Unknown
		Medical implants	Implant material collected from participating crematoria	Unknown	Unknown

3.17 TUNGSTEN

Principal countries of supply	Material form	Applications	Recycling	Scale of re-cycling in UK	European capability
China (>85%)	Tungsten carbide	Cutting, drilling and wear resistant tools and coatings	Ceratizit SA (Austria) and Ticomet Oy (Finland) recover tungsten and tungsten carbide from post manufacture and post consumer scrap	No capability	High
	Alloying addition	High-speed steels		Unknown	Unknown
	Tungsten metal and alloy	Balancing weights, welding electrodes		Unknown	Unknown
	Tungsten compound	Catalyst for removal of nitrogen dioxide, and in petroleum industry	Material collected in UK is exported for recovery elsewhere.	No capability	High

4. Observations on Current Recycling Practice

In their recent submission to the parliamentary enquiry into strategically important metals the Research Councils UK, a partnership which represents the seven UK research councils, made a number of points. They referred to strategically important materials on the basis of their driving technologies, and specifically identified antimony, cobalt, gallium, germanium, indium, niobium, platinum, tantalum, and titanium- all of which are covered in the report. They suggested that the vast bulk of the requirements for strategically important metals will have to be sought from primary sources within the Earth's crust. They also identified that the upper limit of what is available for recycling is determined by what comes back from society. The ceiling on what is returned by society is itself determined by the volume of each material that was consumed during the manufacture of goods some period of time previously. In the case of mobile phones and consumer batteries, for example, this may only be one to 5 years, whilst for automotive vehicles the timeframe is likely to be much longer at 15 years for the mass car market, and probably even longer for commercial vehicles.

The Research Councils UK also suggested that the free-market was ineffective in encouraging recycling resource efficiency, and that policy and related economic instruments have proved more effective at increasing recycling rates. They cited the Aggregates Levy as a positive example that has contributed significantly to the UK's high level of aggregates (crushed stone, sand and gravel) recycling, which is second highest in Europe.

In many ways aggregates can be considered as post-consumer waste. This analysis of the recovery of critical materials has established that for the majority a viable recovery system is in place in the UK for post-manufacturing waste. The extent of its effectiveness does however vary considerably. Although there are many companies that trade in metal waste (and do not accept material from the general public) the destination of the material will depend on market price and it may well end up outside the UK and Europe.

In general, recovery of materials from waste that has entered the wider public domain (post-consumer waste) is however very limited, except for certain specific examples such as the recovery of magnesium-containing, aluminium, beverage cans and platinum/palladium from automotive catalytic converters. The introduction of the collection of implant material in the UK from participating crematoria, requiring the ‘opting in’ by the deceased’s relatives, would suggest that there is a growing consumer awareness of the need for recycling of materials in general.

During a recent mission to Holland to investigate their approach to the recycling of materials, organised by the Materials KTN, the author attended a presentation given by Automobile Recovery Nederland (ARN). ARN is the Dutch centre of expertise for recycling in the automotive sector and has managed the recycling chain in the sector since the late 1990s. Holland goes further than what is required by EU legislation in the environmental aspects relating to disposal of vehicles. They advised that in 2011 the current system of manual dismantling will be replaced by shredding, although easily removed items such as tyres etc will still be extracted, as will the various liquids (hydraulic fluid, oil).

If such a system was to be adopted in the UK this could have significant implications for the recovery of such materials as rare earth magnets, high-value metals in circuit boards, and magnesium alloys, if components containing these materials are not removed prior to processing. It is therefore suggested that the design issues, such as designing for ease of separation and disassembly, are given much greater priority in order that valuable materials are not lost in the more general extraction and classifications of ferrous, nonferrous, and non-metallic fractions. Such considerations are not limited to waste recovery from vehicles alone but should apply to all consumer products.

The main constraint on increasing the levels of recycled material in general and critical materials in particular, is the development of an effective recycling chain for the recovery of post-consumer scrap particularly in high-volume articles such as batteries and electronic equipment.

Although the waste directives place an onus on the manufacture to accept returned items for recycling, the recovery of such items relies on the public’s acceptance that they should not be discarded with the general waste. In many instances the first stage of their recovery necessitates a journey to the nearest recycling facility which may be some distance away. Whilst it is likely that larger items are removed from the post-consumer waste stream, many smaller items can be disposed of in the non-recyclable waste category of door-to-door collection, which are not processed in any Materials Recycling Facilities (MRF). Batteries are a prime example. A possible alternative is for the local authorities to offer a free collection on a two-weekly basis very much in the manner of current waste paper and green waste collections. Where this not practicable a dedicated WEE bag that is left with recyclable waste that is sorted in MRFs could be another option.

As the cost of many critical materials increases due to increased demand, it will become increasingly financially attractive to extract the more valuable fractions. While such an approach would initially appear to enhance the volume of material recovered, it opens the risk of permanently losing other less-valuable materials which could otherwise be recovered in a more comprehensive recycling operation. Essentially the recovery of the less valuable material piggybacks on the recovery of the more valuable fractions, whilst increasing the overall financial viability of the operation. Legislation may be required in the future to avoid such ‘skimming’ operations.

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Please note that the references will be included in the final report in the conventional numerical order

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