

# Metals

*This factsheet provides an overview of **metals**. It forms part of a series on economically important minerals that are extracted in Britain and is primarily intended to inform the land-use planning process. It is not a statement of planning policy or guidance; nor does it imply Government approval of any existing or potential planning application in the UK administration.*

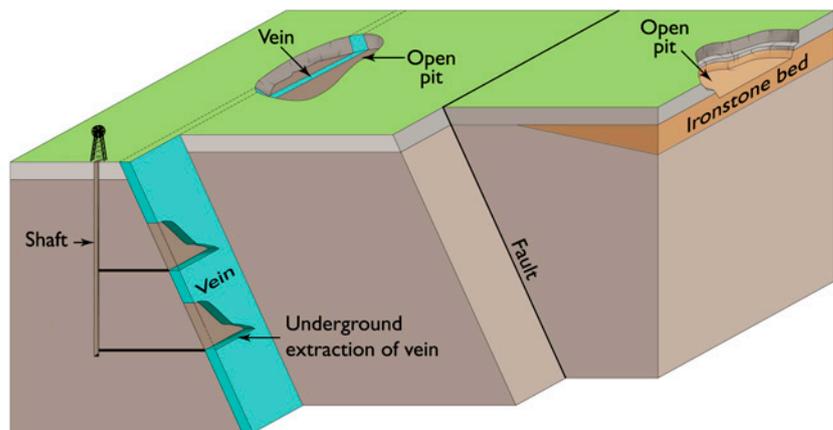
October 2015

The local availability of resources of metals and energy played a crucial role in Britain's development during the industrial revolution. Iron, copper, tin and lead were all produced in large quantities. The abundance of iron, often within or close to coalfields, was particularly important for the production of railway equipment, ships and other engineering products. The production of metals also led to the development of major smelting and refining industries, which continued after the exhaustion of domestic supplies by importing their raw materials, but still using the investment in plant and the skills of the workforce.

Metalliferous minerals are extracted primarily for their metal content. Exceptions include bauxite, which is mined principally as a source of aluminium, but also for its refractory and abrasive properties, and ilmenite, which is an important source of titanium metal but is primarily mined as a source of white pigment. The properties of metals, either singly or in combination, which are of economic importance, are strength and hardness, thermal and electrical conductivity, workability, corrosion resistance and lightness. These properties are generally not destroyed in use and in many applications some metals are available for reuse and recycling, without loss of quality.

**Figure 1** *Underground and open-pit mining of metallic minerals from steep veins and flat-lying beds.*

Metalliferous minerals were formerly extensively mined in Britain, mainly from vein deposits, which occur as narrow, sub-vertical deposits infilling faults and fissures that cut rocks of various geological ages (Figure 1). The metals gold,



silver, iron, manganese, copper, lead, zinc, tin, tungsten, arsenic and antimony have all been mined in Britain. Vein deposits were worked in Cornwall and Devon, the Mendips, North and Central Wales, Shropshire, the Northern and Southern Pennine Orefields, the Lake District and the Southern Uplands of Scotland. They formed the basis of the non-ferrous metal mining industry in Britain, which reached its zenith in the early to mid-19th century when the country was a leading world producer of tin, copper and lead. However, the industry gradually declined in the face of the high cost of working this type of deposit and competition from lower-cost producers overseas. Only modest production survived into the 20th century. The last mine worked solely for lead and zinc in England closed in Cumbria in 1962 and in North Wales in 1978. The last tin mine, South Crofty at Camborne in Cornwall, closed in 1998. Iron ore production increased during the 20th century before declining from the 1960s and ceasing in the early 1980s. Iron ore was mined in the UK over a long period from several sources at a wide variety of grades. Total output approached 1500 million tonnes with the majority of production taking place during the industrial revolution from about 1850 onwards. The main centre for the industry was in eastern and central England where large-scale, open-cast developments worked low-grade (20–35% Fe) Jurassic iron ore from flat-lying beds up to 6m thick (Figure 1). The two main smelting centres were Corby in Northamptonshire and Scunthorpe in Lincolnshire, though ore was also sent by rail to South Wales and Teeside. Smaller centres, working higher-grade (ca. 50% Fe) Carboniferous hematite ore in underground mines, were located in west Cumbria and South Wales.

Domestic metal extraction is currently restricted to three locations: a small gold mine near Omagh in Northern Ireland; the Cavendish Mill in the Southern Pennine Orefield (SPO) in Derbyshire where about 1200 tonnes of smelter-grade lead sulfide is extracted per annum as a by-product of fluorspar mining; and a major new tungsten mine at Hemerdon near Plymouth where the first deliveries of tungsten concentrate took place in the third quarter of 2015. This mine will be one of the largest producers of tungsten in the West when it reaches full production.

There are also possibilities for future commercial production of some of the other metals mentioned above, as well as nickel, cobalt and the platinum-group metals. Iron, manganese, arsenic and antimony are very unlikely to be mined on a commercial scale in Britain.

### Markets

Britain is a major consumer of all the major metals, which are essential for the manufacturing industries making everything from aircraft to domestic appliances, as well as steelwork for construction. Britain is also a major world financial centre and therefore holds large amounts of physical gold for this sector as well as maintaining a thriving jewellery trade that consumes gold, platinum and other precious metals.

With the expansion of new and 'green' technologies, especially for clean energy applications, global demand for a range of metals that hitherto have been little used has increased in recent years and is likely to continue to do so. For example, in the UK the consumption of various metals, such as cobalt, rare earths, lithium, indium and platinum-group metals, is likely to increase to meet demand from the automotive, aerospace and wind energy sectors. It is anticipated that most of these 'technology metals' will be imported into the UK in a range of intermediate forms or in finished components and assemblies.

### Supply

Formerly Britain was a world-scale producer of copper, lead, tin and iron (albeit at levels which were a very small fraction of the current world



**Figure 2** The steel blast furnace at Redcar, Teesside. (Reproduced with permission of SSI Steel UK.)

output of these metals). Until very recently metal mining from indigenous sources in the UK has been on a very small scale. However, the new tungsten-tin mine at Hemerdon in Devon will change this situation from late 2015 onwards.

Some of the major ferrous and non-ferrous metals are smelted in the UK from imported ore or partly refined matte. They include iron, lead, nickel and aluminium (Table 1 and Figure 3).

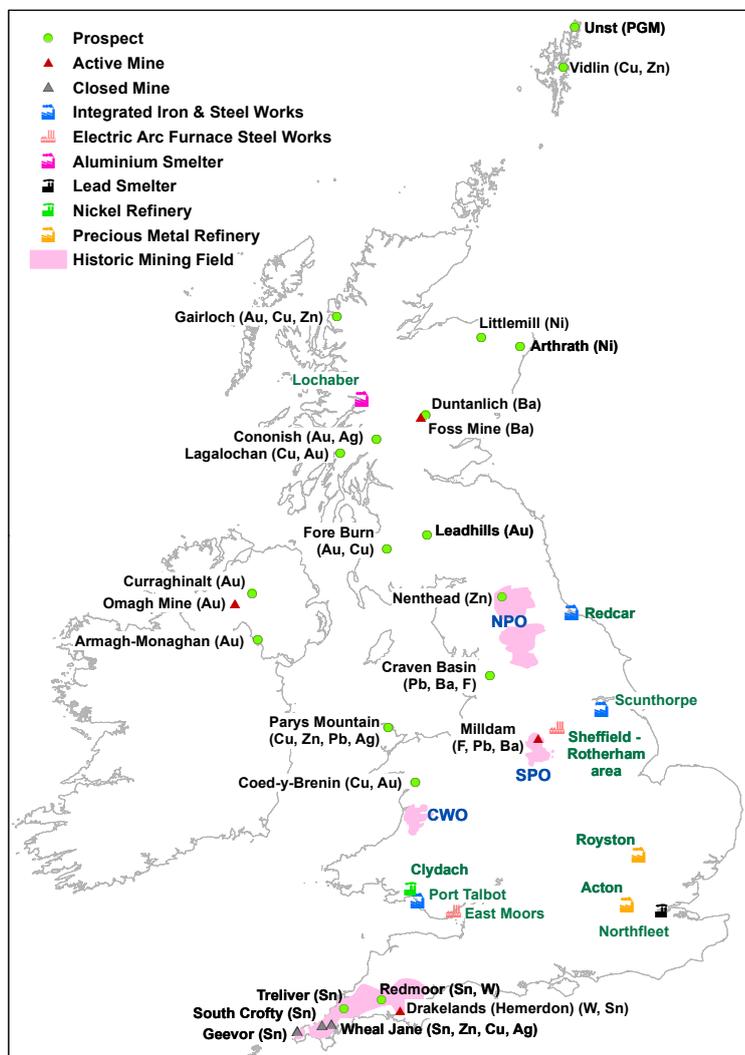
The dominant primary production of metal in the UK is of pig iron (9.4 million tonnes in 2013 (ISSB, 2013)). This is derived from imported

Metal	2009	2010	2011	2012	2013
Aluminium <sup>1</sup>	252 000	186 000	213 000	60 000	45 000
Nickel <sup>1</sup>	17 800	31 600	37 400	34 300	40 400
Lead <sup>1</sup>	157 865	151 000	125 000	156 930	174 200
Pig iron <sup>2</sup>	7 671 100	7 233 000	6 625 000	7 183 100	9 471 000

**Table 1** UK refined metal production (tonnes) from primary sources, 2009–2013. (Sources: <sup>1</sup>World Bureau of Metal Statistics (WBMS) and <sup>2</sup>The Iron and Steel Statistics Bureau (ISSB).)

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**Figure 3** Locations of prospects, historic mining fields, metal smelters and steel mills. (NPO, Northern Pennine Orefield; SPO, Southern Pennine Orefield; CWO, Central Wales Orefield; Ag, silver; Au, gold; Ba, barytes; Cr, chromium; Cu, copper; F, fluorspar; Ni, nickel; Pb, lead; PGM, platinum group metals; Sn, tin; W, tungsten; Zn, zinc).

iron ore and coking coal and is used to make a wide range of steel products, including: blooms, billets and slabs (i.e. cast products), plate and sheet-steel (i.e. flat products) and rods, bars, wires and cables (i.e. long products). There are important integrated steelworks making pig iron and crude steel at Port Talbot, Scunthorpe and Teesside. However, at the time of writing (October 2015), the future of the operations at Redcar on Teesside are uncertain due to the prevailing low price of steel and

the influx of cheap Chinese imports into global markets. There are also a number of Electric Arc Furnace (EAF) steelworks in the Sheffield and Rotherham area that produce high-quality steel mainly from recovered steel scrap, as shown in Figures 3 and 4. In 2013 total crude steel production in the UK was 11.9 million tonnes (ISSB, 2013).

Aluminium production from smelters in the UK peaked at about 370 000 tonnes in 2005, including production from Lynemouth in Northumberland, Holyhead on Anglesey and Lochaber at Fort William in Scotland. However, closure of the smelter on Anglesey in 2009 and the Lynemouth smelter in 2012 has reduced domestic output by about 320 000 tonnes per year. In 2013 the Rio Tinto Alcan-owned Lochaber smelter was the sole UK-based producer of aluminium with an output of about 45 000 tonnes (Figure 3).

The Xstrata plant (Britannia Refined Metals) at Northfleet in Kent refines lead bullion from the company's Mount Isa mine in Australia and also secondary lead sources. The Avonmouth smelter at Bristol produced zinc from Australian concentrates until its closure in 2004. The Vale Inco Ltd refinery at Clydach in south Wales produces about 40 000 tonnes per annum of nickel metal and other products from imported nickel matte. Vale Inco also operates a refinery at Acton in London where it refines platinum-group metals, gold and silver. It also processes primary mining concentrates and secondary materials such as recycled spent catalysts and electronic scrap. Johnson Matthey plc is a global leader in precious metal products and chemicals, in emission control technologies, in the manufacture of catalysts and in the production of fine chemicals for pharmaceutical use. In the UK Johnson Matthey operates facilities at Royston in Hertfordshire and at Brimsdown in Enfield, north London (Figure 3).

Titanium Metals Corporation produces titanium billet and slab for the aerospace sector at its plant in Witton near Birmingham. A second operation at Waunarlwydd in south Wales produces hot rolled titanium bar and plate for use in jet engines and medical applications.

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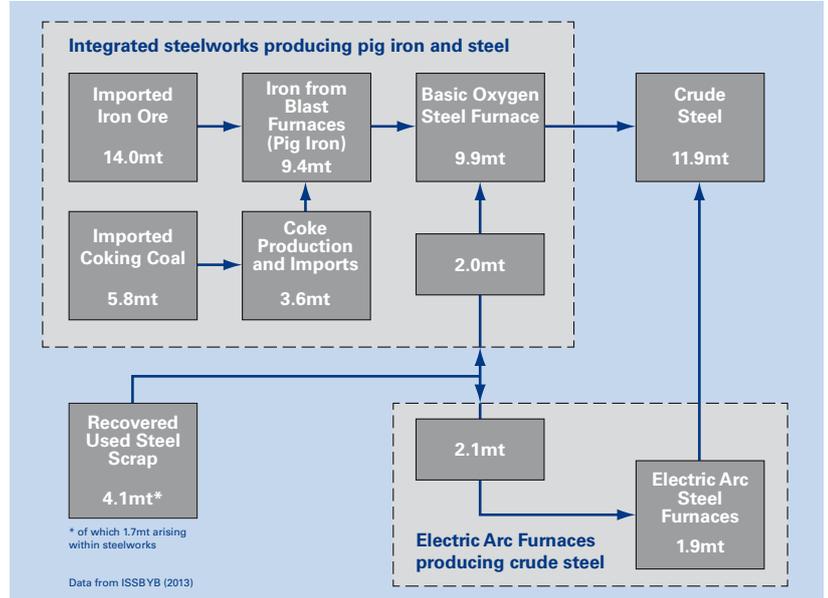
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## Trade

The UK is a major importer of a wide range of both refined and semi-refined metals, in addition to aluminium and iron and steel in which it is largely self-sufficient due to the output from domestic smelters. However, these rely on imported alumina and iron ore as their raw material. The most important metal imports in terms of value are gold, silver, platinum-group metals, copper, iron and steel, nickel, titanium and aluminium (Figure 5a). The UK also exports large quantities of metals as scrap and in a variety of fabricated and semi-fabricated forms. Exports are dominated by gold, followed by iron and steel, platinum-group metals, silver, copper and aluminium (Figure 5b). Precious metal exports go mostly to China and Europe, whilst exports of copper and aluminium are directed to Europe and to China, India and other Asian countries. Exports of steel, mostly in the form of scrap, are mainly to Europe with large amounts also going to India and Egypt.

## Consumption

The consumption of metals in the UK is dominated by iron and steel, used primarily in the construction industry and for the manufacture of motor vehicles (Table 2). The consumption of copper in the UK is also largely driven by the construction industry for use in piping and electric cables. Lead is used in the manufacture of lead-acid batteries, and to a lesser extent as a roofing material. Aluminium has numerous uses, including as a packaging material (e.g.



**Figure 4 UK iron and steel production in 2013.** (Data from ISSB Yearbook, 2013.)

aluminium foil and cans) and as a corrosion-resistant coating in harsh environments. It is also widely used in the construction industry (e.g. roofing and cladding) and in the transport industry for the production of planes, ships, trains and cars.

## Economic importance

The metals industry, which includes a wide range of activities from smelting and metal production to the manufacture of metal products, makes a major contribution to the UK economy. The manufacture of basic metals (iron and

Metal	2009	2010	2011	2012	2013
Aluminium <sup>1 A</sup>	616590	594520	592470	592480	590400
Copper <sup>1 B</sup>	142800	163000	142800	142800	142800
Iron and steel <sup>2 C</sup>	18083400	19580100	19546300	19620000	22447600
Lead <sup>1 D</sup>	188726	211165	210927	229044	273963
Zinc <sup>1 E</sup>	99000	96641	86892	80031	100314

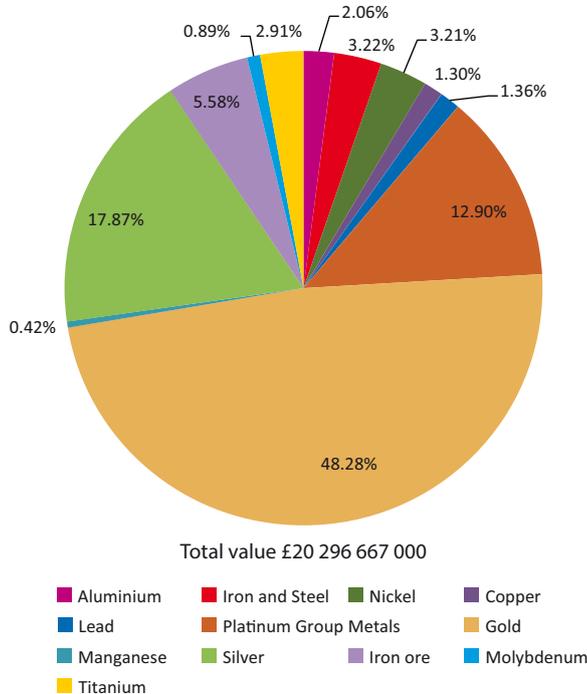
A - Includes primary and secondary aluminium  
B - Includes refined and scrap copper  
C - Includes pig iron, finished steel and scrap

D - Refined lead only  
E - Slab zinc only

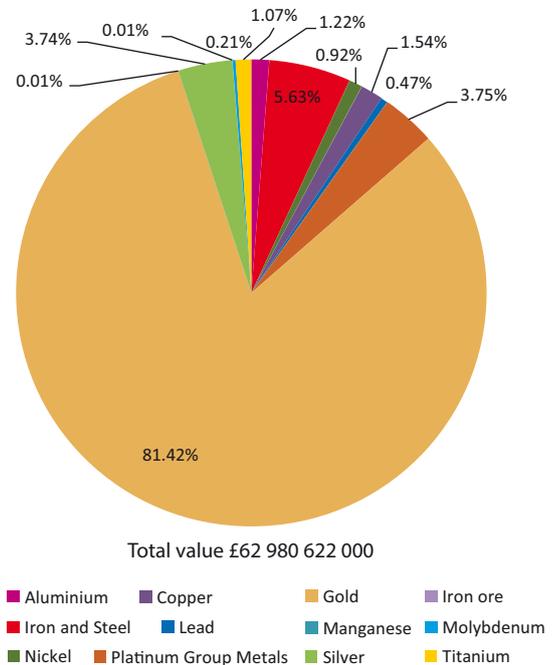
**Table 2 Consumption of selected metals (tonnes) in the UK, 2009–2013.** (Sources: <sup>1</sup>World Bureau of Metal Statistics (WBMS) and <sup>2</sup>The Iron and Steel Statistics Bureau (ISSB).)

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**Figure 5a** Value of selected UK metal imports in 2013. (Source: BGS, 2014a.)



**Figure 5b** Value of selected UK metal exports in 2013. (Source: BGS, 2014a.)

steel, ferro-alloys, aluminium, copper, lead, zinc, precious metals, etc.) employed 70 000 people in about 1500 enterprises in 2013. It had an aggregate turnover of £17.4 billion and an approximate GVA of £4.2 billion (ONS, 2015). The manufacturing of metal products is a larger and more diverse sector with a turnover in 2013 of £33 billion and an approximate GVA of £14.3 billion. In 2013 it employed 296 000 people in about 24 000 enterprises widely distributed across the UK with major contributions from all regions except London, Wales and Northern Ireland (ONS, 2015).

The foundry sector, which produces ferrous and non-ferrous metal castings, had a turnover of £2.2 billion in the financial year 2014–15. It employs about 17 000 people at 400 foundries in some of the more economically deprived areas of the UK (UK Castings, 2015).

The recovery and production of metals from recycled scrap is a long-established industry of considerable economic importance. Metal recycling in the UK contributes annually an estimated £5.6 billion to the economy, with about

8000 direct employees (British Metal Recycling Association, 2015).

### Structure of the industry

The UK retains aluminium and iron and steel smelting industries, but no primary base metal production. As described earlier, the main industry sites were located in the north and west of Great Britain, generally near the coast as most of the feedstock for the smelters was imported. The metal casting industry is more widespread with the main centres located in the English Midlands, Yorkshire and Greater Manchester. The metal fabrication industry, with its large number of participating businesses and wide variety of products, is widely dispersed across the UK.

Partly for historical reasons and partly due to London's position as a world financial centre, many of the major world mining companies are either based in London or have a substantial presence in the UK. Four of the world's five largest mining companies (BHP Billiton, Rio Tinto, Glencore and Anglo American) are listed

on the London Stock Exchange (LSE) and a number of other mining companies are found in the FTSE top 100 companies. The LSE's Alternative Investment Market (AIM) provides a source of capital to help smaller and growing companies, many of them in mining and exploration. Following several years of rapid growth the market collapsed in late 2008 leading to drastic reductions in commodity prices and associated steep falls in share prices across the mining sector. Many junior companies went into administration or delisted from AIM. Worldwide the junior exploration sector continues to experience great difficulty in raising funds, a situation that is likely to persist until global economic recovery is assured.

### Recycling and alternatives

Many metals, including iron and steel, lead, copper and aluminium, can be recovered from products at the end of their life without loss of quality. Consequently recycling of end-of-life products provides an important additional supply of metals to complement that derived from mining (see Table 3). The main sources of metals that are recycled are vehicles, packaging, electrical and electronic waste (WEEE) and batteries (mostly lead acid type). Utilisation of secondary resources extends the lifetime of primary resources and contributes to improved supply security through diversification of the supply base. There are also considerable savings in energy and greenhouse gas emissions in metal production from recycled materials. For example, to produce a tonne of aluminium from scrap uses only 5 per cent of the energy required to produce the same quantity from bauxite ore (British Metals Recycling Association, 2015).

Metal recycling involves a complex chain of activities that begins with collection, sorting, dismantling and pre-processing in order to separate components containing valuable metals or to upgrade individual fractions prior to final metallurgical processing. Each stage involves different operators and requires increasing technical skills and infrastructure together with greater financial investments. Efficient metal recycling requires specialised approaches for every stage, each tailored to specific products and metal combinations. For precious and

Metal	2009	2010	2011	2012	2013
Aluminium <sup>1</sup>	129 800	99 600	99 200	148 800	148 800
Lead <sup>1</sup>	144 000	150 000	150 000	155 000	155 000
Steel <sup>2</sup>	3 459 400	3 713 100	3 890 300	3 674 500	4 084 600

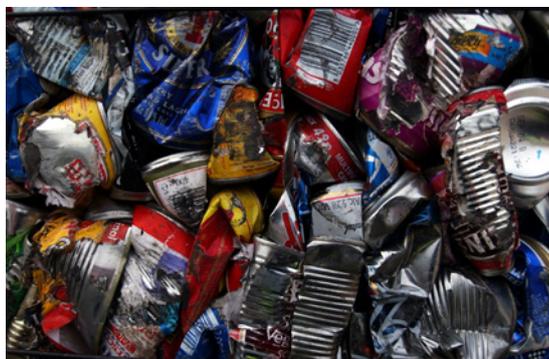
**Table 3 UK production of refined metals (tonnes) from secondary sources, 2009–2013.**  
(Sources: <sup>1</sup>World Bureau of Metal Statistics (WBMS) and <sup>2</sup>The Iron and Steel Statistics Bureau (ISSB).)

base metals metallurgical recovery methods have been developed over long periods and are highly efficient (generally better than 95 per cent). However, the recovery of technology metals that are used in small quantities in complex components in complex products poses a difficult technical and economic challenge. The recovery of metals from combinations that do not occur in nature is particularly problematic as their separation cannot be achieved by established metallurgical recovery routes. For example, all precious metals, most base metals and some technology metals can be recovered from a printed circuit board, but some technology metals, such as gallium, germanium and rare earth elements, are not recoverable (Hagelüken, 2014). Even where metallurgical extraction is technically feasible, the economic viability of recovering a particular metal depends on the intrinsic value of the contained metal and the cost of its extraction. For example, on account of their high value, precious metal recovery rates from products such as car and process catalysts, equipment used in the glass-making industry, circuit boards and mobile phones are generally high. In contrast, the recovery of indium from LCD screens is not currently economically viable.

It is difficult to assess the proportion of metal consumption that is derived from secondary sources. On a global scale end-of-life recycling rates for different metals vary significantly according to the particular application and the country in question. For many of the major industrial metals (e.g. iron, nickel, lead, copper, zinc, tin, titanium) and some precious metals (e.g. platinum-group metals, silver) 25–50 per

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**Figure 6** *Recycling of end-of-life products is making an increasingly important contribution to metal supply in the UK. (Photo courtesy of WRAP)*

cent of material is typically recycled (UNEP, 2011). Recycling of lead from car batteries is reported as reaching 97 per cent, the highest recycling rate for any mineral commodity. However, many metals consumed in smaller quantities, typically for highly specialised applications in new and 'green' technologies (e.g. rare earth elements, lithium, tellurium, germanium), currently have considerably lower (<1 per cent) recycling rates. In some cases this may be due to technical issues related to metal recovery from the products in which they are used or, where extractive techniques are available, it may not be economic to recover the minute quantities used in individual devices.

Some metals can be substituted if the price rises or falls, or in response to concerns over possible disruptions to supply. Aluminium, and to a lesser extent magnesium, is increasingly used in car manufacture, especially in engine castings, but also in bodies to save weight and thus enhance fuel economy. Furthermore, as aluminium is more resistant to corrosion than steel, product life may be increased by the use of aluminium. However, in many applications, it is difficult to substitute certain metals without a significant loss in performance. This is particularly the case for many technology metals, such as the rare earth elements, indium and the platinum-group metals, which are commonly used in a wide range of high-tech equipment such as personal electronic devices. For example, there are no effective substitutes for the

platinum-group metals, platinum, palladium and rhodium, in the catalytic converters used for pollution control in the exhaust systems of modern motor vehicles.

Alternatives to metals are being utilised in some applications. Plastics and carbon fibres are used in some car body components in place of steel or aluminium, and the aerospace industry is using increasing amounts of carbon fibre to replace aluminium. Tin-coated steel drinks cans have been replaced by aluminium and more recently by plastic bottles. Fibre-optic cables can replace copper for carrying electronic communications, but not for electrical power. Ceramics are being developed which may replace metals in some applications.

There is also a move towards thrifting in the use of some materials i.e. using a smaller amount in a particular application with little or no reduction in performance. For example, technological advances in recent years have allowed a considerable reduction in the quantities of platinum-group metals used in automotive catalysts. However, at the same time, emission control standards have been tightened in many countries (e.g. EU, USA and Japan) and global vehicle sales have continued to rise such that overall demand for platinum-group metals continues to grow.

There is also significant global interest in developing alternative technologies for particular purposes and thereby to reduce or remove the long-term risk associated with using metals that may be prone to supply disruption. For example, there is considerable ongoing research aimed at developing alternatives to electric motors and generators that rely on high-strength iron-neodymium-boron magnets. The improvement of product design to allow easy dismantling and separation of parts that can be re-used, or from which individual metals can be readily separated by current metallurgical technology, is another aspect that is receiving particular attention.

### **Security of supply and critical raw materials**

In the light of projected global population growth and the rapidly increasing use of raw

materials in developing countries, there is growing concern within the European Union (EU) over the long term security of supply of mineral raw materials required by European industry. In 2008 the European Commission issued a Communication on raw materials, *The raw materials initiative – meeting our critical needs for growth and jobs in Europe* (EC, 2008). The Raw Materials Initiative (RMI) focussed on ensuring EU access to raw materials from international markets, fostering sustainable mineral supplies from within the EU and increasing resource efficiency and recycling. There is greatest concern over the supply of 'critical raw materials', which are those that are not only important in use (i.e. disruption to their supply would have a high impact) but also have limited availability (i.e. have a high probability of supply restriction). These include many of the technology metals such as those used in information and communications, in pollution control and in 'clean' energy. Important examples include: the platinum-group metals, which are vital components of autocatalysts used in car exhaust systems; rare earth elements, used in high performance magnets in wind turbines and in motors for electric cars; and tantalum, a key component in capacitors used in mobile phones and personal computers.

In 2010 the EC conducted a systematic assessment of mineral raw materials critical to the EU economy (EC, 2010). Of the 42 'candidate' metals and minerals 14, including 12 metals and groups of metals (the platinum-group metals and the rare earth elements), were classified as critical. This assessment was updated in 2013 with 20 raw materials (13 metals/metal groups and 7 industrial minerals) identified as critical from 54 'candidate' materials (EC, 2014a). These pan-EU criticality assessments are intended to provide early warning of potential supply disruption of particular commodities and have raised awareness and understanding of security of supply issues among a wide range of stakeholder groups. In order to avoid future metal supply disruption or to minimize its consequences, the EC has launched a wealth of new policies and research programmes dealing with the complete raw materials value chain from exploration, mining and extractive metallurgy of ores to product manufacture,

use, recycling and disposal. While access to metallic ores may be affected by a wide variety of social, planning, political and environmental factors, the availability of the contained metal is essentially determined by the availability of appropriate technology. In order to diversify and expand production, it is essential to be able to find new resources and to mine and process them efficiently with minimal environmental impact. At the same time it is important to reduce waste through more efficient manufacturing and by reuse and recycling and to develop new materials and new products.

In 2014 the EC issued a major new policy The European Innovation Partnership (EIP) on Raw Materials, 2014–2020 (EC, 2014b). Like the RMI, the EIP targets non-energy, non-agricultural raw materials and promotes both technological and non-technological innovation along the entire value chain. Numerous objectives and targets are specified in the Strategic Implementation Plan (SIP) of the EIP, including improvement of the raw materials knowledge base, data standardisation, development and exchange of best practice, enforcement and improvement of legislation, development of more efficient licensing procedures and fostering international dialogue on policy and research.

In the UK the House of Commons Science and Technology Committee undertook an inquiry into strategically important metals in 2010–11 to gauge the views of government, industry, academia and trade bodies on the vulnerability of the UK economy to supply risks for these materials and related issues including recycling, reuse, substitution, domestic extraction and production and environmental concerns (STC, 2011). In 2012 the UK government published its Resource Security Action Plan which acknowledged that concerns about access to resources and rising commodity prices were already having an impact on UK businesses and that competition for resources was also leading to additional pressures on the environment (Defra, 2012). It provides a framework for business action to address concerns about the availability of some raw materials and sets out high level actions to address resource concerns. These included initiatives to provide

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more information to companies to help them make more informed decisions on the resource risks to their operations and to establish an industry-led network of government, industry and other organisations to disseminate best practice and to provide a forum for policy innovation.

In the UK, the Security of Supply of Mineral Resources (Minerals SoS) programme, with funding of about £15 million provided chiefly by the Natural Environment Research Council (NERC), started in 2015. This programme focusses on the security of supply of some of the elements that underpin green energy technologies, which have been termed 'e-tech elements': cobalt (Co), tellurium (Te), selenium (Se), neodymium (Nd), indium (In), gallium (Ga) and heavy rare earth elements (HREE). Minerals SoS has two high-level aims: (i) improved understanding of e-tech element cycling and concentration in natural systems; and (ii) improved extraction and recovery of e-tech elements from primary sources in order to mitigate the environmental effects of their production. It is being implemented through four major projects that involve over 50 indus-

trial partners and more than 20 universities and research organisations.

## Resources

Figure 3 shows the location of former and current metal mining sites in the UK. Selected prospects with potential for the extraction of metalliferous minerals are also shown.

### England

The major low-grade Hemerdon tungsten-tin deposit, located near Plymouth, comprises a sheeted vein complex hosted by Variscan granite and Devonian metasedimentary rocks. Exploration by Amax in the early 1980s identified a resource of 42 million tonnes at 0.18% WO<sub>3</sub> (tungsten trioxide) and 0.025% Sn (tin). Planning permission for a 2.2 million tonne per year open pit was granted in 1986, valid until 2021. However, the project did not go ahead at that time due to the falling price of tin and tungsten. In 2007 the Hemerdon deposit was purchased by Wolf Minerals Ltd who raised £123 million to take the project forward to mine development. The latest resource estimates, published in March 2015, are 58.6 mil-



**Figure 7** Aerial view of processing plant and waste facility at Drakelands tungsten mine near Hemerdon, Devon (July 2015). (Reproduced with permission of Wolf Minerals Limited.)

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lion tonnes at 0.17% WO<sub>3</sub> and 0.02% Sn in the JORC Measured and Indicated categories (Wolf Minerals, 2015). Included within this resource are proven and probable reserves of 35.7 million tonnes at 0.18% WO<sub>3</sub> and 0.03% Sn. The mine construction and plant commissioning have been completed and ore processing commenced in 2015. At full capacity the mine, now known as the Drakelands mine, will be one of the largest in the West: 3 million tonnes of ore will be mined per annum to produce 3450 tonnes of tungsten trioxide and 460 tonnes of tin. This is based on a ten-year mine life operating 5.5 days per week and assumes an extension of the current planning permission beyond 2021. Contracts for the sale of 80 per cent of the tungsten concentrate have been signed with two major international companies, Global Tungsten & Powders (owned by Plansee) in the USA and Wolfram Bergbau und Hutten (owned by Sandvik) in Austria.

South-west England remains prospective for the discovery of additional deposits of tin, tungsten and copper. However, extensive and intensive historical workings make exploration for new deposits difficult. It is likely that any new deposits would be buried below the ground surface and would require substantial exploration investment. However, new regional geochemical and high-resolution airborne geophysical datasets acquired by the BGS Tellus South West project provide new insights into the geology of the region and will assist in identifying new exploration targets for metals (BGS, 2014). Recent exploration, including programmes of drilling, in south-west England has focussed on tin at Treliver, near St. Austell, and on tin and tungsten at Redmoor near Callington in south-east Cornwall.

The potential for large-scale base-metal (zinc-lead) replacement deposits (flats), adjacent to and under the worked-out vein deposits of the Northern Pennine Orefield (NPO) of County Durham, Northumberland and Cumbria, has attracted the attention of commercial companies on a number of occasions in the past 25 years. Prospective targets are located in the thick basal limestones above the basement of granite, slates and volcanic rocks. Most recently Minco plc reported encouraging zinc-lead

mineralisation from a drilling programme carried out near Nenthead on the County Durham and Northumberland border (Minco, 2014).

## *Scotland*

There are a number of areas associated with mafic-ultramafic igneous rocks in north-east Scotland that are prospective for magmatic nickel-copper sulphide deposits with possible by-product platinum-group metals. The most attractive target is located at Arthrath near Aberdeen where in the late 1960s Rio Tinto discovered a resource estimated at 17 million tonnes at 0.16% copper and 0.21% nickel. In 2006–7, stimulated by high nickel prices, there was renewed commercial exploration at Arthrath, but there is no current activity there. There is another, smaller but higher grade, deposit of nickel-copper sulphide at Littlemill, near Huntly, in the same region.

The major stratiform Duntanlich barite deposit, in Middle Dalradian sedimentary rocks near Aberfeldy in Perthshire, contains about 13 million tonnes of massive barite. However, it remains unworked since its discovery in the early 1980s due to planning issues. These include its location in the Loch Tummel National Scenic Area, the proposed transport routes to Aberdeen and the possible effects on tourism. A revised proposal for the construction of a small underground mine at Duntanlich has been developed by the owners, M-I SWACO, with a view to submitting a planning application in 2015 (M-I SWACO, 2015). This major discovery has made the entire Dalradian belt in the central Highlands prospective for sedimentary exhalative (Sedex) base metal and barite mineralisation.

Several small gold prospects were discovered in the Dalradian terrane by commercial companies and by BGS in the 1980s and 1990s. These include the Calliachar-Urlar Burn veins near Aberfeldy and Stronchullin in Knapdale. The most important discovery was at Cononish near Tyndrum in Perthshire, located within the Loch Lomond and the Trossachs National Park. This deposit, discovered in 1984, was re-evaluated by Scotgold Resources Ltd from 2008 onwards. It comprises a single, near-vertical quartz vein with an average

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**Figure 8** Exploration drilling at the Cononish project near Tyndrum in central Scotland. (Photo courtesy of Scotgold Resources Limited.)

width of 1.7 m. Full planning approval for the development of a small underground mine was granted in 1996 for a ten-year period, but, due to low gold prices, the project did not proceed. In 2010 the company submitted an application to develop the project. This was initially rejected, but a revised planning application was approved in October 2011. Various legal agreements and agreement on a number of outstanding conditions were subsequently concluded and permission for development was granted by the Board of the Parks Authority in February 2012. Updated resources and reserves for the Cononish deposit were published in May 2015: the total (proven + probable) reserve comprises 555 000 tonnes of ore at 11.1 g/t gold and 47.7 g/t silver. A bankable feasibility study was completed in July 2015 (Bara Consulting Ltd, 2015). This study envisages an average production of 23 000 ounces gold equivalent per annum over a mine life of 8 years. The capital cost of developing the mine at Cononish is estimated at £24 million. Scotgold is also exploring for similar deposits over a wide area of the Dalradian belt in Scotland.

Polymetallic, chiefly copper and gold, mineralisation of epithermal-porphyry style was discovered at Lagalochan in the south-west Highlands in the early 1980s. The size and grade of this deposit have never been clearly defined but the

area is currently being explored by a commercial company which undertook geochemical and geophysical surveys and drilling in 2013 and 2014.

The copper-zinc deposits near Gairloch in the north-west Highlands and at Vidlin in Shetland are generally considered to be too small and low grade for commercial production. However, the resources at Gairloch, including its gold potential, were reviewed by a commercial company in 2011/12. The presence of similar deposits concealed under thin Torridonian cover in the Gairloch district cannot be ruled out but has not been systematically investigated.

### Wales

The only advanced prospect in Wales is the Parys Mountain zinc-copper-lead deposit in Anglesey which is owned by Anglesey Mining plc. It is a volcanogenic massive sulfide (VMS) deposit with several zones of mineralisation that has been worked intermittently for hundreds of years, although large-scale mining from open pit workings commenced in the middle of the eighteenth century. Underground production was predominant in the nineteenth century, but by 1900 virtually all mining activity had ceased. Commercial production came close to restarting in 1990, following the sinking of the 300 m deep Morris Shaft, but a sharp fall in metal prices curtailed development at that time. However, planning permission for a 1000 tonne per day mine, which was granted in 1988 and reviewed in 2006, remains valid. High copper and zinc prices in the period 2005–7 stimulated renewed interest in the deposit, although the economic downturn in 2008 led to further delays in project financing. The deposit contains a JORC-compliant indicated resource of 2.1 million tonnes at 6.9% combined base metals and 4.1 million tonnes at 5% combined base metals in the inferred category (Micon, 2012). The resources also include minor amounts of gold and silver. Future mine development at Parys Mountain is dependent chiefly on the market price for zinc which will influence the ability of the owners to raise the required funding. Given the current weak global economic outlook, it is unlikely that the zinc price will increase significantly in the near future.

There may be attractive exploration targets for zinc-lead-silver deposits in the Central Wales Orefield where zinc resources were generally only developed towards the end of the ore-field's life in the early part of the twentieth century. Some small known resources remain and modern exploration may reveal more.

The Coed y Brenin porphyry copper deposit, discovered by Rio Tinto in the 1960s in the Snowdonia National Park, is a low-grade resource with about 180 million tonnes at 0.3% copper (Rio Tinto Finance and Exploration Ltd, 1972). However, it is unlikely to be worked due to economic and environmental reasons.

### Northern Ireland

The small open pit Cavanacaw gold mine, operated by Omagh Minerals Ltd, a subsidiary of the Galantas Gold Corporation, is located near Omagh in County Tyrone. Mining at this site commenced in 2006 with production in the order of a few thousand ounces per annum of gold and silver. Production was curtailed in the fourth quarter of 2013 due to a planning issue and gold production in 2014 was reported by the company as 'minimal'. The Cavanacaw deposit comprises at least 8 veins, with the majority of the resource in the Kearney and Joshua veins. In 2014 Galantas reported a total measured resource of 138 241 tonnes at a grade of 7.25 g/t gold and an indicated resource of 679 992 tonnes at 6.78 g/t gold (Galantas Gold Corporation, 2014). In 2012 Galantas submitted a planning application for an underground mine at Cavanacaw, to the Northern Ireland Planning Services. Planning consent for this development was granted in June 2015. The consent includes various operating and environmental conditions which are being reviewed by the company.

Another deposit, Curraghinalt near Gortin, has been explored by various companies periodically since its discovery in the 1980s. Since 2009 Curraghinalt has been owned by a Canadian company, Dalradian Resources, which is listed on the Toronto and London (AIM) exchanges. Dalradian has greatly increased the resource at Curraghinalt which now stands at 3.5 million ounces of contained gold, comprising 1 million ounces in the



**Figure 9** The Parys Mountain copper-lead-zinc deposit, Anglesey.

Measured category and 2.5 million ounces in the Indicated and Inferred Categories. During 2015 the company is planning to spend about £10 million on additional drilling, underground exploration and completion of a feasibility study. Assuming positive results from this work and from the Environmental Impact Assessment, a planning application for mine development will be submitted in late 2016 (Dalradian Resources, 2015a). At present planned annual production will be 162 000 ounces of gold over a mine life of 18 years (Dalradian Resources, 2015b).

Both Cavanacaw and Curraghinalt are orogenic, high-grade (10–15 g/t gold) narrow vein deposits. The area around these deposits is prospective for the discovery of additional, orogenic gold mineralisation and both companies hold exploration licences over extensive areas around their mine sites.

There are also possibilities for the discovery of base- and precious-metal deposits of VMS and other styles in the Ordovician Tyrone Igneous Complex. High-resolution airborne geophysical survey data and regional geochemical data acquired by the Tellus project (2004–2007), fund-

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**Figure 10** Examining gold-bearing veins at the *Curraghinalt gold deposit, Northern Ireland.* (Photo courtesy of Dalradian Resources.)

ed by the Department of Enterprise, Trade and Investment, contributed to a marked increase in the uptake of exploration licences in Northern Ireland and will continue to help companies identify and prioritise new exploration targets.

### Mineral ownership

The rights to gold and silver in most of the UK are owned by the Crown. Mines of these metals are known as 'Mines Royal.' A licence, known as a Mines Royal Licence, for the exploration and development of these metals must be obtained from the Crown Estate Commissioners through the Crown Mineral Agent. The rights to gold and silver in the former county of Sutherland in northern Scotland are held by the Duchy of Sutherland. Other metallic minerals are mainly in private ownership, although some may be owned by the Crown, and by Government departments and agencies. There is no national register of mineral ownership, but the Land Registry may have details of surface ownership and current ownership of mineral rights.

### Planning issues

**Relationship between metal prices and development interest** — Metals are traded commodities and prices for most are set by the

global market. These prices can be subject to considerable fluctuation which is usually linked to global economic cycles. As a consequence, the level of investment in exploration activity and any subsequent mine development in the UK is likely to be strongly influenced by metal prices on the world market. When metal prices are high, levels of interest in finding metallic mineral deposits and developing/re-opening mines are likely to be higher than when prices are low or on a declining trend.

**National minerals policy framework** — The development of metalliferous minerals in England is covered by the National Planning Policy Framework (NPPF) (DCLG, 2012). However, there is no specific planning guidance for metalliferous mining development. Like the NPPF, Minerals Planning Policy Wales and Scottish Planning Policy also draw attention to the need for mineral planning authorities (MPAs) to safeguard resources and to consider the economic and environmental impacts of extraction (Welsh Government, 2000; Scottish Government, 2014).

**Relationship with environmental and landscape designations** — In the UK, most metalliferous mineralisation is located in older, harder rocks in upland areas. These areas include the Pennines, the Scottish Highlands and central Wales, major parts of which are designated for their landscape or ecological importance. These designations include national parks and Natura 2000 wildlife and ecological sites of European or international significance. Mineralisation may also underlie sites of archaeological importance (sometimes associated with historic mining activity) and also occur within important river catchments.

**Exploration** — Exploration for metalliferous deposits is very different to that for construction or industrial minerals. Much larger areas (10s to 1000s of km<sup>2</sup>) are examined at the reconnaissance stage of exploration for metals, followed by more detailed exploration of smaller areas of a few km<sup>2</sup>. Exploration is generally non-intrusive until the final feasibility stage, when detailed drilling is normally required. Most prospects are abandoned during the early stages of exploration.

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**Deposit size and identification of reserves** —

Deposits of metallic minerals are less common, and more difficult to locate and evaluate than deposits of construction and most industrial minerals. Individual deposits are commonly small and very sporadically distributed. Given the high level of investment required to develop a new metal mine extensive evaluation is required to ensure the reserves justify the capital expenditure.

**Extraction methods** — Because metals command higher prices than construction and most industrial minerals they are commonly amenable to selective mining and frequently exploited underground. Underground mining typically results in a smaller surface footprint than open-pit operations.

**High waste to mineral ratio** — Metallic ores generally form only a very small proportion of the total volume of material extracted. This is particularly the case with open-pit mining of metals. The environmental and amenity impact of tips comprising overburden and interburden waste is likely to be a major planning issue at open-pit metal mines. The waste to ore ratio at underground mines is likely to be significantly lower.

**Ore processing** — Metallic ores generally have a more intensive and complex processing route than construction and industrial minerals. The rock is generally crushed to a fine particle size and may be subjected to sequential leaching or flotation techniques to extract the required mineral. Mine output may well be exported to another country for further treatment, such as smelting.

**Tailings dams** — Fine-grained waste material which remains following the separation of the target mineral is generally stored in tailings dams. These relatively large, visually-intrusive structures are essential to allow the waste material to dewater over a number of years.

**Pollution potential** — Some metallic ores and associated minerals are sulphides. These minerals can oxidise within the mine and/or in waste tips to form acidic mine water which has considerable pollution potential if not managed correctly. Solid waste from metal mining can also contain elevated levels of elements which are potentially harmful to human health and the envi-

ronment if not managed properly. The European Mining Waste Directive, together with other environmental permitting regulations, are the primary means of regulating the management of waste and water from both active and closed metal mines. In England and Wales this regulation is carried out by the Environmental Agency. In Scotland and Northern Ireland, responsibility for regulation is split between the planning system and the national environmental agencies.

**Legacy of historic metal mining** — Britain's long history of metal mining has left a considerable environmental legacy which impacts on land use in some former mining areas. This legacy is chiefly associated with pollution from minewater entering streams and rivers, and from waste tips. In some areas, there are also ground stability problems associated with former mine shafts and adits.

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