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METALS AND DECARBONISATION: A GEOLOGICAL PERSPECTIVE

Andrew Bloodworth[1], Evi Petavratzi and Gus Gunn

British Geological Survey, Environmental Science Centre, Keyworth, Nottingham NG12 5GG, United Kingdom

[1]Contact: ajbl@bgs.ac.uk

Metals are fundamental to human existence. They are ubiquitous in the manufactured goods and supporting infrastructure we use and rely on every day. Metals perform a myriad of functions, including enabling the technologies needed to decarbonise the global economy such as low carbon energy generation and zero emission transport. However, humans use metals in vast quantities and their extraction and processing have profound environmental consequences, particularly in the emission of greenhouse gases. Although metals are an essential component of decarbonisation technologies, their production is currently very carbon intensive. Because all metals originate from the Earth, geologists have a unique perspective on the availability of metals, and the implications of their extraction and use.

Spiralling global demand and ever-increasing pressure on the environment have led the BGS to develop an interest in how 'primary' metals extracted from the Earth flow through society and interact with 'secondary' metals derived from recycled materials. The relationship between primary and secondary raw materials is highly complex, involving a constantly shifting interplay between economic, technological, societal and environmental factors. This briefing summarises the current paradigm for global metal supply and demand, and sets out some of the barriers and opportunities that this presents to the transition to a more sustainable, low carbon economy.

'All metal used in manufacturing, including recycled material, has ultimately been mined from the Earth's crust.'

Primary metal supply from the Earth – mining is a major, global-scale activity

'If you cannot grow it, you have to mine it.' All metal used in manufacturing, including recycled material, has ultimately been mined from the Earth's crust. Demand from population growth and economic and technological development

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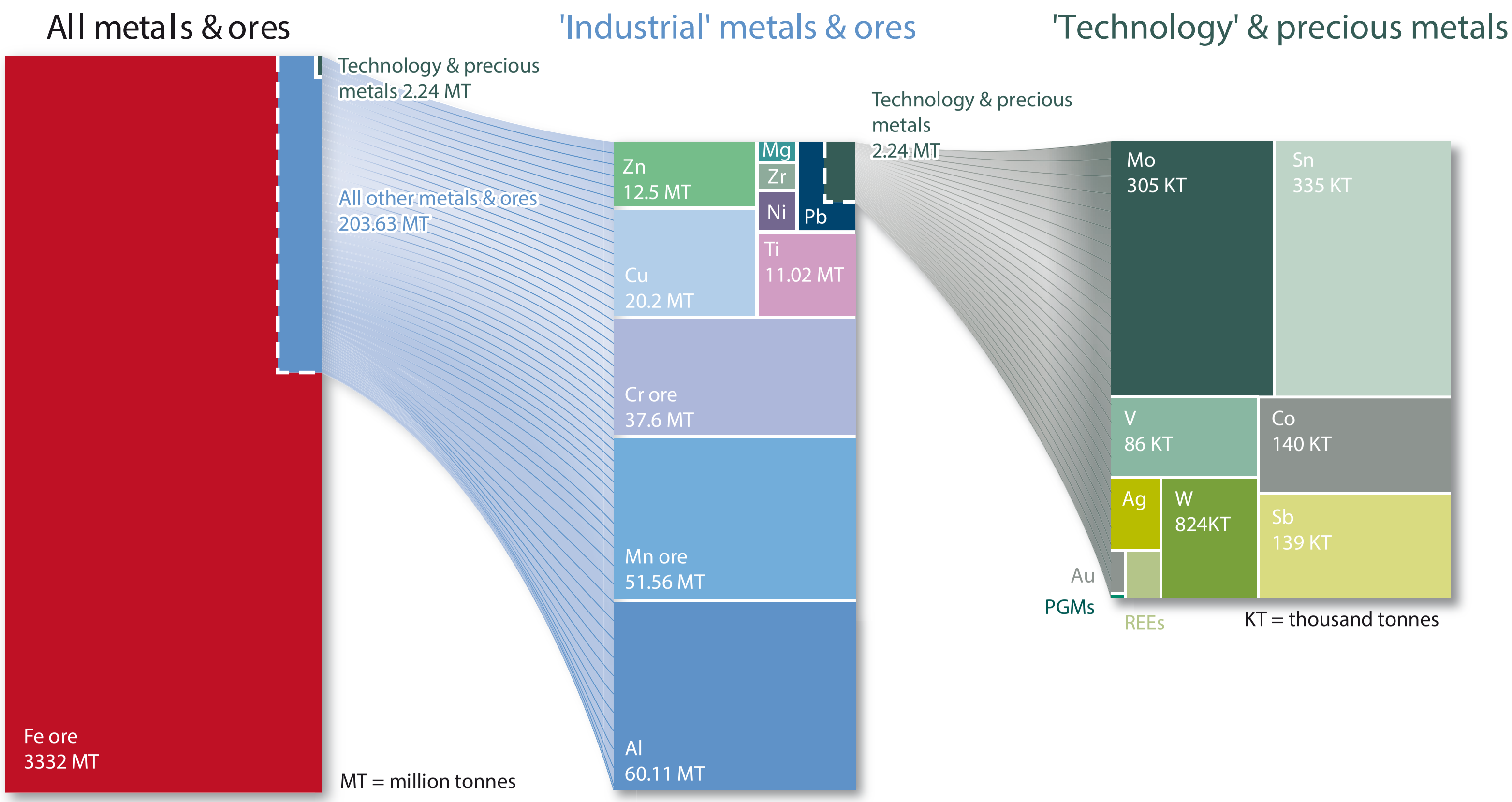

Figure 1 *Global production of primary metals and ores (excluding phosphate rock and potash) in 2017 (tonnes). Total tonnage 3.53 billion tonnes. Source: British Geological Survey, 2019.*

Fe, iron; Zn, zinc; Mg, magnesium; Zr, zirconium; Ni, nickel; Pb, lead; Ti, titanium; Cu, copper; Cr, chromium; Mn, manganese; Al, aluminium; Mo, molybdenum; Sn, tin; V, vanadium; Co, cobalt; Ag, silver; W, tungsten; Sb, antimony; REEs, rare earth elements; Au, gold; PGMs, platinum group metals.

means that the volume and variety of metals produced from the Earth have grown immensely in the last 200 years (Lusty and Gunn, 2014). The global mining industry is now very large. In 2017:

- the top 50 listed mining companies were worth about $896 billion (mining.com, 2018)
- this constituted about 1.1 per cent of global GDP (World Bank, 2018b)
- the global mining industry produced about 3.53 billion tonnes of primary metal/ore
- of which 3.33 billion tonnes was iron ore (British Geological Survey, 2019)

Figure 1 shows global primary production by metal/ore, and illustrates how demand for steel drives the huge production of iron ore that dominates the overall global supply of primary metal. In decreasing volume of production it also shows a group of 'industrial metals' that are used in significant volumes (steel-alloying elements such as chromium, manganese and nickel, as well as aluminium, copper, lead and zinc). Smaller amounts of 'technology and precious metals' (such as magnesium, cobalt, tungsten, gold and rare earth elements) are also produced. Although the amounts produced are orders of magnitude less than iron, steel and the industrial metals, most of these minor metals fulfil vital functional roles in many technologies, including those we need to transition to a low carbon economy.

In satisfying the increasing demand for metal over the last 200 years, the primary supply sector has become a global force. Although the location of workable mineral deposits is very uneven across the world, major advances in exploration, mining and extraction technologies, and transport logistics, together with liberal trade policies, mean that the global mining industry has been able to take advantage of huge efficiency gains and economies of scale. This system has given the manufacturing sector access to secure-relatively cheap supplies of primary metals of consistent and appropriate quality. Although there are sometimes perturbations in the form of price hikes and temporary shortages (Wellmer and Dalheimer, 2012), this supply situation has served the linear manufacturing economy very well for many years. In part, supply chains and manufacturing methods have been configured to maximise the benefits delivered by this economically efficient, global, primary metal supply sector. Driven principally by economic growth in emerging

> 'Driven by economic growth in emerging economies, annual global use of metal will more than double between now and 2060.'

economies, annual global use of metal will more than double between now and 2060 (OECD, 2018).

Recycled metal supply — a sector struggling with technical and socio-economic complexity

Stocks of metal in the human environment (anthroposphere) are theoretically abundant and may be recovered as raw materials through recycling. When compared to production from primary ores, energy savings associated with production of metal from recycled stocks are substantial (Table 1).

Although reliable data on waste production are sparse, global municipal waste production in 2016 was estimated at 2.01 billion tonnes and is expected to increase to 3.40 billion tonnes by 2050 (World Bank, 2018a). Around four per cent of the global municipal solid waste generated in 2016 is estimated to be metals, which equates to about 80 million tonnes. Special waste streams, for example industrial waste, construction and demolition waste, electronic waste and others, are reported separately. At the global level, it is estimated that the quantity of industrial waste (global average waste generation: 12.73kg/capita/day) is around 18 times greater than municipal solid waste and more often finds use in the secondary materials market. The global waste recycling market was valued in 2017 at $264.93 billion and is forecast to grow at a compound annual growth rate of six per cent up to 2024 to reach $376.78 billion (ZION Market Research, 2019).

The recycling industry has an important role to play in the provision of resources and economic growth, but on its own it cannot satisfy the global demand for materials. Currently, metal recycling tends to focus on specific metals such as steel, aluminium and copper. Recycling rates for these high volume 'industrial metals' are often relatively high, sometimes in excess of 50 per cent, whereas rates for lower volume 'technology metals' such as tantalum, indium or rare earth elements are much lower, often less than one per cent (UNEP, 2011). The use of metal scrap is commonly an integral part of the manufacturing cycle. However, products have become increasingly complex over time and recovering valuable elements contained within end-of-life products is a major challenge (UNEP, 2013). In addition to technological complexity, a range of other social, technical and economic factors severely restricts the utilisation of this resource. These include issues such as end-of-life collection, consumer behaviour, product design, metallurgical processing and commodity prices (UNEP, 2013; Hagelüken, 2014). A useful approach might be to consider primary and secondary metal resources together as part of one, sustainable system, rather than considering these restrictive factors in isolation.

Table 1 Energy savings associated with production of some metals from recycled materials. Source: UNEP, 2013.

Metal	Energy saving of recycling (%)
Aluminium	90–97
Copper	84–88
Platinum	95
Steel	60–75
Nickel	90
Gold	98

As long as consumption rates grow, we will continue to need metal from mines (Wellmer et al., 2019). However, a long-term future situation where consumption begins to level off and secondary resources progressively displace mined material can be envisaged. This presumes that the costs associated with identification, collection, processing and extraction of the target secondary metals are similar to those associated with exploration, mining, beneficiation and extraction from natural ore bodies. The efficiency of the primary sector has already been noted. However, current manufacturing practice means that secondary (recycled) metals are often uncompetitive with those from primary sources. Metals are generally incorporated into products with complex compositions and sold into markets across the globe. The 'dispersive' use of metals in products such as mobile telephones makes them hard to recover, as does their combination in functional but thermodynamically incompatible groups (Hagelüken, 2014). Sophisticated waste management systems, along with appropriate incentives, are required to collect these products at the end of their lives. These systems may comprise local or national remanufacturing and recycling, or rely on international trade in metal-bearing recyclates.

'...dispersive use of metals in products such as mobile telephones makes them hard to recover, as does their combination in functional but thermodynamically incompatible groups.'

Toward more sustainable, lower carbon metal supply – the importance of whole system understanding

Although primary metals are non-renewable resources, most geologists consider that physical exhaustion of metal in the Earth's crust is very unlikely in the foreseeable future (Lusty and Gunn, 2014). However, primary metal extraction is energy (carbon) and water intensive (Allwood and Cullen, 2012). Between seven to eight per cent of global energy production is consumed in the extraction and refining of metals (Wellmer et al., 2019). We are, therefore, likely to meet the environmental limits on our use of primary resources far sooner than we will reach physical exhaustion. With this in mind, we must consider what policies or approaches will be most effective in improving the sustainability and reducing the carbon footprint associated with metal supply. Meaningful interventions are difficult to identify without an understanding of the whole system, acquired through good data and metrics on the stocks and flows of these materials as they move from the geosphere through to the anthroposphere (Bloodworth, 2013).

Thus major reductions in carbon emissions and other environmental benefits can be achieved by improving our use, re-use and recycling of the major industrial metals

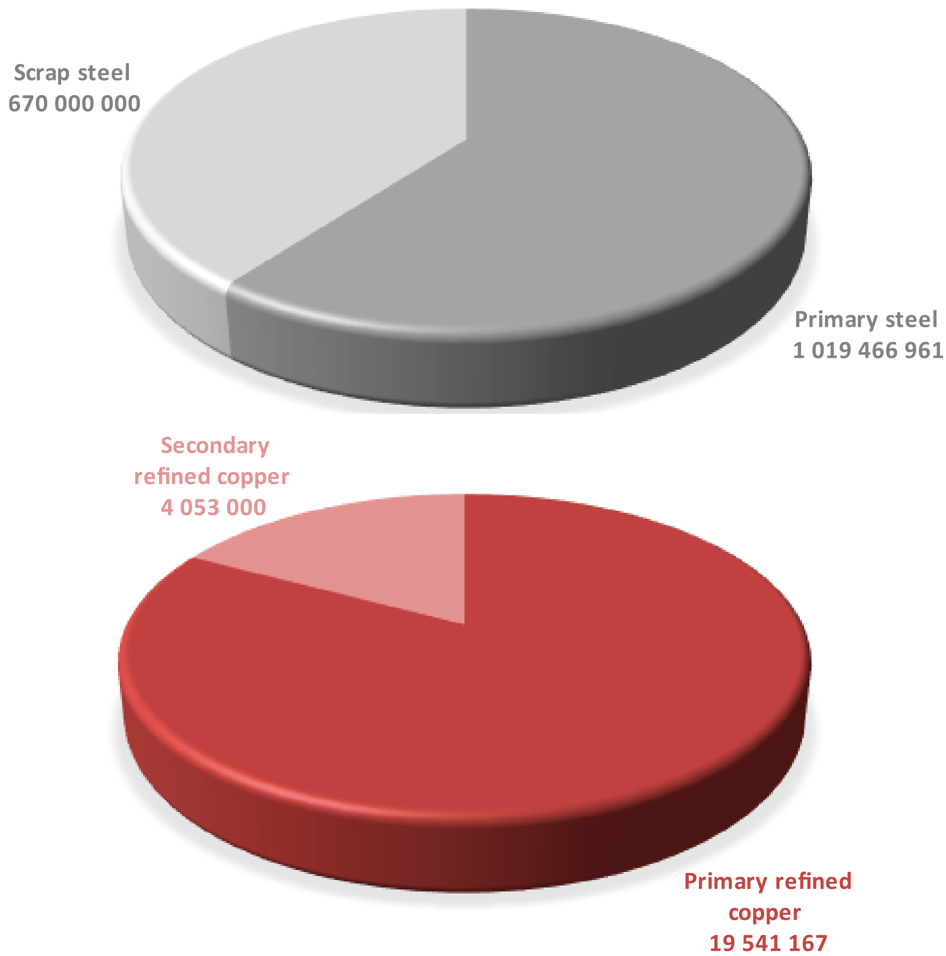

Figure 2 Derivation of steel and copper produced in 2017 (tonnes).
Source: World Steel Association, 2019; International Copper Study Group, 2019; British Geological Survey, 2019.

(such as iron and steel, aluminium and copper). Because we use these metals in such large amounts (Figure 2), even relatively small efficiency gains in their use, re-use and recycling have the potential to help with dematerialisation and reducing the environmental impacts, especially of greenhouse gas emissions, associated with their primary extraction and processing. However, we have also shown that recycling is not a 'magic bullet' to a sustainable, low carbon supply of metal. Considerable technical, economic and social barriers must be overcome to achieve meaningful increases in recycling rates for most metals. Even if this is achieved, growth in global demand means that primary mined metal will still be required.

The mitigation of environmental impacts (including greenhouse gases) associated with metal extraction and use cannot rely solely on abatement of emissions. A step change is also required in the manner in which we produce and consume these resources. Decarbonising our metal use requires multiple interventions, including low carbon extraction, processing and refining of primary metal, increased utilisation of recycled stocks, doing more with less and designing products with re-use, remanufacturing and recycling in mind. A systems approach is needed to ensure that interactions between the economy and environment are properly accounted for, the optimum stages for intervention are identified, and impacts are not hidden by shifting them to other regions or sectors.

For British Geological Survey publications on global metals production and flows go to: https://www.bgs.ac.uk/mineralsuk/statistics/home.html

References

ALLWOOD, J M, and CULLEN, J. 2012. Sustainable materials — with both eyes open Cambridge UIT Cambridge Ltd.

BLOODWORTH, A. 2013. Resources: track flows to manage technology-metal supply Nature News Nature Publishing Group December 2013: 19–20.

BRITISH GEOLOGICAL SURVEY. 2019. World mineral production 2013–17. Keyworth, Nottingham British Geological Survey

HAGELÜKEN, C. 2014. Recycling of (critical) metals Critical Metals Handbook. A G GUNN, BGS, AGU & Wiley.

INTERNATIONAL COPPER STUDY GROUP. 2019. World Refined Copper Production and Usage Trends 2013–2019 [online]. https://www.icsg.org/index.php/component/jdownloads/finish/165/871

LUSTY, P A J, and GUNN, A G. 2014. Challenges to global mineral resource security and options for future supply. Geological Society, London, Special Publications 393.

MINING.COM. 2018. Value of top 50 mining companies surge $140 billion in 2017 http://www.mining.com/value-top-50-mining-companies-surge-140-billion-2017/

OECD. 2018. Global Material Resources Outlook to 2060. OECD Paris.

UNEP. 2011. Recycling Rates of Metals. A Status Report of the Working Group on the Global Metal Flows to the International Resource Panel. *Graedel et al.*, UNEP.

UNEP. 2013. Metal Recycling – Opportunities, limits, infrastructure. A Report of the Working Group on the Global Metal Flows to the International Resource Panel. *Reuter et al.*, UNEP.

Wellmer, F W, and Dalheimer, M. 2012. The feedback control cycle as regulator of past and future mineral supply. Mineralium Deposita **47** (7): 713–729.

Wellmer, F W, Buchholz, P, Gutzmer, J, Hagelüken, C, Herzig, P, Littke, R, Thauer, R K. 2019. Raw materials for future energy supply. Springer International Publishing AG. Switzerland.

World Bank. 2018a. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648-1329-0. License: Creative Commons Attribution CC BY 3.0 IGO.

World Bank. 2018b. World Development Indicators database: gross domestic product 2017.

World Steel Association. 2019. Raw Materials [online]. https://www.worldsteel.org/steel-by-topic/raw-materials.html

Zion Market Research. 2019. Waste Recycling Services Market by Waste Type (Compost & Food Waste, Glass & Fiberglass, Metal Scraps, Waste Paper, Electronic Waste, and Others) and by Application (Municipal, Industrial, and Others): Global Industry Perspective, Comprehensive Analysis, and Forecast, 2018—2024. Retrieved 06/06/2019, from https://www.zionmarketresearch.com/report/waste-recycling-services-market.