Road map to mineral supply

Richard Herrington

Access to metals and minerals is restricted mostly by geopolitical constraints, and not by a shortage of mineable deposits. In the face of rising demand, a full inventory of these commodities — in the Earth's crust as well as in recyclable waste — is urgently required.

When China stopped exporting rare earths to Japan in 2010 for almost two months, the rather tenuous nature of the mineral supply chain came into full focus. The move threatened to hit the renewable energy sector that relies on high-strength magnets fabricated from those metals, and made headlines around the world. As a result, the notion that the extraction of metals and minerals from the Earth's crust may soon reach its highest level and decline from then on — termed 'peak minerals' — has received renewed attention.

Metals and minerals — like fossil fuels — are distributed unevenly across the planet, concentrated in small volumes of the Earth's crust through distinct geological processes. As non-renewable resources, they cannot be replenished by humans and are inherently finite. 'Limits to supply' of these non-renewable resources were most famously predicted in 1972[1]. However, many studies on the concept of peak minerals or peak metals rely on estimates of mine reserves — that is, the economically extractable portion of a resource — as an accurate measure of what the planet has to offer[2]. This approach is flawed, because estimates of mine reserves vary substantially over time as a function of metal prices and the costs of recovery.

Specifically, the costs of extraction change as mining technology advances. Economic viability of exploitation fluctuates with metal and mineral prices; thanks to new technologies, raw materials can now be recovered from deposit types that were considered inaccessible a few decades ago, and models that are used to estimate ultimate resources are constantly being improved. For example, copper resources at depths accessible to mining have been estimated[3] to be large enough to supply world production for 5,500 years, way beyond the 61 years proposed by economists in 2007[2]. Furthermore, slowing global economic growth, improved recycling, higher process efficiency and longer product life have all served to allay the ultimate fears of peak supply. But despite this more optimistic view on the total supply, it is not straightforward to ensure access to the Earth's wealth in metals and minerals for all who need it.

The actual availability of commodities today is controlled not only by geological accessibility, but also by social constraints, politics, legislation, environmental regulations, economics and the availability of skilled professionals to find and extract the resources. Notably, the geographical restriction of key deposits leads to a potential for local environmental issues or political manipulation to deny access to supply. This is unlikely to change in the foreseeable future.

I therefore argue that a more reliable inventory of the distribution of the full diversity of commodities in the Earth's crust is needed, particularly from those regions

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Figure 1 | Chuquicamata open-pit copper mine in Chile, one of the largest in the world. Chile currently accounts for over 30% of the world's mined copper and 50% of its rhenium supply.

where supply to industrial markets can be guaranteed. An optimized inventory will make it more straightforward to track the provenance of mineral commodities and unravel unethical supply chains — both from an environmental and humanitarian point of view.

The big scale-up

Metal and mineral availability is naturally dictated by geographical restrictions. This circumstance is, however, exacerbated by the increasing concentration of production in the hands of a few global corporations. Seeking an economy of scale, the largest mining companies develop ever-growing mega-mines and processing facilities, to the point where the bulk supply of some commodities — sometimes more than 50% — becomes focused in a handful of geographical regions (Table 1). For example, only two mines in South Africa supply more than 80% of the world's platinum, a metal essential for catalytic converters and new fuel cell technologies. And even a widely used metal such as copper has more than 30% of its production in Chile (Fig. 1). The political risks inherent to such a lack of geographical spread of key raw materials were clearly demonstrated during the oil crisis in the 1970s, when restrictions to supply of oil from the Middle East resulted in price hikes and downturns in the western economies.

> Illegal and often unethical mining has been effectively condoned by the market place for the sake of access to rare and high-value commodities.

Opening up giant resources that are often located in vulnerable and challenging remote locations makes balancing development and environmental protection a precarious task. The new frontiers of discovery are places such as the wilderness area of Alaska. Canadian mining company Teck runs the world's largest zinc mine, called Red Dog, in the Arctic of Alaska, from where they can only ship concentrate out to Canada between July and October each year because of the winter sea ice. In this pristine region, the environmental stewardship is demanding[4]. UK-based mining company Anglo American and partners are looking to develop a new large copper mine in Alaska in another sensitive environmental area. Again, the benefits have to be weighed carefully against any disturbances[5].

Finally, the effort required to provide the necessary infrastructure for these giant mines outweighs by far the difficulties in discovering, opening and operating the mine itself. At Red Dog, a 75 km all-season road had to be built to truck the ore to a new port built on the Alaska coast. For the Simandou iron-ore project in Guinea, West Africa, the UK company Rio Tinto was able to confirm the rights to produce 95 million tonnes of ore per year only on the condition of significant infrastructure development. The agreement with the Guinean government asks for the construction of a 670 km trans-Guinean railway to the Guinean coast and the development of a new deep-water port south of the capital Conakry[6] to bring development and infrastructure to the host country, rather than opening a shorter railway route to the coast through a neighbouring country where a port already exists.

Metals in mine waste

Not only giant mines are on the rise — the portfolio of elements used in new technologies in relatively small quantities is expanding, too. Rarer metals are required in the production of the next generation of photovoltaic devices, computers, mobile phones and other components of a high-tech, low-carbon economy. In addition, the Materials Genome Initiative in the US[7] aims to shorten the lead-time from discovery to application for new materials; this is likely to create a demand for the rarer elements at short notice.

Technology metals such as indium, rhenium or cobalt generally lack their own production infrastructure. Instead, they are largely recovered as by-products from the mining and refining of another metal. Rhenium, for example, is essential for the production of nickel superalloys that are used in the aerospace industries. Its total production amounts to a mere 45 tonnes of metal per year, and more than half of the world's rhenium comes as a by-product from copper mining in Chile. The availability of these elements can rise and fall dramatically: industrial unrest at the Chilean copper mines in 2008 resulted in supply constraint and a meteoric rise in the price of rhenium[8]. More worryingly, potentially valuable by-products are often not recovered, because suboptimal processing methods were implemented when the mine started up many years ago. Inertia often holds back attempts to upgrade processing.

Unsavoury origins?

Conflict diamonds and coltan (short for columbite-tantalite) have been exposed as commodities mined to finance weapons in war zones. More recently, leading electronics companies were implicated in the sourcing of illegally mined tin in Indonesia[9], highlighting that unregulated, illegal and often unethical mining has been effectively condoned by the market place for the sake of access to rare and high-value commodities. Tracking the origin of mineral supply, similar to the efforts of the food industry to achieve source traceability, is therefore increasingly being seen as necessary.

The Kimberley Process, a joint initiative from governments, industry and members of society to illuminate the provenance of traded diamonds, has successfully run for a number of years. A Fairtrade scheme is now in place to provide an ethical certification scheme for artisanal and small-scale gold miners[10]. The scheme could potentially be expanded to cover other rare commodities where supply chains are ambiguous.

Table 1 | Geographical restrictions on non-energy commodity supply

Commodity	Producer	Market share %
Rare Earths	China	97
Antimony	China	91
Gallium	China	83
Platinum	South Africa	80
Germanium	China	79
Tungsten	China	75
Indium	China	58
Silicon	China	58
Tantalum	Australia	53
Rhenium	Chile	53
Chromium	South Africa	45
Cobalt	Congo	45
Lithium	Chile	44
Iron Ore	China	43
Palladium	Russia	43
Vanadium	South Africa	38
Copper	Chile	31

Compilation table showing commodities where one country is responsible for >30% of the world mine production, showing the percentage market share (2008–2012 figures)[17,18].

Old World riches

A different solution to the problem of determining provenance would be the local sourcing of minerals. Indeed, some raw materials may be available closer to home than we think. Copper was first produced from mines in Europe more than 4,500 years ago. Both the European Renaissance and the Industrial Revolution were underpinned by production from Europe's non-renewable resources[11].

Despite centuries of production, there is still good potential to find more. Current mining operations in Europe yield significant amounts of base and precious metals, and regions such as Fennoscandia, Spain, Ireland and even the UK have yielded new discoveries and the re-evaluation of known prospects with a view to mining[12]. Innovative biology-based technologies developed in Europe have unlocked low-grade, previously uneconomic ore[13]. These initiatives have opened the possibility of a new generation of sustainable mining in our own back-yard — which could address concerns about ethical sourcing, and shift control of energy and water use as well as environmental stewardship to the regional scale.

Existing European operations could also be modified to recover many metals essential for new technologies. With the latest technologies, nickel extraction operations in Greece and the Balkans could recover up to 30% of Europe's demand for cobalt from material currently discarded as processing waste[14]. In another case, phosphate wastes from the iron ore mines in Sweden could be reprocessed for rare Earth elements[15], whose shortage caused such a stir in 2010.

Urban mining — the retrieval of raw materials from household waste — is also a potential source of technology metals. Discarded electronic equipment could be recycled locally, instead of being shipped to Asia for processing[16]. To achieve this, the European Union and a number of other countries have banned the export of computer waste. Better component labelling and less inbuilt obsolescence could prevent valuable components from being lost in the mountains of waste.

A role for geoscientists

The discovery and exploration of these non-renewable mineral resources, as well as their environmentally safe handling, are key tasks for geoscientists. Reliable assessments are needed of the global distribution of resources, of the potential for supply disruption, and of the environmental consequences of their use. With both the world's population and its standard of living on the rise, demand for minerals is bound to soar.

We must acknowledge and control the complexity of giant mining projects with their demands on infrastructure and the environment. We need to work hard to understand any ethical issues with the provenance of new resources. Better ways of recycling valuable metals from discarded electronic equipment are required. And geoscientists need to undertake a thorough audit of the natural occurrences of mineral deposits that will feed our economies. There may well be high future demand for elements that many people have never even heard of. ❐

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References

1. Meadows, D. H., Meadows, D. L., Randers, J. & Behrens, W. W. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (Universe Books, 1972).
2. Cohen, D. *New Scientist* **2605,** 34–41 (2007).
3. Kesler, S. & Wilkinson, B. H. *Geology* **36,** 255–258 (2008)
4. http://reddogalaska.com
5. http://www.pebblepartnership.com
6. http://www.riotintosimandou.com/ENG/media/media_releases_1536.asp
7. http://www.whitehouse.gov/mgi
8. http://in.reuters.com/article/2008/07/10/metals-rhenium-idINL1037587920080710
9. http://www.theguardian.com/environment/2013/apr/25/samsung-tin-mines-indonesia-child-labour
10. http://www.fairtrade.org.uk/gold
11. Lynch, M. *Mining in World History* (Reaktion Books Ltd, 2002).
12. *European Exploration: A record-breaking year* (Mining Journal Report, 23 March 2012).
13. Riekkola-Vanhanen, M. *Nova Biotechnologica* **10,** 7–14 (2010).
14. Herrington, R. *Geophys. Res. Abstr.* **14,** EGU2012–13888 (2012).
15. http://www.metal-supply.com/article/view/58422/waste_turns_to_gold_at_lkab
16. http://sometimes-interesting.com/2011/07/17/electronic-waste-dump-of-the-world
17. Korinek, J. & Kim, J. *OECD Trade Policy Working Paper No. 95* (2010); http://www.oecd.org/trade
18. Merchant Research & Consulting Ltd; http://mcgroup.co.uk

Metals for a low-carbon society

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Renewable energy requires infrastructures built with metals whose extraction requires more and more energy. More mining is unavoidable, but increased recycling, substitution and careful design of new high-tech devices will help meet the growing demand.

Renewable energy forms the basis for a low-carbon society. Numerous wind turbines, solar power stations and other facilities will need to be constructed if a significant proportion of global electricity is to be produced sustainably. Building these facilities will require vast amounts of metals and other raw materials, which will then be sequestered for several decades and cannot immediately be recycled. Easily mined ore deposits are quickly declining and although new resources will be found in the deep subsurface or in remote locations, mining these deposits will consume large amounts of energy. Humankind faces a vicious circle: a shift to renewable energy will replace one non-renewable resource (fossil fuel) with another (metals and minerals).

Potential future scarcity is not limited to the scarce high-tech metals that have received much attention. The demand for base metals such as iron, copper and aluminium, as well as industrial minerals, is also set to soar. Here we argue that energy production and the recovery of metals and minerals are inseparable issues that need to be addressed in one comprehensive framework.

A low-carbon future

Dependence on fossil fuels, such as oil, gas and coal, has caused pollution and environmental damage. We now look forward to a low-carbon society where renewable resources of energy replace fossil fuels. Renewable power resources coming from the sun (175,000 TW), geothermal flux (40–50 TW) and gravity (for example, tidal energy, 3–4 TW)[1] could supply a thousand times our current and future (2050) global energy needs, estimated at 140 × 10^3 TWh (16 TW) (ref. 2) and 280 × 10^3 TWh (32 TW) (ref. 3), respectively. However, most renewable