MINERAL RESOURCES: NATURE'S MOST VERSATILE LIFE SUPPORT SYSTEM

Christopher J. Morrissey
Independent Economic Geologist, Bath, England

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Summary

Mineral resources have been pivotal to human development since the dawn of recorded history. The raw materials they provide play essential roles in every material aspect of life and are continuously finding new uses. They rank as a life support system because life without them would be short and uncomfortable for the vast majority of the human race.

By any reasonable definition, mineral resources are exceedingly abundant and significantly renewable.

Known resources of every mineral commodity underwrite supplies well into the future. Current supplies come from a worldwide multitude of mines with various forms of ownership and extreme differences in scale and technical sophistication.

Resource depletion is being outstripped by new mineral discoveries. The pattern of discovery is reinforcing a trend for production to become concentrated geographically and in the hands of a fairly small number of state enterprises and public companies.

Global demand for mineral products is constantly increasing. Recycling helps to meet demand on a wide front, but to a large extent demand has to be met by land-based mining. Other sources of supply are only viable for a few commodities and are not likely to lessen the future need for mining on an enormous scale.

The characteristics of mining do not rule out making it a sustainable activity in the eyes of host communities and governments. The onus for achieving that goal rests on them and their advisors as well as on mining companies. It is achievable through consultation, technical expertise, and imaginative forward planning.

1. Introduction

Nature provides only a few major classes of raw material. Although the past hundred years have seen enormous growth in the use of synthetics based on hydrocarbons, natural metals and minerals still have a vast number of uses. It is as true now as it was in 1556, when these words of Georgius Agricola in *De Re Metallica* were first published, that:

> If we remove metals from the service of man all methods of protecting and sustaining health and more carefully preserving the course of life will be done away.

Very few of the chemical elements that are the basis of all matter are common in nature as native metals or alloys. Gold is one of the exceptions, along with platinum group metals, silver, copper, and a few others. Only gold is mined largely in its original metallic form. All the other metals, semimetals, and semiconductors referred to in this article are produced mainly or entirely from naturally occurring chemical compounds termed "minerals."

The versatility of metals and alloys rests on their extremely wide range of physical and chemical properties. Some of the ways in which they differ from one another are specific gravity, melting point, hardness, electrical conductivity, tensile strength, ease of working, and resistance to oxidation.

To appreciate how wide the differences are it is only necessary to make a mental comparison between (say) hard, corrosion-resistant chromium and fluid, volatile mercury.

The range of properties at normal temperatures and pressures is greatly expanded at other temperatures and pressures. Metal-based superconductors, for instance, only become efficient at temperatures approaching zero degrees Kelvin. The range can also be expanded by additives ("doping"). Silicon doped with traces of heavy metals is the main constituent of computer microchips.

Turning to minerals, there are about 3 000 named species of which about a half have practical uses. With many of them the main or only use is as a source of the metals they contain. These are termed "ore minerals," to distinguish them from another large group loosely termed "industrial minerals." Included in this group are feedstock minerals for a great variety of chemical processes such as the manufacture of fertilizers and cement. It is difficult to exaggerate the variety and practical importance of industrial minerals, which merge with another major group of natural resources exemplified by building stone and natural aggregates.

Mineral raw materials prove their versatility by playing essential roles in every material aspect of life, and by continuously finding new uses as lifestyles change. Whatever the lifestyle, it is rarely possible to look around and see nothing made from minerals or with mineral-based tools. Directly and indirectly, people in well-off societies use hundreds of mineral products every day. They usually do not realize it, and since minerals generally are raw materials rather than end products, mineral producers make little effort to explain their usefulness to the general public.

2. Uses of Metals and Minerals

Table 1 lists the main uses of a range of metals and a few industrial minerals. Some are deeply traditional, like the use of gypsum for plaster and of gold for jewelry. Many became important as more and more activity, not only work, was handed over to machines—a continuing trend in virtually all societies. Many stem from the harnessing of electricity as a power source, petroleum as a motive force, and of electrons as a means of storing and transferring information.

One area of life in which minerals play a crucial role is in the creation and maintenance of what can loosely be called "infrastructure"—power lines, water distribution systems, roads, railways, bridges, telecommunication networks, hospitals, schools, and buildings of every sort. That list could be much longer, and it only takes a moment's thought to appreciate where mineral-based materials make their contribution in each case. In affluent countries infrastructure tends to be taken for granted, and some aspects of it resented, but to a large extent better infrastructure is the key to higher standards of living. That last term covers better housing and better facilities for education and health care as well as greater freedom of movement and communication.

Another large area of use is consumer goods, some as essential as food and clothing. Minerals support food production as fertilizers and soil conditioners, and then right through the supply chain in such things as tractors and packing equipment. Clothing depends on minerals in analogous ways, and again there are very few exceptions. Without minerals, clothing would mainly be animal skin.

Most so-called "consumer durables"—television sets, washing machines, refrigerators, air conditioners, motor cars, and so on—are mineral-based to a considerable extent. Television sets, for instance, contain as many as 30 different metals. Probably the most contentious, especially in parts of the world where there are plenty of them, are motor cars. Typically, about two-thirds of the weight of a modern car is made up by metals, principally steel, aluminum, copper, lead, and zinc. Car batteries account for a high proportion of the total use of lead. Tomorrow's car will be different—but see below.

Table 1 makes it clear that focusing on infrastructure and consumer goods leaves wide areas of mineral use unmentioned. One area is the industry that makes the tools that make the goods. Another is armaments, though they normally account for only a small proportion of mineral usage.

Metals, metallic minerals and derivatives	
Aluminum	Transport (vehicle components), building, packaging, consumer durables
Antimony	Flame retardants, transport
Arsenic	Industrial and agricultural chemicals, e.g. wood preservatives, herbicides
Beryllium	Electronic components, aerospace, defence
Bismuth	Chemicals and pharmaceutical, metallurgical, e.g. casting
Cadmium	Ni–Cd batteries, pigments, plating
Chromium	Stainless steel, refractories. chemicals
Cobalt	Superalloys, magnetic alloys
Copper	Electricity transmission, electrical equipment, construction, engineering
Gallium	Opto-electronics e.g. liquid crystals, integrated circuits
Germanium	Fiber optics,infrared systems, semi-conductors
Gold	Jewelry, electronics
Indium	Solders and alloys, coatings
Iron	Steel-making, ferroalloys, wrought and cast iron (numerous applications)
Lead	Storage batteries, sheeting and piping for construction etc.
Lithium	Ceramics and glass, aluminum production, batteries, lubricants
Magnesium	Lightweight alloys, castings, refractories, chemicals
Manganese	Ferroalloys and aluminum alloys for machinery, transport etc.
Mercury	Instruments, batteries, electrical and electronic equipment
Molybdenum	Stainless steel, construction, chemicals, ceramics
Nickel	Stainless steel and alloys used in transport etc., electroplating
Niobium	Light alloys and steel, superalloys
Platinum group	Autocatalysts, jewelry
Rare Earths	Catalytic converters, petroleum cracking, permanent magnets
Rhenium	High-temperature superalloys, petroleum refining
Selenium	Glass, chemicals, pigments, electronic components
Silicon	Ferrous and steel products for transport, construction, engineering etc.
Silver	Photography, jewelry, silverware
Tantalum	Electronic components (capacitors), cutting tools
Tellurium	Iron and steel products, catalysts, rubber compounding, electronics
Tin	Tin plating, solders, alloys, chemicals
Titanium	Aircraft construction, pigment for paint, paper, plastics
Tungsten	Cutting tools, electric light filaments, superalloys
Uranium	Nuclear power generation, armaments
Vanadium	Special steels for machinery, construction, transport etc.
Zinc	Galvanizing, brass, die-cast components for construction, transport etc.
Industrial minerals	
Asbestos	Brake linings and other friction products
Fluorite	Aluminum and steel production
Graphite	Refractories, brake linings
Kaolin	Paper coating and filling
Phosphate	Fertilizers, animal feed supplements
Potash	Fertilizers, chemicals
Soda ash	Glass, chemicals, detergents
Sulphur	Fertilizer production, petroleum refining, chemicals

Source: modified from Crowson, 1998.

Table 1. Main uses of some metals and minerals. Source: modified from Crowson, 1998.

Note the frequent mention of electronics in Table 1, and references to such things as liquid crystal displays and superconducting alloys. These are low-intensity uses—the entire computer microchips made in a year requires only a few thousand tonnes of silicon, for instance—but a wide range of metals and metallic compounds is involved, and it is a rapidly expanding area of use. Most of the new "tools" that people now use for work, leisure, and convenience depend in some way on metals and their derivatives. Mobile phones are a good example: their proliferation has driven a surge in demand for tantalum, which has nearly doubled over the five years to 2003.

With some high-intensity uses like vehicle manufacturing the future is obscure. Globally there is a large unsatisfied demand for personal transport, and vehicle production volumes are rising fast. However, the car of tomorrow will be different from that of today, probably with a lower metal content and a different starting system. Yet it will surely contain a wide range of metals, and its nonmineral components as well as its actual construction will depend on mineral-based tools. To repeat the opening sentence: nature provides only a few major classes of raw material.

3. The Scale of World Demand

By value
Very large (say US$20–35 billion per year each):
Aluminum, copper, gold, iron ore

Large (say US$5–10 billion per year):
Zinc, nickel, gem diamonds, silicon, phosphate

Next largest (say US$1–5 billion per year):
Lead, potash, sulfur, silver, platinum group metals, kaolin, cobalt, magnesium, manganese, molybdenum, uranium, asbestos

Others more than about US$100 million per year:
Chromium, titanium, vanadium, industrial diamond, soda ash, talc, asbestos, fluorspar (0.5–1.0 billion)
Antimony, barite, beryllium, boron, iodine, lithium, magnesite, niobium, rare earths, tungsten

By volume
Very large (say 1 billion tonnes per year):
Iron ore

Large (say 100–500 million tonnes per year):
Salt, phosphate rock, bauxite (aluminum ore), ores of gold and copper

Note: This table is intended simply to give an idea of the league rankings of mineral commodities with world markets worth more than about $100 million a year. It is based on 1996 productions and 1997 average prices. Source data are from Crowson, 1998.

Table 2. Scale of demand for mineral products

Table 2 gives an idea of the scale of world demand for metals and minerals. It is takes account of secondary production (recycling) where that contributes to meeting demand. For comparison, world oil consumption in 1999 was 3.46 billion tonnes currently valued at about US$750 billion, and world coal production was about 4.6 billion tonnes.

Recycling is an increasingly important source of supply, but for most metals and minerals world mine production continues to be a key measure of recurrent demand. For some it is the only measure of demand, inaccurate though it may be year-to-year because of lags between production and usage. Only gold is stockpiled in amounts that greatly exceed recurrent demand. (About 85% of the gold ever mined, estimated to have totaled 128 000 tonnes, can still be accounted for in "stocks" of one kind or another.)

Table 3 shows 1999 world mine outputs of some major metals and minerals, and lists the leading producers by country. Metal outputs are given as the metal content of mine products, ignoring small losses during smelting and refining. With aluminum the mine output figure is for bauxite, which has to be converted to synthetic alumina to give a feedstock for metal production.

Metal	*1999 world mine output*	*Typical ore grades*	*Largest producers*
Iron (ore)	1,010 Mt	35–66% Fe	China, Brazil, Australia,Russia
Aluminum (bauxite)	131 Mt	55–65% Al_2O_3	Australia, Guinea, Brazil, Jamaica
Copper	12.7 Mt	0.5–2.0% Cu	Chile, USA, Indonesia, Australia
Zinc	8.1 Mt	4–10% Zn	China, Australia, Canada, Peru
Nickel	1.08 Mt	1–5% Ni	Russia, Canada, Australia, New Caledonia
Gold	2,490 t	2–10 g t^{-1} Au	South Africa, USA, Australia, China

Source (except typical ore grades): BGS, 2000.
Mt: million tonnes

Table 3. World mine output of major metals. Source (except typical ore grades): BGS, 2000.

Metal recoveries into mine products are never complete. With the main metals they are more likely to be 80–90%. On the other hand, many ores yield more than one metal. Common coproducts are nickel and copper, copper and molybdenum, and lead and zinc. Mixed metal ores make an important contribution to world mine supplies of precious metals.

A number of minor metals (for instance, cadmium, indium, rhenium, and tellurium) are only mined as trace constituents of base or precious metal ores. Others like tantalum and niobium are mined for their own sake but in trivial amounts compared with the major metals.

Typical ore grades in Table 3 give an idea of the amount of ore that has to be mined and processed to yield a given amount of new metal. Note their wide spread, from a few parts per million for gold to over 65% for iron. Some ores have grades well outside the quoted ranges, for instance a large single-metal gold mine in Brazil with a mean ore grade of about 0.45 g t^{-1} Au.

Ore grades give little indication of the amount of material that may have to be moved in the production process. Subeconomic and/or barren material usually has to be mined to get access to ore, and to engineer efficiency and safety into ore production. There is little or no direct income from this material, so mine operators minimize it as far as they can. Overall, it nevertheless represents a significant multiplier of the amount of ore that has to be produced to meet the needs of metal and mineral users.

Table 4 shows rates of growth in world mine production of four major metals in the 1970s and 1980s. It belies the idea that mineral production is an industry that has outlived its usefulness. In fact, consumption of metals and minerals is still a key indicator of progress towards higher standards of living in large parts of the world.

	Percentage growth per year	
	Medium-range (1970–2000)	*Short-range (1990–2000)*
Aluminum	2.4	3.2
Copper	2.0	3.6
Lead	0.7	2.1
Nickel	2.0	3.7
Zinc	1.4	3.0

Source: *Rio Tinto 2000 Data Book*

Table 4. Growth in world consumption of major metals. Source: *Rio Tinto 2000 Data Book.*

Progress in that sense is reflected by trends in per capita use of particular metals like copper and aluminum, and of mineral raw materials used in construction and agriculture. Historically, there are definite relationships between figures of that sort and others that reflect the prosperity and well-being of the society concerned, for example, average income, average longevity, the number of doctors per unit of population, and the proportion of school-leavers going on to tertiary education.

The relationships are complex, and differ considerably from one mineral commodity to another. Using copper as an example, a recent study identified several different patterns of consumption at the national level. They can be described most simply by saying that a) developing countries tend to use more copper per head as they get richer but do not do so systematically or irreversibly, and that b) copper consumption in relatively rich countries tends to decline from levels that may be as high as 18 kg per head per year or as low as 1 to 2 kg per head per year.

Reading the future into this sort of information is difficult and risky. With copper it is possible to calculate that current world reserves could run out just a few years into the twenty-first century, justifying heavy investment in exploration for new deposits and a rush to get unworked deposits into production. An alternative reading of the omens sees long-term adequacy of reserves, cyclical over-production, and long periods when there will be little incentive to explore for copper or commission new mines. Similarly conflicting projections can be made about many metals and minerals.

In any case, there is a continuing need for mining on a very large scale. Meeting world demand for new metal makes it necessary to mine many billions of tonnes of ore each year, plus a similarly large tonnage of waste and lean rock. Industrial minerals make large additions to the total, construction materials even larger.

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Biographical Sketch

Christopher John Morrissey qualified as a mining geologist at the Royal School of Mines, London, and obtained his Ph.D. there in 1970. After five years with the Northgate Group as an exploration geologist in Ireland and Canada, he returned to the Royal School of Mines as Research Fellow on a contract in Saudi Arabia. He joined the RTZ (now Rio Tinto) Group in 1977 as manager of exploration in Europe and South America and retired as Group Chief Geologist (Western Hemisphere) in 1998. He was on the Board of the British Geological Survey for many years. He continues to take an active interest in mineral exploration and writes occasional articles for lay and technical publications.