Mining, Minerals and Sustainable Development

www.iied.org/mmsd

MMSD Draft Report for Comment
4 March 2002

Part II: Current Trends and Actors

Chapter 4
The Need for and Availability of Minerals

International Institute for Environment and Development

World Business Council for Sustainable Development

Mining, Minerals and Sustainable Development is a project of the International Institute for Environment and Development (IIED) in London, UK.
The project is made possible by the support of the World Business Council for Sustainable Development (WBCSD).
IIED is a company limited by guarantee and incorporated in England. Reg. No. 2188452. VAT Reg. No. GB 440 4948 50.
Registered Charity No. 800066

Chapter 4: The Need for and Availability of Minerals

The 'Need' for Minerals 2

Need Versus Demand 3

Basic Needs 4

Seeking a Balance 4

The Availability of Minerals 5

Physical Measures 6

Economic Measures 8

Global Versus Local Scarcity 10

Assessing Long-term Availability 11

Conclusion 12

The Sustainable Development Imperative 12

This chapter considers how to assess society's 'need' for minerals. People use minerals and products made from or with minerals in a nearly infinite number of ways. Yet any discussion of 'need' must include consideration of the availability of resources to meet those needs. Growth in world population together with improvements in standards of living in many countries and the development of new uses for minerals have fuelled the pace of exploitation. This in part has been facilitated by advances in technology that allow lower-cost and more-efficient extraction along with increased recycling. To balance the discussion of need, the second part of the chapter therefore looks at the availability issue.

The 'Need' for Minerals

One way to assess the need for minerals is to look at the benefits derived from the use of mineral products – from minerals consumed directly, such as zinc dietary supplements, to durable uses such as tools, bricks, and aeroplanes as well as non-mineral products that are made through the use of minerals (such as food produced using tractors, ploughs, and other equipment made with metal). Society today is highly dependent on the use of most metals and minerals for energy generation and transmission, mobility and transportation, information and communication, food supply, health delivery, and countless other services. Minerals use and production is also essential in terms of the livelihoods provided through employment and income generation. (See Chapter 3 for a detailed discussion of the end-uses of minerals and the employment generated in the sector).

The demand for mineral commodities is likely to rise with increases in population and real per capita income. Judging by the experience of industrial countries, rising income leads to increases in life expectancy and population. As development proceeds and, among other things, education and health care are extended to women, the birth rate declines and population growth slows and eventually ceases. A similar trend might be expected in developing countries over the next 50–100 years. Current projections suggest that global population will reach 9 billion by 2050 and then stabilize at 10–11 billion by the end of this century.[1] Most economists also believe that per capita income will rise over the next century. The difficult questions regarding the use of minerals are, how fast will income rise? How much of the growth will occur in developing countries, where the elasticity of demand for minerals is likely to be greater and focused on high metals-intensive products, such as infrastructure? What are the implications for minerals and metals use of mass rural-to-urban migration?

Particularly in industrial countries, increases in demand caused by growth in population and income may in part be offset by increases in the intensity of mineral use as a result of new technologies. Improved materials have led to reductions in mineral consumption in many applications, and the creation of new materials has led to substitution. However, increases in population and income, particularly in countries in metal-intensive phases of development, will undoubtedly have major ramifications for the demand for minerals and necessitate more-efficient methods of production, use, and recycling.

Need Versus Demand

Even when the discussion is limited to the benefits of mineral use, there are different ways to look at need. A basic economics textbook definition of 'need' sees it as synonymous with the demand for a particular product. Individual consumers determine need by their choices in the marketplace. If there are people willing to pay a price that provides an adequate return to a producer, the product is by definition 'needed'. In this view, the amount of any mineral that is needed is the amount that consumers will purchase at the prevailing price.

The problem with this strictly free-market approach is the notion that a desire constitutes a need – that is, if someone is willing to pay for it, the need is established. Yet the fact that a market exists for something does not constitute adequate demonstration that a need exists. Markets and the demand for products are sensitive to consumer taste, fashion, and advertising (as seen in the current advertising campaign aimed at stimulating demand for gold). Moreover, in the absence of the 'needed' commodities, demand may be met in other ways. Finally, there are endless examples of things people may like to buy but that society prohibits, such as archaeological treasures, products made from endangered species, and chlorofluorocarbons. A free-market approach also leads to underconsumption by some and overconsumption by others because it is based on what people can afford rather than what they truly need.

The discussion of need can also be approached from an ethical perspective. This stems from the belief that modern consumer economies have a tendency to generate 'ever-greater and wasteful consumption'.[2] The eco-efficiency approach asks how the services provided by metals and minerals can be delivered with minimal resource use and pollution. The concept of eco-sufficiency aims to ensure that there is 'enough for all' in terms of access to critical environmental resources.[3] Such a normative approach has its own difficulties, not least being who decides what is 'wasteful' and what is 'enough', and based on what criteria. (This is discussed further in Chapter 11.)

It is hard not to get involved in some highly judgemental calls about how materials are being used. Is the Statue of Liberty an example of wasteful overconsumption of copper? Any attempt to focus on what is 'wasteful' necessarily involves value judgements that will vary from one person to the next and from one region to another. The overall legitimacy of use is also sometimes in question. For example, some people argue that the use of gold and gemstones for decorative purposes such as jewellery and other adornment is not 'needed' to meet basic human requirements, or could be replaced by more benign materials. They also argue that the stockpiling of gold by central banks is subsidizing large-scale mining and environmental degradation.[4] (See Chapter 5.)

Basic Needs

Critical to any discussion of need is the goal of alleviating poverty for the majority of the world's population. The Universal Declaration of Human Rights states that:

> Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control.[5]

Although in many parts of the world these rights remain an aspiration, the minerals sector already plays a key role in achieving them through improving the lives of the poorest. Better access to clean water, better agricultural techniques, transportation to markets, electricity generation and transmission, and improved health care all rely on the availability of resources to buy mineral products or the services they provide. Minerals can thus make an important contribution to realizing the various capital assets – natural, social, human, physical, and financial – that people draw on to build their livelihoods. Employment in the mining sector can also play an important role in providing a source of income or reducing seasonal vulnerability to joblessness.

Any attempt to calculate an individual's minimum need for minerals will ultimate involve value judgements, particularly with respect to the need for private goods. Many of the minerals that can improve the quality of life of individuals are found in communal or public goods and services, such as potable water and electricity delivery systems, public transportation and communication networks, improved health services and medical facilities, and better schools. So an ideal measure of whether basic needs are being satisfied might be made at a community level. In the meantime, as a proxy, statistics on national consumption per capita can be used to contrast countries at different levels of development. (See Chapter 3.)

Despite this important conception of the need for metals, little research has been done to examine how much metal demand would increase if the world met some of the most basic needs of the poorest people.

Seeking a Balance

The *1998 Human Development Report* from the UN Development Programme reveals that 86% of the money that goes towards personal consumption world-wide is spent by just 20%

of the world's population. The wealthiest 20% also use 58% of total energy, have 74% of all telephone lines, and own 87% of all vehicles.[6] A balance has to be achieved between expanding minerals consumption in developing countries to meet basic needs for growing populations and expanding it to match current consumption levels in industrial countries, which some view as globally unsustainable from an ecological perspective. In the words of Gro Harlem Brundtland, 'It is simply impossible for the world as a whole to sustain a Western level of consumption for all. In fact if 7 billion people were to consume as much energy and resources as we do in the West today we would need 10 worlds not one to satisfy all our needs.'[7]

Some observers maintain that in order to achieve more equitable global patterns of minerals use without exceeding ecological limits, levels of use in industrial countries must be reduced. (See Chapter 11 for a discussion of resource efficiency concepts and targets.) But opinion is divided, and there are many counter-arguments and alternative solutions. For example, in terms of achieving more equitable patterns of use, there is no guarantee that limiting the consumption of the rich will necessarily enhance the consumption of the poor. Moreover, the notion of imposing limits on consumption raises ethical questions about individual freedoms as well as practical political concerns. Furthermore, others argue that these concerns can in part be addressed by improvements in methods of production, refining, use, and recycling.

What is clear is that for levels of use to be optimal in terms of sustainable development, governments will need to use a package of voluntary and mandatory policy tools that take into account equity, efficiency, and environmental factors. These tools include market mechanisms, regulation, and educational campaigns. Mandatory approaches have been used to conserve scarce materials in wartime, for example, when national security was deemed to be at stake. But it is important to remember the role that markets can play in reconciling demand and supply. The real danger is when markets cannot adjust, either because they do not exist (for instance, for carbon in the atmosphere) or because they are distorted by bad policies, such as subsidies in various forms. Companies, too, will need to incorporate efficiency and other targets into their business strategies, and consumers will need to take some responsibility.[8] (See Chapter 11 for further discussion.)

The Availability of Minerals

In terms of primary extraction, most minerals cannot be considered a renewable resource on any time scale of relevance to the human race.[9] Consequently, there is an extensive history of concern about minerals use and long-run availability.[10] For example, in the early 1950s the US President's Materials Policy Commission raised concern at the 'gargantuan and so far insatiable' appetite for materials and pointed to the security consequences of the depletion of domestic sources of minerals.[11]

But it was with the rise of environmental concern in the 1960s and 1970s that the dependence of industrial society on minerals began to be questioned, most notably in the 1972 *Limits to Growth* report. This concluded that 'if present growth trends in world population, industrialization, food production and resource depletion remain unchecked, the limits to growth will be reached sometime within the next hundred years'.[12] The first 'oil shock' of 1973–74 served to further focus public concerns on the possibility of running out of vital resources. The controversy has raged ever since, much of it negative, but it is worth noting that a major part of the thesis concerned ecosystem functions and limits, not resource scarcity. The report warned, for example, of the effects of increased carbon dioxide concentrations in the atmosphere due to human activities and the potential impact on climate. The same message is delivered today by the Intergovernmental Panel on Climate Change.

Assessing the long-term availability of mineral commodities is complex and has divided opinion within academia and the mining industry for more than 30 years. The debate between those concerned about the depletion of mineral resources and those less worried about it is as relevant today as it was then. The pessimists, often scientists and engineers, are convinced that Earth simply lacks the resources to support the world's demand for mineral resources forever. They see mineral commodities as a fixed stock that can be physically measured. The optimists, often economists, believe that with the help of market incentives, appropriate public policies, material substitution, recycling, and new technology, Earth can meet the world's needs far into the future. They rely on economic measures to assess availability, which reflect the opportunity costs of finding and producing mineral commodities. Assessment of availability is further complicated when considered within the framework of sustainable development.

Physical Measures

Physical measurement is intuitively appealing. There are several approaches. At one extreme are calculations of the life expectancies of reserves (the quantities of a mineral commodity found in subsurface resources, which are both known and profitable to exploit with existing technology and prices). (See Table 4–1.) At the other extreme are calculations of the life expectancies of the whole resource base (all of a mineral commodity contained in Earth's crust). (See Table 4–2.) In between, and much easier to defend, are calculations of the life expectancies of various assessments of resources – that is, the reserves of a mineral commodity plus the quantity contained in deposits that are economic but as yet undiscovered or that are expected to become economic as a result of new technology or other developments within some foreseeable future. (See Figure 4–1.) Unfortunately, getting the correct assessment of resources is not straightforward.

Figure 4–1. Reserves, Resources, and the Resource Base
Source: Tilton (2002)

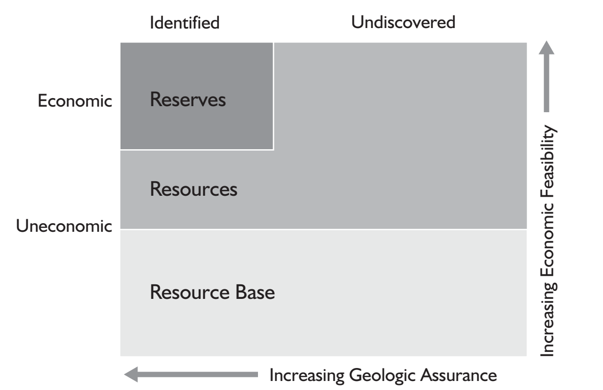

Table 4–1. Life Expectancies of World Reserves, Selected Mineral Commodities

Mineral Commodity[a]	1999 Reserves[b]	1997–1999 average annual primary production[b]	Life expectancy in years, at three growth rates in primary production[c]			Average annual growth in production 1975–1999 (%)
			0%	2%	5%	
Coal	987×10^{9}	4561.3×10^{6}	216	84	49	1.1
Crude Oil	1035×10^{9}	23.7×10^{9}	44	31	23	0.8
Natural Gas	5145×10^{12}	80.5×10^{12}	64	41	29	2.9
Aluminium	25×10^{9}	123.7×10^{6}	202	81	48	2.9
Copper	340×10^{6}	12.1×10^{6}	28	22	18	3.4
Iron	74×10^{12}	559.5×10^{6}	132	65	41	0.5
Lead	64×10^{6}	3070.0×10^{3}	21	17	14	-0.5
Nickel	46×10^{6}	1133.3×10^{3}	41	30	22	1.6
Silver	280×10^{3}	16.1×10^{3}	17	15	13	3.0
Tin	8×10^{6}	207.7×10^{3}	37	28	21	-0.5
Zinc	190×10^{6}	7753.3×10^{3}	25	20	16	1.9

[a] For metals other than aluminium, reserves are measured in terms of metal content. For aluminium, reserves are measured in terms of bauxite ore. [b] Reserves are measured in metric tonnes except for crude oil (in barrels), and natural gas (in cubic feet). [c] Life expectancy figures were calculated before reserve and average production data were rounded. As a result, the life expectancies shown in columns 4, 5 and 6 may deviate slightly from the life expectancies derived from the reserve data shown in column 2 and the annual primary production data shown in column 3.

Sources: Tilton (2002); US Bureau of Mines (1977); US Geological Survey (2000a); US Geological Survey (2000b); American Petroleum Institute (2000); BP Amoco (2000); International Energy Agency (2000).

Table 4–2. Life Expectancies of Resource Base, Selected Mineral Commodities

Mineral Commodity	Resource base (metric tonnes)[a]	1997–1999 average annual primary production[b]	Life expectancy in years, at three growth rates in primary production			Average annual growth in production 1975–1999 (%)[b]
			0%	2%	5%	
Coal[c]	n/a	4561.3×10^{6}	n/a	n/a	n/a	1.1
Crude Oil[c]	n/a	23.7×10^{9}	n/a	n/a	n/a	0.8
Natural Gas[c]	n/a	80.5×10^{12}	n/a	n/a	n/a	2.9
Aluminium	2.0×10^{18}	123.7×10^{6}	89.3×10^{9}	1065	444	2.9
Copper	1.5×10^{15}	12.1×10^{6}	124.3×10^{6}	736	313	3.4
Iron	1.4×10^{18}	559.5×10^{6}	2.5×10^{9}	886	373	0.5
Lead	290.0×10^{12}	3070.0×10^{3}	9.4×10^{6}	607	261	-0.5
Nickel	2.1×10^{12}	1133.3×10^{3}	1.8×10^{6}	526	229	1.6
Silver	1.8×10^{12}	16.1×10^{3}	111.8×10^{6}	731	311	3.0
Tin	40.8×10^{12}	207.7×10^{3}	196.5×10^{6}	759	322	-0.5
Zinc	2.2×10^{15}	7753.3×10^{3}	283.7×10^{6}	778	329	1.9

[a] The resource base for mineral commodity is calculated by multiplying its elemental abundance measured in grams per metric tonnes times the total weight (24×10^{18}) in metric tonnes of Earth's crust. It reflects the quantity of that material found in the crust. [b] The figures for the 1997–1999 average annual production and the annual percentage growth in production for 1975–1999 are from Table 4–1 and the sources cited there. [c] Estimates of the resource base for coal, crude oil, and natural gas are not available. The US Geological Survey and other organizations do provide assessments of ultimate recoverable resources for oil, natural gas, and coal. While these are at times referred to as estimates of the resource base, they do not attempt to measure all the coal, oil, and natural gas found in Earth's crust. As a result, they are more appropriately considered as resource estimates rather than assessments of the resource base.

Sources: Table from Tilton (2002). The data on the resource base are based on information in Erickson, (1973) pp.22-23 and Lee and Yao (1970).

Geologists classify elements as geochemically abundant or geochemically scarce. There are eight geochemically abundant elements: oxygen, silicon, calcium, sodium, potassium, and three widely used metals – aluminium, iron, and magnesium. This group accounts for 99% of the outermost layer of Earth's solid sphere. The other 90 or so known elements, including all other metals, account for the remainder.[13] It would be easy to assume, therefore, that all elements in the first group are easy to produce whereas those in the second might be far more difficult. However, thanks to the geological processes that give rise to mineral formation, this is not always so. For example, some of the scarcer elements, such as copper (number 28 in order of occurrence in Earth's crust), are found in large deposits at concentrations hundreds or even thousands of times greater than the crustal average.

The viability of the mining industry rests on the continued availability of minerals that have been naturally enriched by geochemical processes occurring in Earth's crust. Mineable ores of copper, zinc, and lead are all highly enriched compared with the crustal average. But the scarcest elements, which in aggregate constitute a large proportion of the total copper, zinc, and lead found in Earth's crust, are distributed as atomic substitutes in very low grade minerals, the extraction and processing of which are rarely feasible. So an intriguing question is, how much of the commercially important but geochemically scarce metals remains to be exploited from enriched minerals?

Copper provides a good example here. Globally, the average grade of copper ore currently mined is about 0.8%.[14] Since higher grades normally are exploited first, the quality of ore being mined has been declining. Using current technologies, it is unlikely to be possible to extract copper from grades of lower than 0.1%. At this level, copper is not present in the form of distinguishable copper-containing minerals, but only as atomic substitutions in minerals commonly found in Earth's crust. This is known as the mineralogical barrier.[15]

The energy required to recover copper that is present as atomic substitutions in silicates would be hundreds, if not thousands, of times greater than current levels. Moreover, the water required to mine copper from non-enriched crustal rock, in quantities comparable to current US consumption using existing technologies, would amount to something like five times the annual flow of the Mississippi river.[16] As a result, the recovery of copper from common crustal sources is currently economically and ecologically unviable. Physical measurements of copper-enriched mineable resources suggest that current demand could be satisfied for about 30–60 years.[17]

For this reason, those who subscribe to the fixed-stock paradigm are pessimistic about the long-term availability of commercially important metals such as copper and zinc. The implication, they say, is that the resources of metals with patterns of distribution similar to copper's may be exhausted within 60 years.

Economic Measures

Optimists point to four major problems with the fixed-stock paradigm and the estimates of long-term availability that it gives rise to. First, they argue that this approach ignores secondary production and recycling, and the fact that many mineral commodities are not destroyed after they are used. Recycling can significantly affect the rate of primary production, and hence of depletion. For example, the use of lead in the US grew by about 15% between 1970 and 1993–94.[18] Government policies regulating the recycling of car batteries and the use of lead in paints and petrol, however, led to a fall in primary production over the same period as recycling and secondary production more than doubled.[19] But for most minerals, at least in the medium term, while the overall demand for mineral products continues to rise, the effect on primary production of increased recycling is likely to be minimal. Efforts to lower material intensity in product manufacture and design can also play a role in reducing the demand for primary extraction. (Keys to advances in recycling and materials intensity are discussed in Chapter 11.)

Second, the depletion of one mineral may lead to its replacement by another. Aluminium can replace copper in certain end-uses, for instance. Technologies may also be modified to accept substitutes for minerals. Third, new sources of mineral commodities, such as from beneath Earth's crust (or, indeed, from space) may seem far-fetched today but are feasible and should certainly not be discounted.[20]

Fourth, the optimists point out, the fixed-stock paradigm ignores the critical role of new technology. New exploration technologies such as 3D seismics and hyper-spectral surveying have greatly increased the ability to find new supplies of minerals.[21] Moreover, it is conceivable that at some point in the future, new technology might allow the recovery of mineral commodities from very low-grade deposits, even deposits on the other side of the mineralogical barrier. On the other hand, it is also possible that new technology will not be sufficient to allow the complete exploitation of the lower-grade deposits still on this side of the mineralogical barrier. In this case, rising costs could eradicate demand long before the resource is entirely exploited. So the quantity of a mineral commodity yet to be exploited is largely irrelevant if the cost of extraction is prohibitively high. Economic depletion occurs before physical depletion becomes an issue.

For these reasons, members of the opportunity-cost school favour economic measures of resource availability. Three such measures are widely recognized: the marginal costs of extraction and production, the market price of commodities, and user costs.

Marginal costs – the cost of producing one more unit of the commodity at various levels of output – focus on the production process and its impact on availability. In an important study published in 1963, H J Barnett and C Morse showed that despite considerable growth in the consumption of mineral commodities in the US, between 1870 and 1957 production costs fell by more than 75%. They attributed this dramatic reduction to the impacts of new technology, which allowed known but previously uneconomic deposits to be exploited, permitted less scarce resources to be substituted for scarcer ones, and reduced the resources needed to produce final goods and services.[22] There were several criticisms of the study: that it failed to consider inputs such as energy consumption in addition to labour and capital; that it ignored rising environmental costs; and that it chose 1957 as its cut-off point, whereas if the study had been extended it might have shown an increase in costs.[23] Despite these criticisms, the findings have proved robust and suggest the growing availability of mineral commodities over time.

Mineral commodity prices in constant prices have also fallen over the past century. However, recent trends are more difficult to interpret. While some studies show prices continuing to fall and are optimistic about long-term mineral availability, others suggest that scarcity is now on the rise.[24] Despite the historical trend, it is unlikely that real prices can continue to decline indefinitely – so this trend will level off or possibly reverse at some stage. Reserves are sensitive to prices and to the amount of money spent on exploration. When prices have spiked up, exploration spending has increased, and the amount of known mineral reserves has increased. Many parts of the world are still underexplored using the most modern methods.

The third economic measure is user costs – the present value of the future profits that a producer would lose as a result of increasing current output by one unit. The argument here is that the decline in future profits arises because increased production today leaves less or poorer-quality mineral deposits in the ground for future exploitation.[25] This measure under certain conditions reflects trends in the value of mineral resources in the ground. The relevant type of resources here are those that are currently just barely economic to exploit. The dearth of data on user costs makes it difficult to estimate this indicator of availability over long periods, and the few existing studies have posted different findings. In any case, the impacts of new technology can make user costs irrelevant. For example, the user costs of mining Swedish iron ore in the first half of the twentieth century were zero, because of the technological leap in the 1960s that made the ocean transport of bulk commodities possible. Cheaper transport over large distances deprived Sweden of the comparative advantage it had enjoyed from being close to European steel industries. More recently, technological breakthroughs have changed the economics of some metals (such as new leaching methods for copper, gold, and nickel).

Despite the problems described, economic measures do permit two general conclusions: First, depletion has not resulted in scarcity of mineral commodities over the past century, despite the fact that demand for those commodities has never been higher. Second, long-term trends in availability are not fixed and can change in either direction. The lesson seems to be that just because mineral availability has increased in the past, there is no guarantee that it will continue to do so in the future. The underlying factors influencing mineral supply and demand, such as new technology and the rate of global economic growth, could change in ways that ultimately lead to economic scarcity.

Global Versus Local Scarcity

The availability of minerals can also be considered in the geographical context of markets. For example, where commodities have high value per unit weight, such as gemstones and gold, they can be shipped anywhere and compete in global markets. At the other end of the spectrum are commodities with a low value-to-weight ratio, such as aggregates and sand, meaning that transportation costs dictate they can only be sold in a local market. (See Box 4–1.) An intermediate range of materials (for example, limestone and some grades of coal) can be sold in broad regional markets but are not able to compete globally. For goods sold in local markets, local scarcity may arise long before the mineral faces scarcity at the regional or global level.

Box 4–1. Aggregates in the Metropolitan Region of São Paulo

The metropolitan region of São Paulo is one of the fastest growing urban areas in Brazil, with more than 17.5 million people spread over 8,051 square kilometres. The metropolitan area is the country's largest consumer of gravel and sand. Between 1994 and 2000, the consumption of gravel in São Paulo increased from 11.8 million to 17.7 million tonnes. The region is also the country's biggest producer of gravel and sand, as it is home to 22% of national gravel reserves and 37% of the sand reserves.

Both gravel and sand are geologically available near the city. Almost all the gravel used in São Paulo is produced locally. But only about 25% of the sand is locally produced; the balance comes from sites over 100 kilometres away. This is because most of the potential reserves of gravel and sand in the metro area are no longer accessible due to urban occupation. Uncontrolled expansion of housing allotments in outlying areas has resulted in land use conflicts and the shut-down of many gravel and sand quarries. The very high cost of transporting gravel means that it cannot be brought in from far away, whereas the constraints on local aggregate production have made it economically viable to transport sand.

Source: Coelho (2001).

Assessing Long-term Availability

The long-term availability of mineral commodities depends on the outcome of the competing forces of depletion and new technology. The rate of depletion depends on various factors, including geological and technological. Geological factors take into account the incidence and nature of mineral occurrences. The pattern of distribution will affect the rate of depletion; as depletion proceeds, lower grades of ore will be exploited. Whether the shift towards lower grades is smooth or not depends on the geochemistry of the mineral and the way in which advances in minerals processing technologies are adopted. An example of this is a method called high-pressure acid leaching, which, if successful, could significantly change the economics of nickel recovery from certain tropical soils called laterites. These soils form the majority of known reserves of nickel in the world but have not been susceptible to economic recovery until recently.

Alongside the exploitation of conventional terrestrial mineral reserves, it is important to consider other sources of minerals. These remain unexploited due to technological limitations. For instance, in selective samples manganese nodules on the ocean floor and mineralization around geothermal vents have been found for metals such as gold, nickel, copper, and cobalt at grades far greater than currently exploited from terrestrial sources. It is conceivable that landfill sites may also be important metal reserves in the future.[26] More knowledge about deposits that are presently uneconomic to exploit could provide useful insights on the future availability of mineral commodities.

Technology and input prices cover all the variables that affect the cost of producing mineral commodities other than geological considerations. The cost-reducing effects of new technology as well as changes in the prices of labour, capital, energy, and materials need to be taken into account. In the past, the effect of the latter on availability has been dwarfed by new technology; although this may happen again in the future, it is impossible to forecast it.

Recycling and secondary production may also reduce the need to extract minerals from the ground. The bleaker the prospects for primary production, the greater the likely role for recycling (for minerals that can be recycled), and vice versa.

Conclusion

Despite many years of debate between the pessimists and the optimists, there is still uncertainty regarding the long-term availability of mineral commodities. There are simply too many unknowns. It is broadly agreed, however, that the world is unlikely to face shortages of commercially important mineral commodities at a global level in the next half-century. The further projections go beyond 50 years, the less certain the situation.

The debate has helped reveal the inadequacies of the fixed-stock paradigm and the superiority of economic measures over physical ones in predicting future availability. It has also shown that the argument centres on whether people are prepared to trust in new technologies to continue to stave off the consequences of mineral depletion or instead believe that mineralogical barriers are insurmountable and will, in the foreseeable future, make certain commodities unavailable.

The Sustainable Development Imperative

Although trends in minerals production, consumption, and the estimated resource base have reduced concerns that the world is 'running out' of minerals, the potential limits that environmental and social factors may place on mineral availability are receiving mounting attention. Developments that may limit the availability of minerals include:

- the availability of energy or the environmental effects of energy use as energy per unit output increases at lower ore grades;
- the availability of water for minerals production or the environmental impacts of using increasing amounts of water at lower ore grades;
- society's preference to use land for reasons other than mineral production, whether for biological diversity and pristine wilderness protection, cultural significance, or agriculture and food security;
- community intolerance of impacts of mineral facilities;
- changing consumption patterns; and
- ecosystem limits on the build-up of mineral products or by-products (especially metals) in the air, water, topsoil, or vegetation.

Even where concern is limited to physical factors, reduced availability can have environmental or social implications. For example, from an environmental perspective the extraction of lower-grade ores may result in an increased generation of waste. Increased scarcity may also require goods to be transported longer distances to markets, raising the environmental impacts of transportation. It may also mean mines are opened in sites that are less desirable from a social or environmental perspective. This may be particularly so where minerals are produced and sold in a local market.

Since mineral resources are non-renewable, an additional concern is the way in which the revenues gained from depletion are invested or used. These topics are at the very heart of the challenges of sustainable development and are discussed in Part III.

Endnotes

[1] US Census Bureau (2001).
[2] This argument was put forward forcefully in Packard (1960).
[3] See, for example, Robins and Roberts (1996).
[4] Mineral Policy Center (2000).
[5] United Nations (1948) Part 1 of Article 25.
[6] UNDP (1998) p.2.
[7] Brundtland (1994).
[8] see, for example, WBCSD (2001).
[9] This section draws heavily on Tilton (2002).
[10] The debate over resource availability can be traced back at least 200 years to the classical economists, such as Malthus, Ricardo, and Mill, though the past 30 years have been particularly active. See for example, Meadows et al. (1972) and Meadows et al. (1992).
[11] See Packard (1960).
[12] Meadows et al. (1972).
[13] Wedepohl (1995).
[14] For example, the copper content of the ore mined in Stora Kopparberget, Sweden during the period 1290-1628 was estimated at 6.3%. Between 1630 and 1716, the average grade was 3.1% and the copper content of the ore mined during 1716-1906 was approximately 1.9%.
[15] Skinner (1976).
[16] Gordon et al. (1987).
[17] Ayres et al. (2001).
[18] The Interagency Working Group on Industrial Ecology, Material and Energy Flows as reproduced in Brown et al. (2000) p.14.
[19] USGS: http://minerals.usgs.gov/minerals/pubs/commodity/lead.
[20] Gertsch and Maryniak (1991).
[21] Gingerich et al. (2002).
[22] Barnett and Morse (1963).
[23] Cleveland (1991) pp.289-317; Johnson et al (1980); Hall and Hall (1984).
[24] Hotelling (1931); Kesler (1994); Slade (1982).
[25] User costs are also called Hotelling rent and scarcity rent - see Tilton (2002) Chapter 3.
[26] Ayres et al. (2001).