The Limits of Supply

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While future mineral scarcity has all but disappeared as an issue among specialists in the field of mineral economics, it remains an important touchstone among environmental and population activists, as well as those concerned with the inequality between industrialized and developing countries. The influential 1972 Club of Rome report, **The Limits to Growth**, continues to resonate with many who believe that mineral commodity production cannot meet the legitimate material aspirations of future generations if consumption continues to increase. The Factor Ten Club of notable resource economists has issued the **Carnoules Declarations** calling for a swift 10-fold increase in material efficiency among industrialized countries to free materials for people in developing countries.

Mineral supply is not just a matter of the physical existence of materials within the Earth's crust and dissolved in its oceans. It is also a function of demand generated by the price people are willing to pay; the investment they are willing to make in exploration, plant, and other infrastructure; technological innovation; availability of substitutes; tenure patterns and employment practices; government policies; environmental disruptions; and sociocultural passions. An assessment of potential supply requires a whole systems approach, both in physical terms by looking to the flows of materials through the economy, and in human terms by adding the domains of finance, environment, government, and values. This is the domain of industrial ecology and that analytical framework can help us understand supply.

This is not a totally new approach. In 1929, D.F. Hewett, of the United States Geological Survey (USGS) defined the four factors he deemed most important in influencing metal production.

1. **Geology** "First, there are the geological factors, which are concerned with the minerals present; their number and kind, which determine whether the problem of recovery is simple or complex; the degree of their concentration or dissemination; their border relations; the shape and extent of the recognizable masses."
2. **Technology** "Second, there are the technical factors of mining, treatment and refining. A review of these leaves a vivid impression of the labor involved in their improvement but they necessarily yield cumulative benefits."
3. **Economics** "The third group of factors that affects rate of production are economic, and among these factors cost and selling price are outstanding...Since 1800 the trend of prices for the common metals, measured not only by monetary units but by the cost in human effort, has been almost steadily downward…"
4. **Political** "The fourth group of factors that affect metal-production curves are political or *lie between politics and economics.* [Emphasis added.]

Reflecting events in his time, Hewett concentrated on the effects of war on metal production. But there are many other influences that *lie between politics and economics*. Social constraints and drivers – including reactions to environmental issues, the influence of governmental and corporate policies, and the structure of the mining industry are all influences that affect the supply of minerals. Each of these influences operates on the supply of minerals at each node (see Figure 1) of our material economy. The USGS is currently embarked on a study entitled *Scarcity in the 21st Century* that will explore these influences. This paper is a preliminary overview of some of the thinking behind that larger study.

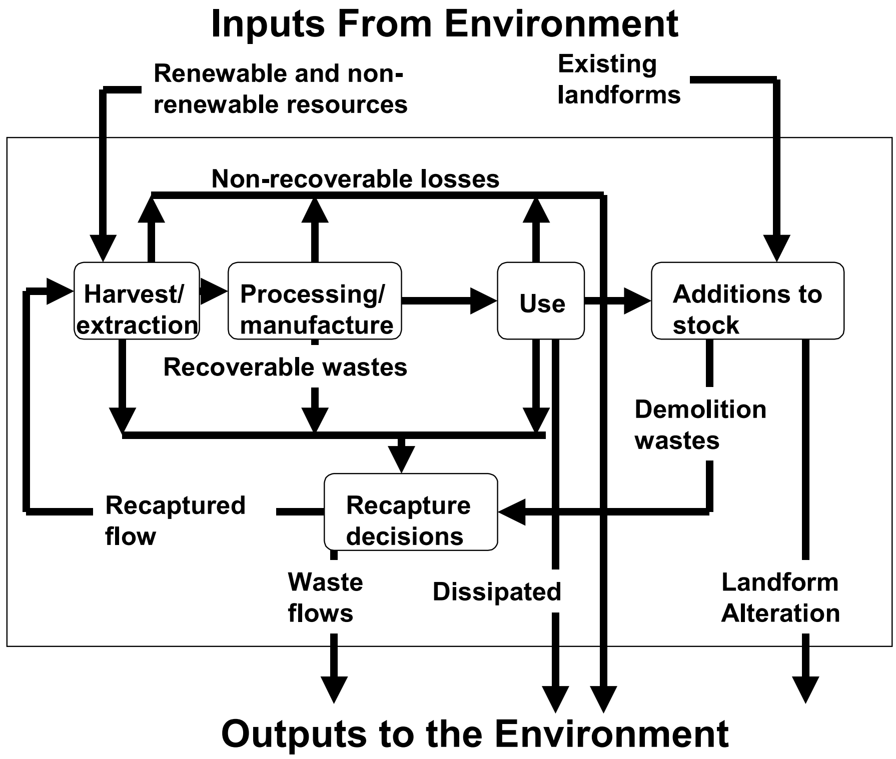

Figure 1. Material flows.
Source: U.S. Geological Survey

PHYSICAL LIMITS

Geologic reality provides the base upon which supply depends, but it is not the only residence of mineral commodities. Materials exist for potential use throughout the anthroposphere. The most obvious supply is embodied in infrastructure, durable goods, and other stock-in-use, but minerals also exist in overburden and tailings from extraction, emissions (especially to land and water) from processing and use, and middens of final deposition.

Many minerals are simply abundant, including those of greatest economic importance. In the United States, all but 2 (copper and gold) of the 12 most valuable mineral commodities produced fall into this category, as do all of the 12 of those commodities ranked highest in tonnage produced (e.g., stone, sand and gravel, iron, and clays). While the United States does not currently mine bauxite for aluminum production, its resources (of currently unexploited subeconomic aluminum resources embodied in deposits of clay, alunite, and other minerals) for the production of aluminum metal are huge (as are those of the world as a whole).

Other mineral commodities can be classified as abundant, not because of their geologic reality, but because they can be manufactured. These include the mineral cryolite (depleted as a geologic resource), as well as minerals such as gemstones, abrasives, mica, zeolites, soda ash, and graphite.

Of course, many commodities are more geologically limited, but even in these cases production continues to increase. Copper production, for example, has increased steadily throughout the 20th century. (See Figures 2 and 3.) Copper is an essential commodity of modern industrial lifestyles and its depletion would be a serious blow, given current technology. Depletion of the natural resource of copper, however, will not come any time soon. Whenever it does come, another resource is already in place for copper supply, for after extraction, copper does not simply disappear. Much of it – certainly over 50 percent – remains contained in goods and other stock-in-use and is available for reuse.

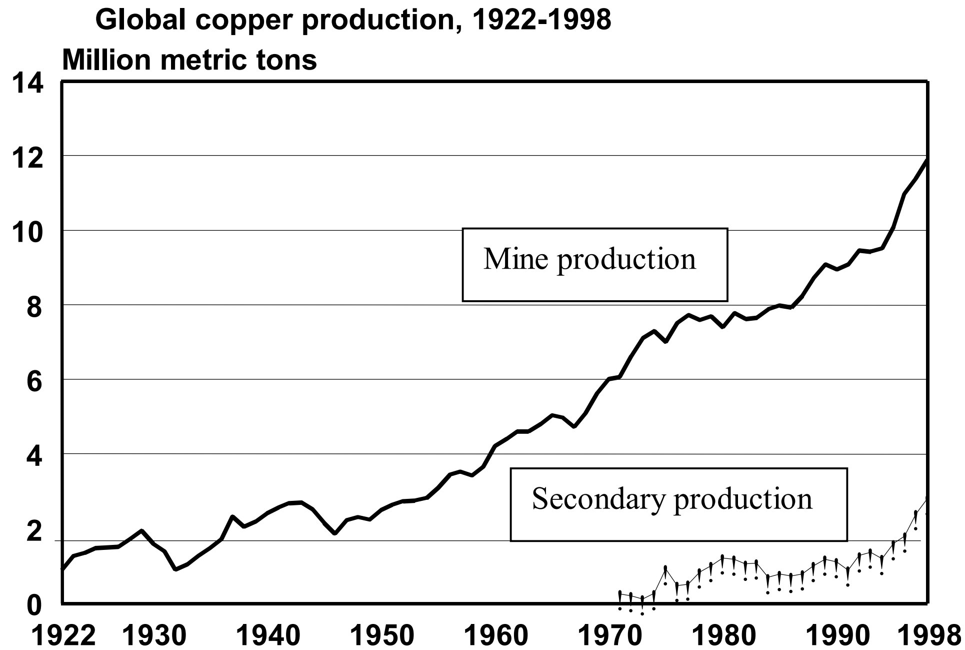

Figure 2. Global copper production has increased throughout the century, as has the use of secondary (recycled) copper.
Source: U.S. Geological Survey

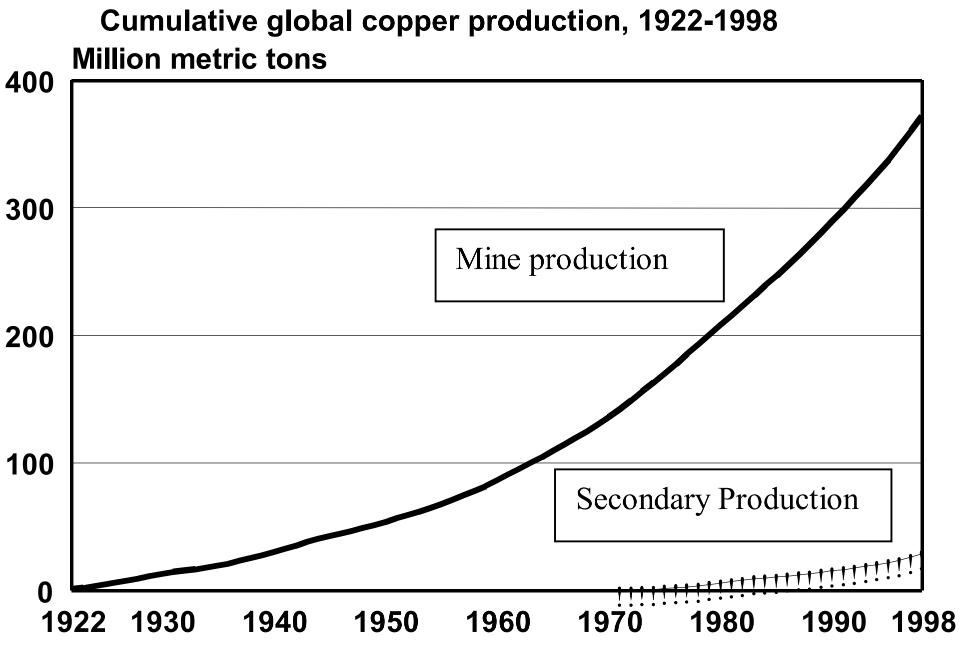

Figure 3. The cumulative production of copper is an upper limit on stocks-in use. According to a World Resources Institute study of material flows in the United States, the lower limit is about 48% of cumulative production.
Source: U.S. Geological Survey

Few non-fuel minerals are actually consumed in any way except in terms of value added. Many remain available embodied in goods that can be recycled, reused, or remanufactured. Others are available in waste streams (emissions, process leakages, tailings, and landfills) that can be intercepted and returned to the supply stream.

ECONOMIC LIMITS

As ore grades decline, the cost of entry into the industry, or the cost of developing a mineral operation, tends to increase. But, the price received for minerals tends to decline over time, seemingly regardless of the natural abundance of the mineral. (See Figures 4, 5, and 6.)

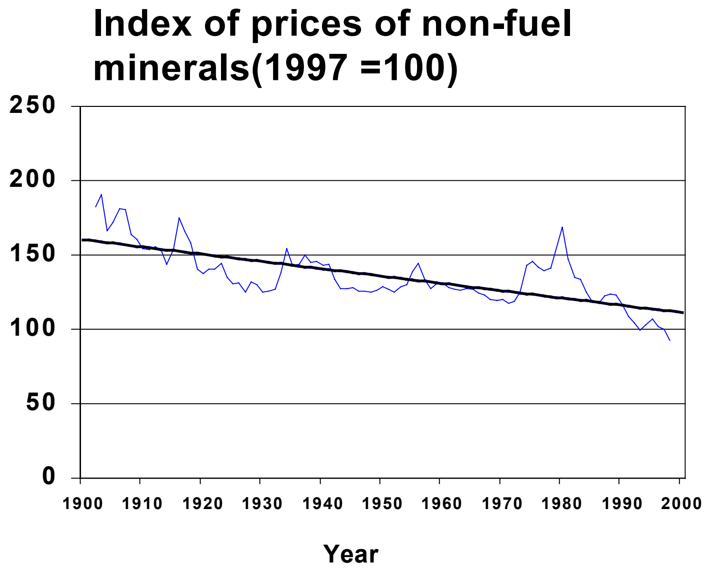

Figure 4. This index shows an overall decline in U.S. non-fuel mineral prices (1997 constant dollars) throughout the 20th century.
Source: U.S. Geological Survey (These indices were calculated by using a standard indexing technique – the price of minerals in each year is weighted by the production of minerals in the base year. The industrial mineral and metal indices each include the highest value minerals in each category that together sum to about 90% of U.S. production. Aluminum is not included because it is not mined in the United States, but it too shows a dramatic decline in price over the century**.)**

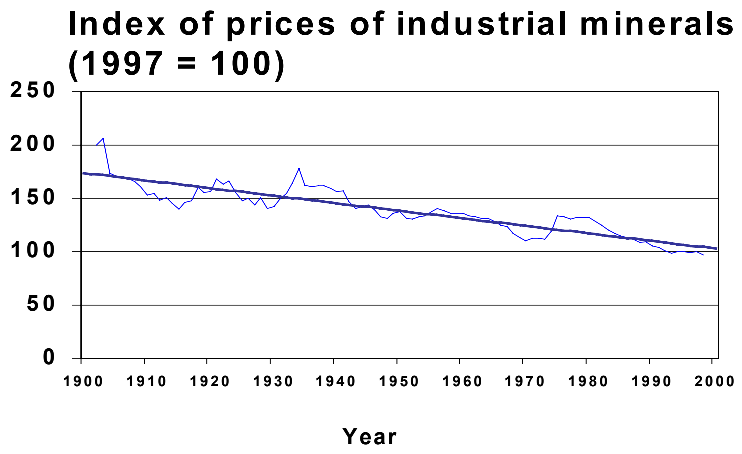

Figure 5. Industrial mineral prices have declined smoothly in real terms throughout the 20th century. Source: U.S. Geological Survey

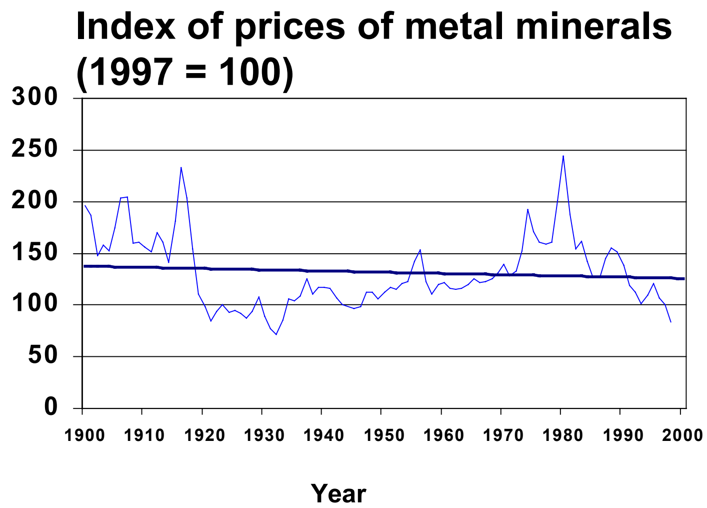

Figure 6. Metal prices have tended to decline during the 20th century except for a peak during the 1980's due to an anomalous rise in the price of gold – associated with fears of inflation. Iron ore prices added to the increase prior to 1980.
Source: U.S. Geological Survey

Throughout the last century (and, as observed by Hewett , in the 19th century), mineral prices have declined. The reasons for this decline are many, but this decline has structured the availability of minerals as much as has their physical reality. Because of generally low prices, many natural resources are uneconomic. But, this is also true for many resources that have already been extracted. Waste rock from extraction, tailings piles from initial processing, waste and emissions from further processing, and goods and materials discarded as waste might well contain significant quantities of mineral commodities but are uneconomical for recapture. The cost involved in re-concentrating a widely dispersed commodity (e.g., silver contained in waste photographic chemicals) can exceed its price as a commodity. (See Figure 7.)

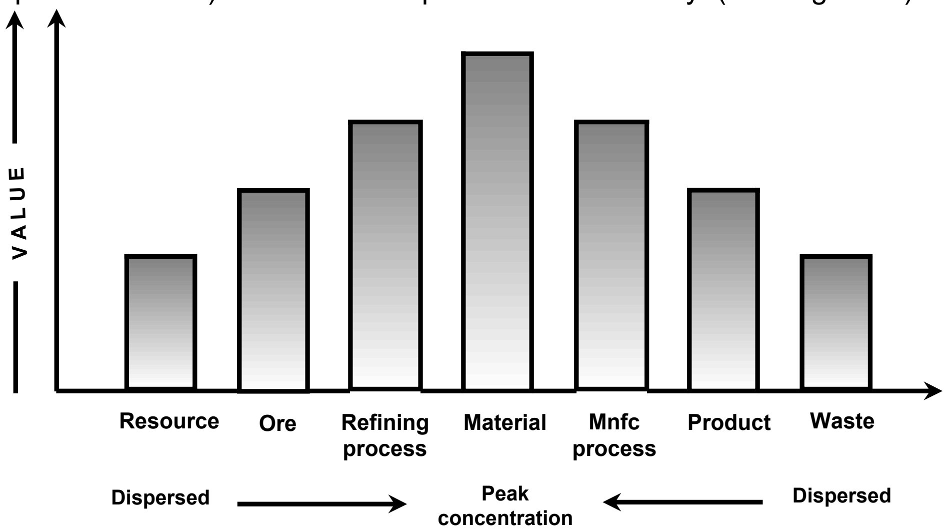

Figure 7. The value per ton of a mineral commodity, as a material only, depends on its concentration. The peak value per ton of a commodity may be approached from the direction of extraction or from the direction of waste. In either case, it is the concentration of "dispersed" materials that adds value to the commodity.
Source: U.S. Geological Survey

TECHNICAL LIMITS

The technical limits on mineral supply have changed continuously with the effect of expanding commodity production throughout human history, decreasing the cost of production, and reducing the ultimate price of the commodity. There is no reason to believe that this trend would not continue into the future. Technology affects exploration, mine development, extraction, refining, design, manufacturing, and recapture. The general trend of technology development in mineral commodity supply has been toward greater and greater efficiency in terms of commodity use, energy use, labor, and return on capital.

This efficiency is seen most clearly in extraction. Larger scale operations with larger and larger machines characterize the surface operations of firms. Efficient use of explosives provide the greatest bang for the buck, removing great quantities of overburden and shattering target ores in preparation for removal. The extraction of mineral rich brines has further expanded the supply of materials.

Technological advances in refining have provided access to new resources (created new ores) that would otherwise not be viable. Alternative ores and previously uneconomical grades of ore are now worth developing because of these processing advancements. Flotation (exploiting the differential wetting of ore and gangue components) has enabled the separation of metals from difficult ores and from each other. Solvent leaching, whether with sulfuric acid for copper or cyanide for gold, has greatly advanced production, minimized environmental effect, and increased the efficiency of recovery. Bio-leaching of sulfide ores holds similar promise. Direct-reduced iron (DRI) technology has increased the overall efficiency of iron and steel production.

Efficient engineering, design, and advances in metallurgy have decreased the amount of materials required for products (ranging from the design of aluminum cans to electronic circuits to bridges) and therefore increased the potential amount of materials available for other uses. Substitutes have been identified for many mineral commodities, with the important exceptions of nitrogen, potassium, phosphorus, and sulfur – which are abundant.

The recapture of mineral commodities from wastes, emissions, and stocks-in-use has advanced as well. As the technology of extraction and processing has improved, stocks of overburden and tailings have been revisited for reprocessing (e.g., magnesium from asbestos tailings, copper and gold from older tailings). Sulfur from smelting (or coal combustion) can be captured as gypsum or extracted for use and sale as sulfuric acid. DRI technology is used in mini-mills (electric arc furnaces for the recycling of steel) to recapture of oxides and mill scale, supplementing scrap supplies. Magnetic flux separators are used to segregate metals found in mixed waste streams. Rotary hearth furnaces are used to process mixed hazardous (heavy metal) wastes that result from a variety of processes. By changing the post-use-fate of mineral commodities, technology has increased the supply of materials available for use.

SOCIAL LIMITS

Demand for products based upon mineral commodities is the primary driver of supply (but not the only one, as the existence of potential supply has also driven the development of new products which then create demand). As population grows, so does the demand for material goods to meet peoples' aspirations for a rich material life. (See Figure 8.)

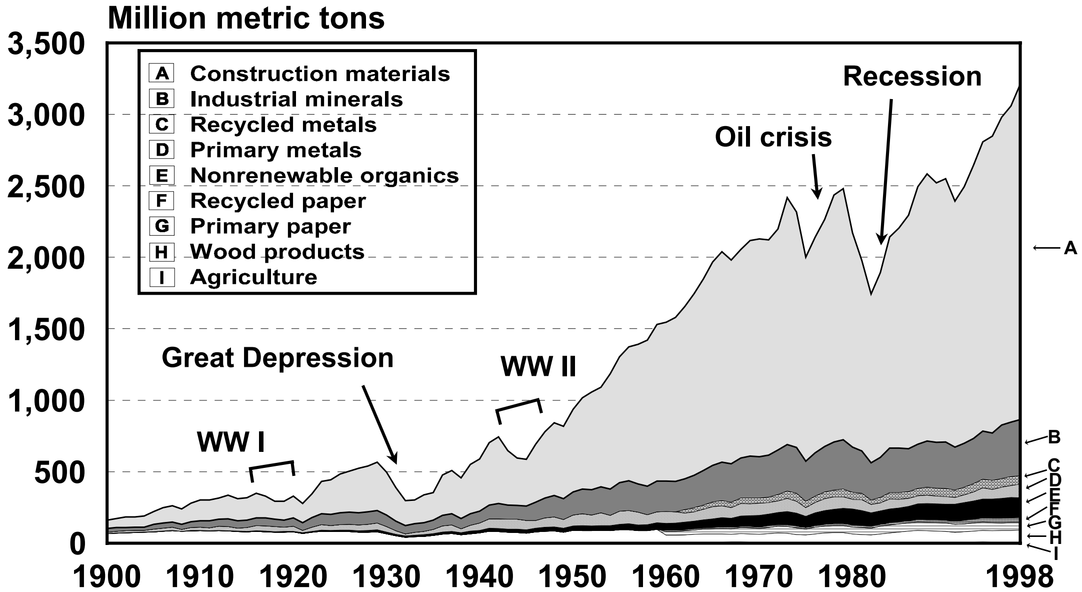

Figure 8. U.S. demand for commodities has increased on an absolute basis throughout the 20th century. There is little reason to expect this trend to end given existing per capita demand and continued population growth.
Source: U.S. Geological Survey

But, along with increasing material wealth comes the demand for the fulfillment of other, often noncomplementary, values. Mineral extraction is often seen as the road to economic development. Yet economic development itself leads to demands for a cleaner environment, healthy ecosystems, and social equity.

This trend is clearest in demands for sustainable development where economic growth, environmental values, and social justice and equity go hand in hand. The sustainable development movement would hold that the wealth created by the extraction of nonrenewable resources be used to create enduring wealth in the environment and society.

There is no consensus on the details of sustainable development. They can include demands as far ranging as the protection of views from the sight of mining operations to the control of dust, to investment in education and infrastructure, to the hiring of local labor. For some, sustainable development includes the demand for no mining, or for the cessation of heap leaching – especially using cyanide (e.g., referenda in the U.S. States of Montana and possibly in Colorado, and reaction in Turkey). People can support or oppose particular mining activities, processing, recycling, or waste disposal practices because of the potential impact on the quality of their lives (e.g., changes in employment, esthetics, leisure activities, traffic, income, or migration), or their perception of that effect given the historic consequences of mining, manufacturing, and disposal.

Environmental passions can lead to the call to modify mine development and refining/processing operations to minimize air and water pollution, or to protect endangered wildlife and pristine habitat. These same passions can call for greater recycling and waste minimization activities, as well as designing products for the environment – leading to a shifting of the supply of materials from mining to recapture.

POLICY LIMITS

Governmental policy often reflects social attitudes, and this relation is certainly true in relation to the supply of mineral commodities. Government policies typically can both promote mineral exploration and development, often in the name of national security or economic development, and provide speed bumps if not roadblocks to development and use of mineral commodities for environmental, esthetic, spiritual, or social justice reasons.

Governments often limit mining in areas judged to be of national importance for those latter reasons. Some potential mining areas have been "sterilized" because of zoning, or the conversion of lands to parks or monuments.

Regulation of refining operations, processing, manufacturing, and waste disposal also has an effect on mineral commodity supply – both positively and negatively. Environmental and health regulations can increase the cost of smelting and refining or even forbid those activities to the extent that domestic mining operations are no longer competitive. This was the fate of the Black Cloud mine (lead) in Colorado, after the closing of its U.S.-based smelter. The United States no longer produces arsenic or mercury, despite having identified resources, for its own use -- depending instead on imports of arsenic and of mercury scrap.

The control of hazardous wastes (from processing, manufacturing, and use) has limited international trade in what can be valuable raw material for further manufacturing and use. At the same time, recyclers of heavy metals find that payments from producers to accept hazardous wastes, in lieu of greater fees for disposal, can be a valuable addition to their bottom line.

The promotion of recycling in general acts to keep mineral commodities moving within the anthroposphere, rather than exiting to the environment. This recapture of valuable materials that has aged out of stock-in-use, or would otherwise enter the waste stream, provides an additional source of supply. Yet, regulations regarding the recycling of materials deemed hazardous can limit the flow of those materials back into the materials cycle. Remanufacture and reuse of materials, certainly the most environmentally benign of possible recapture methods, can be hindered by government procurement regulations demanding only "new" products.

Government regulations also deal with the assimilative capacity of the planet's life support systems for pollutants. In targeting the kind, quantity, and place of pollution, governments respond to social pressures by limiting activities that relate to supply.

In recent years, governments have become more attuned to the cultural needs and property rights of people, especially indigenous people. Policies have been articulated that aim to give indigenous people a greater say in the development of their traditional lands and areas of cultural importance.

Governments also create policies that promote mining and exports to earn foreign exchange, for industrial self-sufficiency and national security reasons.

Except in times of war, when recycling is encouraged on national security grounds, governments also can promote recapture on environmental grounds. They can and do create the reward background against which private enterprise operates. In the United States, for instance, government policies to minimize the environmental harm of hazardous wastes have led to large fees for their disposal by approved waste disposal enterprises. Hazardous waste recyclers can take this potential liability off the hands of producers (for a lesser fee) and sell the recycled product. This has had the effect of a restructuring in certain industries. Lead mining companies, for example, have become lead material companies, specializing in the provision of lead from whatever source and taking back lead-contaminated wastes (for a fee) from their customers for recycling.

INDUSTRIAL LIMITS

Mineral commodities are fungible across international boundaries and the international trade in such mineral commodities, including scrap, continues to grow. Except for the low-value commodities (e.g., sand and gravel), mineral producers must compete on a global stage. This competition fosters the dominance of "senior companies" that can afford the capital investment, time, and personnel to develop a mine and maintain its operation in a legally and socially acceptable manner. These senior companies, on the other hand, need to exploit relatively large deposits to support their methods and overhead. "Junior" companies tend to focus on exploration, seeking partnerships with senior companies to develop and operate mines or exploiting smaller resources than senior companies can afford. Senior companies have easier access to capital. Junior companies often obtain capital for exploration from these potential partners. Nevertheless, to be successful all companies must learn to work in a variety of cultural, linguistic, and policy settings. Globalization requires adapting to local rules and social realities.

THE LIMITS OF SUPPLY

The potential supply of mineral commodities is and will be the result of a complex interplay among technology, economic realities, social attitudes, government policy, and the nature of industry. Of these, the true limiting dimension falls into the realm "between economics and politics" – the social attitudes, perceptions, values, and behaviors that drive policy, for, in the medium term, there are no inherent limits to the mix of physical resources, few technological impediments to their extraction or recapture, and no economic pressures that might limit supply.

Ultimately, social realities drive policy that might lead to the opening or closing of land to mining and to the adoption or abandonment of technologies for extraction, refining, processing, and manufacture. These policies can affect the design of products, their use, and ultimate fate. Government policies affect the cost of supply and the ability to recapture emissions, wastes, and materials for recycling, remanufacture, or reuse. And, it is these social attitudes that will ultimately define the economics of the supply train within the anthroposphere.

There are inevitable tradeoffs among the divergent social realities that drive supply. There is no obvious calculus that would allow an optimal solution to balancing these tradeoffs. This is, instead, the realm of politics where facts, analysis, debate, ideology, and the needs and wants of citizens will combine to produce a politically acceptable result.

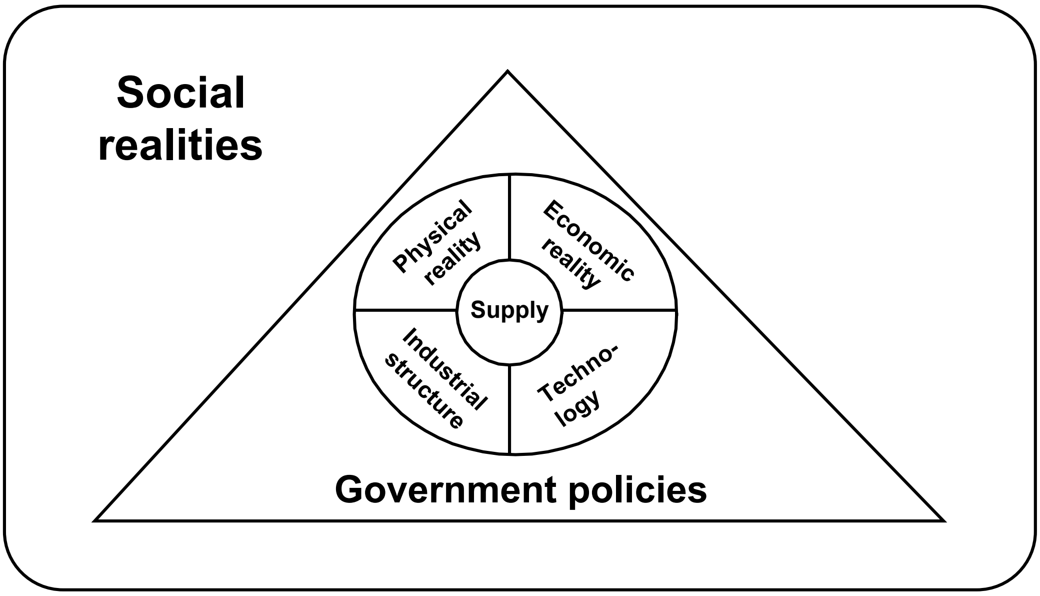

Figure 9. Social realities shape the policy that influences activities within the anthroposphere to produce politically acceptable levels of mineral commodity supply.
Source: U.S. Geological Survey

References:

Brobst, D.A., and W.P. Pratt, eds., 1973, United States mineral resources: U.S. Geological Survey Professional Paper 820, 722 p.

Cameron, E.N., 1981, changes in the political and social framework of United States mineral resource development, 1905-1980, *in* Economic geology: Seventy fifth anniversary volume: El Paso, Texas, The Economic Geology Publishing Company, p.955-964.

DeYoung, Jr., J.H., and Singer, D.A., 1981, Physical factors that could restrict mineral supply, *in* Economic geology: Seventy fifth anniversary volume: El Paso, Texas, The Economic Geology Publishing Company, p.939-954.

Factor 10 Club, 1995, Carnoules Declarations 1994/1995 of the Factor 10 Club: Wuppertal Institute, Wuppertal, Germany, 6p.

Hewett, D.F., 1929, Cycles in metal production: Transactions of the American Institute of Mining and Metallurgical Engineers, 1929 Yearbook, p. 65-98.

Mathews, E., et al., in press, The weight of nations: The material outflows of industrial economies: World Resources Institute, Washington, D.C.

Meadows, D.H, and Meadows D.L., 1972, The limits to growth: Universe Books, New York, N.Y.

U.S. Geological Survey, 2000, Mineral commodity summaries 2000: U.S. Geological Survey, 199 p.