Chapter 3

Minerals Supply, Demand, and Future Trends

CONTENTS

Box

Figures

Tables

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INTRODUCTION

Commodities, materials, and mineral concentrates—the stuff made from minerals-are actively traded in international markets. An analysis of domestic demand, supply, and prices of minerals and their products must also consider future global supply and demand, and international competition. This is important to all mining and minerals ventures, but particularly so for seabed minerals, which must not only compete with domestically produced land-based minerals, but which must also match the prices of foreign onshore and offshore producers. [1]

The commercial potential of most seabed minerals from the EEZ is uncertain. Several factors make analysis of their potential difficult, if not impossible:

- First, very little is known about the extent and grade of the mineral occurrences that have been identified thus far in the EEZ.
- Second, without actual experience or pilot operations, the mining costs and the unforeseen operational problems that affect costs cannot be assessed accurately.
- Third, unpredictable performance of domestic and global economies adds uncertainty to forecasts of minerals demand.
- Fourth, changing technologies can cause unforeseen shifts in demand for minerals and materials.
- Fifth, past experience indicates that methods for projecting or forecasting minerals demand fall short of perfection and are sometimes incorrect or misleading.

Mineral commodities demand is a function of demand for construction, capital equipment, transportation, agricultural products, and durable consumer goods. These markets are tied directly or indirectly to general economic trends and are notably unstable. With economic growth as the "common denominator' for determining materials consumption and hence minerals demand, and with recognition of the shortcomings in predicting global economic changes, any hope for reasonably accurate forecasts evaporates.

It is probably unwise to even attempt to speculate on the future commercial viability of seabed mining, but few can resist the temptation to do so. The case of deep seabed manganese nodule mining offers a graphic example of how external international and domestic political events and economic factors can affect the business climate and economic feasibility of offshore mining ventures. After considerable investment in resource assessments, development and testing of prototype mining systems, and detailed economic and financial analyses, the downturn of the minerals markets from the late 1970s through the 1980s continues to keep the mining of seabed manganese nodules out of economic reach, although many of the international legal uncertainties once facing the industry have been eliminated through reciprocal agreements among the ocean mining nations. As a consequence, several deep seabed mining ventures have either shrunk their operations or abandoned their efforts altogether.

[1] J. Broadus, "Seabed Materials," *Science, vol. 235,* Feb. 20, 1987, p. 835.

TRENDS IN MINERALS CONSUMPTION

Minerals consumption for a product is determined by the number of units manufactured and the quantity of metal or material used in each unit. Total demand is influenced by the mix of goods consumed in the economy (product composition), because each consumes different materials as well as different amounts of those materials. Finally, minerals demand is closely related to macroeconomic activity, consumer preference, changing technologies, prices, and other unpredictable factors (see box 3-A).

Long-term demand is difficult to forecast. Simple projections of consumption trends may be misleading (figure 3-1).[2] From the late 1970s through

'J. Tilton, "Changing Trends in Metal Demand and the Decline of Mining and Mineral Processing in Nonh America, paper presented at Colorado School of Mines Conference on Public Policy and the Competitiveness of U.S. and Canadian Metals Production, Golden, CO, Jan. 27-30, 1987.

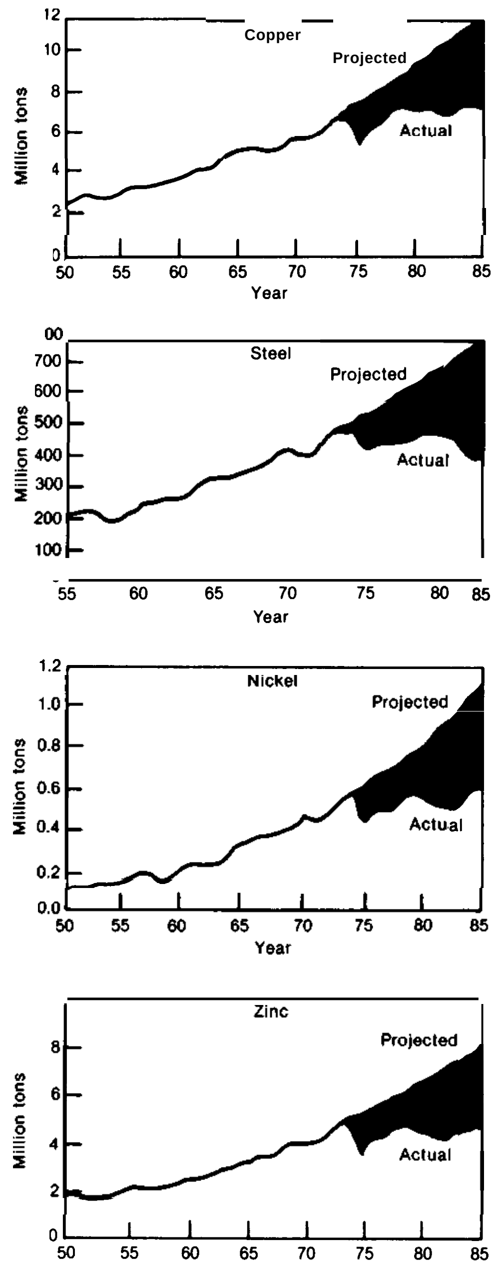
Box 3-A.—Government Sources of Information and Units of Measure Used in This Report

The U.S. Bureau of Mines compiles statistics related to production, demand, and availability of minerals and mineral commodities. The U.S. Geological Survey compiles information and data about domestic and world mineral resources. Both are agencies of the U.S. Department of the Interior which has responsibility for managing the resources of the Outer Continental Shelf (OCS) and the onshore public lands. The Minerals Management Service (MMS) administers the OCS program, and the Bureau of Land Management (BLM) [illegible] surface lands within the Department of the Interior.

Information on [illegible] and manufacturing is also available from the International Trade Administration (ITA) and the Bureau of Economic [illegible] in the Department of Commerce. The National Oceanic and Atmospheric Administration (NOAA), another Commerce agency, is responsible for information and services related to the ocean [illegible] science; it is also a [illegible] related to the resources of the EEZ.

Although [illegible] statistics are often reported in [illegible] of weight depending on [illegible] being discussed, all tonnage has been converted to short tons (2,000 pounds) in this report unless otherwise specified; all uses of the term "ton" means "short ton." Weights are reported in [illegible] form, although some [illegible] compounds, e.g., [illegible] as titanium dioxide (TiO_2) for pigments.

Figure 3-1.—Actual and Projected Consumption of Selected Minerals in the Market-Economy Countries (1950-85)



Changes in the world economy since 1973 have made it difficult to forecast the long-term consumption of metals by the Market-Economy Countries.

SOURCE: J. Tilton, "Changing Trenda in Metal Demand and the Decline of Mining and Mineral Processing in North America," paper presented at a conference on public Policy and the Competitiveness of U.S. and Canadian Metals Production, Colorado School of Mines, Jan. 27-30, 1967 (modified).

middle 1980s, unforeseen changes in the world economy significantly altered consumption; these changes were partially caused by economic pressures resulting from substantial increases in energy prices, coupled with technological advancements (including substitution), changes in consumer attitude, imports of finished products rather than raw materials, and growth in the service sector of the U.S. economy.

These shifts in minerals demand are reflected in both the intensity of use and in consumption.[3] Of the major industrial metals derived from minerals known to occur in the U.S. EEZ, only two—platinum and titanium—show growth in domestic consumption between 1972 and 1982. Whether the long-term trends in use intensity and consumption will continue, stabilize, or recover depends on many complex factors and unpredictable events that confound even the most sophisticated analyses. However, there are indications that trends in reduced intensity of use and consumption for some metals, e.g., nickel, have stabilized since 1982.

3 Intensity of use, as used in this report, is the quantity of metal consumed per constant dollar output.

COMMODITY PRICES

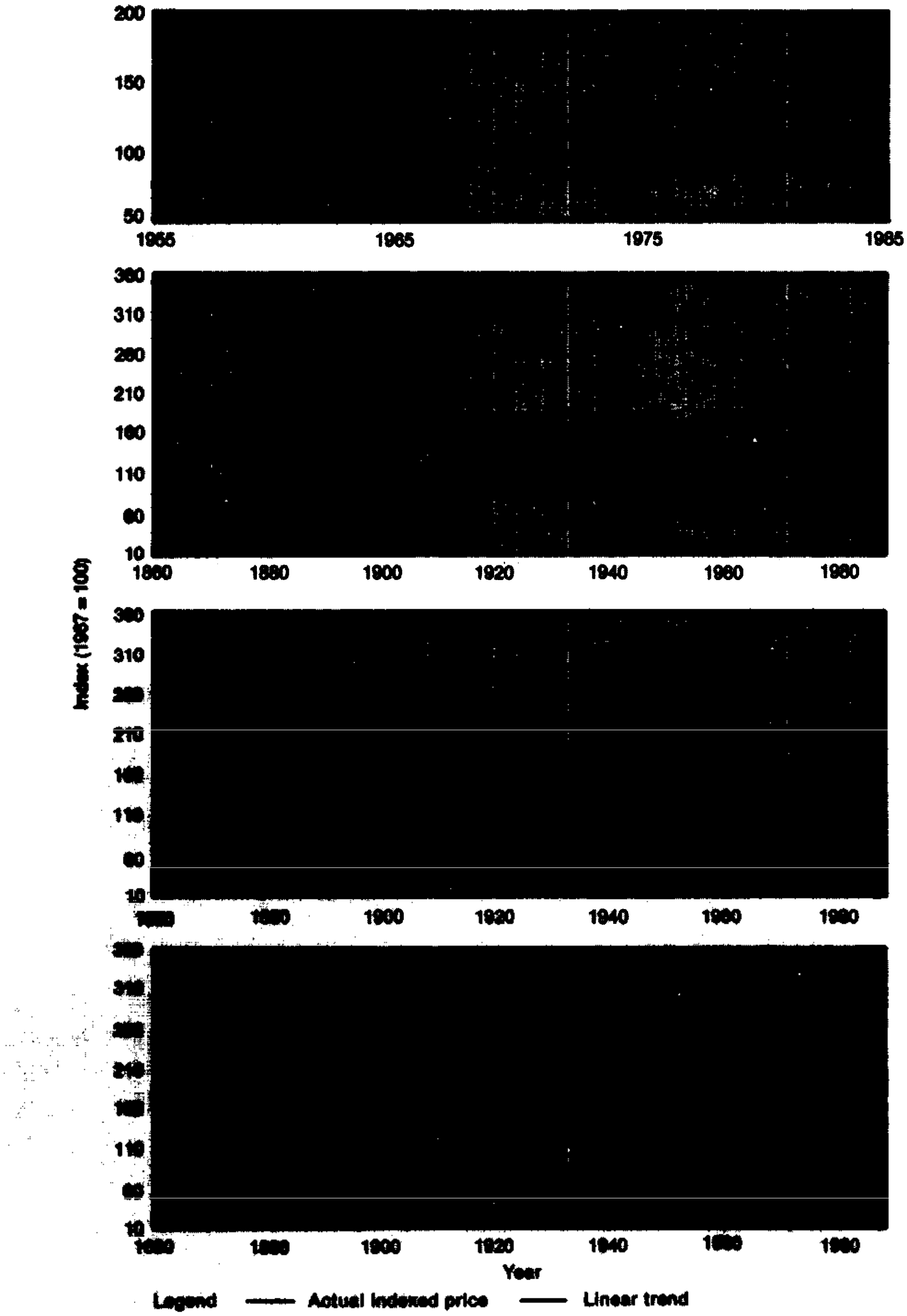
For most minerals, the normal forces of supply and demand resulting from macroeconomic trends determine the market price.[4] Mineral prices and demand are notably volatile (figure 3-2). While all minerals are subject to some oscillations in market prices due to normal economic events, some that are produced by only a few sources (where there is a relatively low level of trade, e.g. , cobalt) and

4 Broadus, "Seabed Materials," p. 857.

Photo credit: Jenifer Robison

Considerable onshore mining capacity remains idle as a result of depressed mineral prices, foreign competition, and reduced demand. Idle capacity will likely be brought back into production to satisfy increased future consumption before new mining operations are begun either onshore or offshore.

Figure 3-2.–Price Trends for Selected Seabed Mineral Commodities



Prices of several commodities that are derived from minerals known to occur on the seabed within the **U.S. EEZ** can change abruptly in world markets.

SOURCE: J.M. Broadus, "Seabed Materials," *Science*, vol. 235, Feb. 20, 19S7, p. S57 (modified and abbreviated).

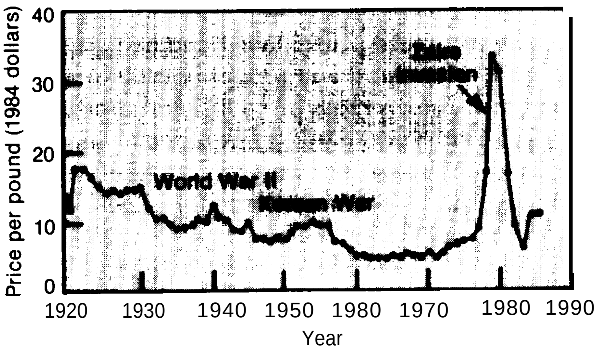
those that are targets of speculators (e. g., the precious metals) undergo drastic and often unpredictable swings in price. Although attempts at forming mineral cartels similar to Organization of Petroleum Exporting Countries (OPEC) in order to stabilize prices have generally failed eventually, e.g., attempts by Morocco to control the production and price of phosphate rock and the International Tin Council's effort to stabilize tin prices, they nevertheless can trigger serious price disruptions.[5] Speculative surges, such as that encountered by silver in 1979-80, also can have tremendous impacts on price structure.

In addition, unforeseen supply interruptions or the fear of such interruptions can drive the price of commodities up. The short-lived guerrilla invasion of the Zairian province of Shaba in 1977 and 1978, had a psychological effect on cobalt consumers that sent prices up from $6.40 per pound in February 1977 to $25 per pound in February 1979, although the invasion caused little interruption in production and Zairian cobalt production actually increased in 1978 (figure 3-3).[6] Threats of a possible cutoff of the supply of platinum-group metals from the Republic of South Africa, resulting from U.S. sanctions against apartheid, recently caused similar increases in the market price of platinum.

[5] S. Strauss, *Trouble in the Third Kingdom* (London, U. K.: Mining Journal Books, Ltd., 1986), p. 116; see also, K. Hendrixson and J. Schanz, Jr., *International Mineral Market Control and Stabilization: Historical Perspectives, 86-601* S (Washington, DC: Congressional Research Service, 1986).

[6] Office of Technology Assessment, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability,* OTA-ITE-248 (Washington, DC: U.S. Congress, 1985), pp. 97-104; see also, W. Kirk "A Third Pricing Phase: Stability?" *American Metal Market,* Aug. 23, 1985, pp. 9-12.

Figure 3-3.—Cobalt Prices, 1920-85



Cobalt is a good example of how mineral commodity prices can be affected by the fear of a supply interruption. Although supplies of cobalt were only briefly interrupted during the Shaba guerrilla uprising in Zaire, the psychological impact on traders caused cobalt prices to skyrocket from 1978 to 1979.

SOURCE: F. Manheim, "Marine Cobalt Resources," Science, vol. 232, May 2, 19S6.

Such commodity price fluctuations pose significant economic uncertainties for investors in new mineral developments, including seabed mining. Macroeconomic cycles coupled with macroeconomic disruptions within the minerals sector make planning difficult and the business future uncertain.

Nonmetallic minerals, while not completely immune from downturns in the business cycle, as a whole have fared better than metals in recent years. The prices of phosphate rock, sulfur, boron, diatomite, and salt have all increased at a higher rate than has inflation since 1973, whereas only the prices of tin (temporarily) and certain precious metals have matched that performance among the nonferrous metals.[7] However, all mineral prices fluctuated greatly during that period.

[7] Strauss, *Trouble in the Third Kingdom,* p. 140.

STATE OF THE MINING INDUSTRY

The downturn in the world minerals industry into the 1980s had a combination of causes:

- First, there has been a long-term (but only recently recognized) trend toward less metal-intensive goods.
- Second, growth has slackened in per capita consumption of consumer goods and capital expenditures.
- Third, developing countries' economies have not expanded to the point that they have become significant consumers, while at the same time some of these countries have become low-cost mineral producers competing with traditional producers in the industrialized countries.
- Fourth, petroleum companies diversified by investing in minerals projects that turned out

to be poor investments due to the 1982-83 recession.[8]

As a result, metal prices have remained quite low during the 1980s and will probably remain so until demand absorbs the unused mineral production capacity. The World Bank Index of metal and mineral prices indicates that the constant-dollar value of mineral prices in the 1981 to 1985 period was 19 percent below the value from 1975 to 1979 and 37 percent lower than the years 1965 through 1974.[9] To survive these prices, the domestic industry has undergone a significant shakedown and restructuring, coupled with cuts in operations to improve efficiency. While the surviving firms may emerge as stronger competitors, their ability and willingness to invest in future risky ventures such as seabed mining are likely to be limited.

Recent increases in the number of government-owned or state-controlled foreign mining ventures have added a new twist to the structure of the world mining industry. The domestic industry tends to blame state-owned producers for ignoring market forces and maintaining production despite low prices or supply surpluses. There is some evidence that state-owned operators may continue production in order to maintain employment or generate much-needed hard currency.[10]

Until recently, production costs in the United States have been well above the world average. Overvalued currency (high value of the dollar) during 1981-86 also may have contributed to making North American production less competitive. These factors may have masked any effect that state ownership might have played in distorting the world market.[11] Nevertheless, domestic competition with state-owned mining ventures is a trend that will likely continue in the future.

[8] Tilton, "Changing Trends in Metal Demand."

[9] World Bank, Commodities Division, "Primary Commodity Price Forecasts, Aug. 18, 1986.

[10] M. Radetzki, "The Role of State Owned Enterprises in the International Metal Mining Industry, paper presented at Conference on Public Policy and the Competitiveness of U.S. and Canadian Metals Production, Colorado School of Mines, Golden, CO, Jan. 27-30, 1987, p. 15.

[11] J. Ellis, "Copper," *The Competitiveness of American Metal Mining and Processing* (Washington, DC: Congressional Research Service, 1986). p. 17.

FERROALLOYS

Manganese, chromium, silicon, and a number of other alloying elements are used to impart specific properties to steel. Manganese is also used to reduce the sulfur content of steel and silicon is a deoxidizer. Most elements are added to molten steel in the form of ferroalloys, although some are added in elemental form or as oxides. Ferroalloys are intermediate products made of iron enriched with the alloying element. Ferromanganese, ferrochromium, and ferrosilicon are the major ferroalloys used in the United States. There are no domestic reserves of either manganese or chromium; therefore the United States must import all of these alloying elements.

U.S. ferroalloy producers have lost domestic markets to cheaper foreign sources. Higher domestic operating costs related to electric power rates, labor rates, tax rates, transportation costs, and regulatory costs have given foreign producers a competitive edge.

As a result, the form of U.S. chromium imports has changed during the last decade. Since 1981, the United States has imported more finished ferroalloys and metals than chromite (figure 3-4). Domestic production of chromium ferroalloys has decreased steadily since 1973, when 260,000 tons (chromium content) of ferroalloy was produced, to 59,000 tons in 1984 (largely conversion of stockpiled chromite).[12] Foreign producers now supply U.S. markets with about 90 percent of the high-carbon ferrochromium consumed and all of the ore used domestically for the manufacture of chemicals and refractories.

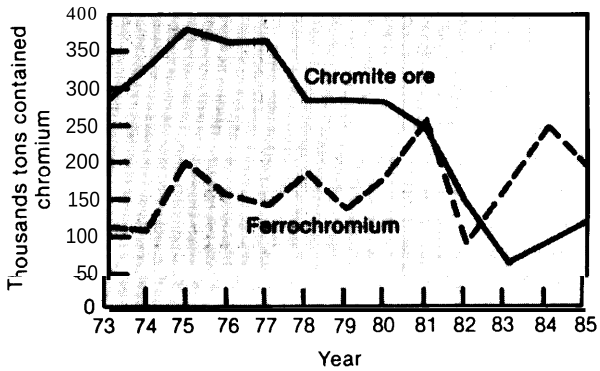
This shift from imports of ores and concentrates to imports of ferrochromium and finished metals could have important strategic implications. Since 1975, an increasing number of ferrochromium

[12] R. Brown and G. Murphy, "Ferroalloys," *Mineral Facts and Problems—1985 Edition,* Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 269.

plants have been built close to sources of chromite ores in distant countries, such as the Republic of South Africa, Zimbabwe, Greece, the Philippines, Turkey, India, and Albania. This trend in the movement of ferrochromium supply is expected to continue. Decline of U.S. ferroalloy production capacity in relation to demand will likely make the United States nearly totally dependent on foreign processing capacity in the future.

Domestic demand for ferroalloys is related to steel production. Domestic steel capacity fell by almost 50 million tons (30 percent) between 1977 and 1987. Iron castings capacity also has shrunk considerably in recent years. In 1986, the United States imported about 21 percent of its iron and steel. The decline in domestic steel production has also reduced the domestic demand for ferroalloys. With the decreases in both U.S. ferroalloy production and iron and steel production, demand for chromium and manganese ores for domestic production of ferroalloys is likely to continue to decline proportionately.

Figure 3-4.—U.S. Ferrochromium and Chromite Ore Imports



The United States is now importing significantly more chromium in the form of ferrochromium and as stainless steel than as chromite ore. This trend of increasing ferrochromium imports is threatening the existence of the domestic ferrochromium industry, and some analysts predict the extinction of the U.S. industry in the near future.

SOURCE: Office of Technology Assessment, 1987.

NATIONAL DEFENSE STOCKPILE

In 1939, Congress authorized stockpiling of critical materials for national security. World War 11 precluded the accumulation of stocks, and it was not until the Korean War that materials stockpiling began in earnest. Since that time, U.S. stockpile policy has been erratic and subject to periodic, lively debate. Past presidents have supported stockpiling critical materials for times of emergency, but some have favored disposal of some of the stockpiled items for fiscal or budgetary reasons. The question of how much of each commodity should be retained in the stockpile remains a hotly debated issue.

Stockpile goals are currently based on the materials needed for critical uses for a 3-year period that are vulnerable to supply interruption. Some observers conclude that an increase in one unit of domestic production capacity from domestic reserves could offset three units of stockpiled materials. This view argues in favor of promoting domestic production of stockpiled materials where feasible so as to reduce the need for emergency stockpiling. Several seabed minerals, including cobalt, manganese, and chromium could be considered as candidates for special treatment if government policies were to shift away from emergency stockpiling toward economic support of marginal resource development for strategic and critical purposes. To be considered a secure source of supply, however, marine mineral operations offshore would have to be protected from saboteurs or hostile forces.

The stockpiling program was overhauled in 1979 to create a National Defense Stockpile with a Transaction Fund that dedicates revenue received by the Federal Government from the sale of stockpile excesses to the purchase of materials short of stockpile goals.[13] In 1986, the stockpile inventory was valued at approximately $10 billion. If the stockpile met current goals, it would have a value of about $16.6 billion.[14] A number of materials de-

[13] Strategic and Critical Materials Stock Piling Act of 1979, Public Law 96-41, 50 U.S. C. 98 *et seq.*

[14] Federal Emergency Management Agency, *Stockpile Report to the Congress: October 1985-March 1986,* FEMA 36, 1986, p. 61,

rived from minerals known to occur within the U.S. EEZ are included in the stockpile: r-utile, platinum-group metals, chromium, lead, manganese, nickel, cobalt, zinc, chromium, copper, and titanium (table 3-l).

The stockpile program can affect minerals markets when there are large purchases to meet stockpile goals or sales of materials in excess of goals, although the authorizing legislation prohibits transactions that would disrupt normal marketing practices. Stockpile policies have on occasion opened additional markets for certain minerals, while at other times sales from the stockpile have significantly depressed some commodity prices. The mere existence of stockpile inventories can also have a psychological effect on potential mineral producers' actions.

Table 3-1.—Major U.S. Strategic Materials Contained in the National Defense Stockpile

Most vulnerable	Vulnerable	Less vulnerable
Chromium	Bauxite/alumina	Copper
Cobalt	Beryllium	Lead
Manganese	Columbium	Nickel
Platinum-group	Diamond (industrial)	Silver
	Graphite (natural)	Zinc
	Rutile	
	Tantalum	
	Tin	
	Titanium sponge	
	Vanadium	

SOURCE: Adapted from Federal Emergency Management Agency, *Stockpile* Report to the Congress (Washington, DC: Federal Emergency Management Agency, 1986), pp. 30-31.

SUBSTITUTION, CONSERVATION, AND RECYCLING

Changes in production technology can substantially affect minerals and materials use. Changes in use are generally made in response to economic incentives, although environmental regulations also have been instrumental in promoting some conservation and recycling. Cheaper materials or materials that perform better can replace their competitors by substitution. Similarly, there is significant motivation to reduce the amount of material used in a production process or to use it more efficiently. Finally, if the material is valuable enough to offset the cost of collecting, separating, and reclaiming scrap, there is an incentive to recycle the material through secondary processing. Each of these options can reduce the demand for primary minerals production.

Materials substitution is a continuing, evolutionary process where one material displaces another in a specific use. Examples of substitution abound. Steel has replaced wood for floor joists, studs, and siding in many construction applications. Plastics are replacing wood as furniture parts and finishes, many metals in non-stress applications, and steel in automobile bodies. Ceramics show promise for displacing carbide steels in some cutting tools and some internal combustion engine components. Glass fiber optics have replaced copper wire in some telecommunications applications. At a more elemental level, there are other examples: manganese can partially substitute for nickel and chromium in some stainless steels; the increased use of nickel-based superalloys have reduced the quantity of cobalt used in aircraft engines; and, for some electronic applications, gold can replace platinum.

Conservation technologies can reduce the amount of metal used in the manufacturing process. Near-net-shaping, in which metals are cast into shapes that correspond closely to the final shape of the object, can reduce materials waste in some instances. Conventional processing generally involves considerable machining of billets, bars, or other standard precast shapes and generates substantial amounts of mill cuttings and machine scrap. In some cases, the ratio between purchased metal and used metal may be as high as 10 to 1.[15] While much of this "new scrap" is reclaimed, some is contaminated and is unusable for high-performance applications like aircraft engines.

Improvements in production processes can also reduce metals needs. The use of manganese to desulfurize steel has been reduced with the intro-

[15] Office of Technology Assessment, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability,* p. 24.

duction of external desulfurization processes. Continuous casting technology can reduce the amount of scrap produced in steel manufacturing. Emerging technologies, for example, surface treatment technologies (e. g., ion-implantation) and powdered metal technologies, may also reduce the use of some metals for high-performance applications in the future.

For several metals, ' 'obsolete scrap' (''old scrap' could play an even more important role in reducing the need for virgin materials if economic conditions change and institutional problems are overcome. Recycling and secondary production has become a stable sector for several of the minerals (e. g., copper, lead, zinc, nickel, silver, iron, steel, and to a lesser extent platinum, chromium, and cobalt). Very little manganese is recycled. Economic factors largely determine the recyclability of materials, factors such as price; cost of collecting, identifying, sorting, and separating scrap; and the cost of cleaning, processing, and refining the metal. It is technologically possible to recover significantly more chromium, cobalt, and platinum from scrap should the need arise and economics permit.

MAJOR SEABED MINERAL COMMODITIES

Cobalt

Properties and Uses

Cobalt imparts heat resistance, high strength, wear resistance, and magnetic properties to materials. In 1986, about 36 percent of the cobalt consumed in the United States was for aircraft engines and industrial gas turbines (superalloys contain from 1 to 65 percent cobalt); 14 percent was for magnetic alloys for permanent magnets; 13 percent for driers in paints and lacquers; 11 percent for catalysts; and 26 percent for various other applications. These other applications included using of cobalt to cement carbide abrasives in the manufacture of cutting tools and mining and drilling equipment; to bind steel to rubber in the manufacture of radial tires; as a hydrators, desulfurizer, and oxidizer and as a synthesizer of hydrocarbons; in nutritional supplements; and in dental and medical supplies.

There are currently no acceptable substitutes or replacements for cobalt in high-temperature applications, although alternatives have been proposed. However, the possible substitutes are also strategic and critical metals such as nickel. While ceramics have potential for high-temperature applications, it will be some time in the future before they can be used extensively in jet engines or industrial gas turbines. Use of some cobalt-rich alloys could be reduced by substitution of ceramic or ceramic-coated automobile turbochargers, and there are possible replacements for cobalt in magnets.

National Importance

The United States imported 92 percent of the cobalt it consumed in 1986.[16] Cobalt is considered to be a potentially vulnerable strategic material (table 3-1) and is a priority item in the National Defense Stockpile. The stockpile goal for cobalt is 42,700 tons, and the inventory is currently 26,590 tons of contained cobalt, or about 62 percent of the goal. Much of the stockpiled cobalt is of insufficient grade to be used for the production of high-performance metals, although it could be used to produce important chemical products and for magnets.[17]

No cobalt has been mined in the United States since 1971. Zaire supplied 40 percent of U.S. cobalt needs from 1982 to 1985, Zambia 16 percent, Canada 13 percent, Norway 6 percent, and various other sources 25 percent.[18] In addition, about 600 tons of cobalt was recycled from purchased scrap in 1986, or approximately 8 percent of apparent consumption. There has been no domestic cobalt refinery capacity since the AMAX Nickel Refining Company closed its nickel-cobalt refinery at Port Nickel, Louisiana, (capacity of 2 million pounds of cobalt per year), although two firms use the facility to produce extra-fine cobalt powder from virgin and recycled material.

[16] W. Kirk, ' 'Cobalt, " *Mineral Commodity Summaries-1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 38,

[17] American Society for Metals, *Quality Assessment of National Defense Stockpile Cobalt Inventory* (Metals Park, OH: American Society for Metals, 1983), p. 40.

[18] Kirk, ' 'Cobalt, ' ,*Mineral Commodity Summaries—1987,* p. 38.

With 56 percent of cobalt imports originating from Zaire and Zambia, which together produce almost 70 percent of the world's supply of cobalt, the U.S. supply of cobalt is concentrated in developing countries with uncertain political futures. For example, the invasion of Shaba Province in Zaire in 1977 and 1978 by anti-government guerrillas caused some concern about the impact of political instability on cobalt supply. Abrupt increases in market prices followed, driven more by market opportunists and fear of the consequences than from direct interdiction of cobalt supply. Mining and processing facilities were only briefly closed and the impact on Zaire's production capacity was negligible.[19]

Domestic Resources and Reserves

Cobalt is recovered as a byproduct of nickel, copper, and, to a much lesser extent, platinum. Economic deposits typically contain concentrations of between 0.1 and 2 percent cobalt. The U.S. reserve base is large (950,000 tons of contained cobalt), but there are currently no domestic *reserves* of cobalt. Domestic cobalt resources are estimated at about 1.4 million tons (contained cobalt).[20]

The economics of cobalt recovery are linked more with the market price of the associated major metals (copper and nickel) than with the price of cobalt. It is necessary, therefore, that the major metals be economically recoverable to permit the recovery of cobalt as a byproduct. As a result, the price sensitivity of cobalt production is difficult to forecast. Depressed prices for the base metals reduce the economic feasibility of recovering cobalt.

Domestic land-based cobalt-bearing deposits are likely not to be mined until some time in the future. However, in an emergency and with government support, they could produce a significant proportion of U.S. cobalt consumption for a short time.[21] In addition, cobalt-rich manganese crusts in the Blake Plateau off the southeastern Atlantic coast and crusts or pavements on seamounts in the Pacific Ocean contain cobalt concentrations of between 0.3 and 1.6 percent (some ferromanganese crust samples have been reported to contain up to 2.5 percent), along with nickel, manganese, and other metals. These compare favorably with U.S. land-based resources that range from 0.01 to about 0.55 percent cobalt.[22]

Future Demand and Technological Trends

U.S. consumption generally accounts for about 35 percent of total world consumption. There is little prospect for major reductions in cobalt demand through substitution. Total U.S. demand for cobalt in 2000 is forecast to be between 24 million and 44 million pounds, with a probable demand of 34 million pounds (table 3-2).[23] Future demand for cobalt is difficult to forecast. Both the intensity of cobalt use and the amount of cobalt-based materials consumed have changed abruptly in the past and will likely continue to change in the future.

Chromium

Properties and Uses

Chromium is used in iron and steel, nonferrous metals, metal plating, pigments, leather process-

[19] Kirk, "A Third Pricing Phase: Stability ?," pp. 9, 12.
[20] Kirk, "Cobalt," Mineral Commodity *Summaries—1987*, p. 39.

[21] G. Peterson, D. Bleiwas, and P. Thomas, *Cobalt Availability—Domestic*, IC 8849 (Washington, DC: U.S. Bureau of Mines, 1981), p. 27.
[22] C. Mishra, C. Sheng-Fogg, R. Christiansen, et al., *Cobalt Availability—Market Economy Countries*, IC 9012 (Washington, DC: U.S. Bureau of Mines, 1985), p. 10.
[23] W. Kirk, "Cobalt," *Mineral Facts and Problems-1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 180.

Table 3-2.—Forecast of U.S. and World Cobalt Demand in 2000

	Actual	2000 Low	2000 Probable	2000 High	Annual growth 1983-2000
			(thousand pounds)		(percent)
United States	15,000[a]	24,000	34,000	44,000	3.9
Rest of world	31,500	50,000	65,000	75,000	3.5
Total world	—	74,000	99,000	120,000	3.7

[a] U.S. data for 1986 from W. Kirk, "Cobalt," *Mineral Commodity Summaries— 1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 38.

SOURCE: Adapted from W. Kirk, "Cobalt," *Mineral Facts* and Problems–1985 Edition, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 182.

ing, catalysts, and refractories. In 1986, 88 percent of the chromite (common ore form of chromium) consumed in the United States was used by the metallurgical and chemical industry, and 12 percent by the refractory industry.

Metallurgical Uses.—Chromium is used in a variety of alloy steels, cast irons, and nonferrous alloys. Chromium is used in these applications to improve hardness, reduce creep, enhance impact strength, resist corrosion, reduce high-temperature oxidation, improve wear, or reduce galling.

High-carbon ferrochromium contains between 52 and 72 percent chromium and between 6 and 9.5 percent carbon. Low-carbon ferrochromium contains between 60 and 75 percent chromium and between 0.01 and 0.75 percent carbon. Ferrochromium-silicon contains between 38 and 45 percent silicon and between 34 and 42 percent chromium.

The largest amount of ferrochromium (76 percent in 1986) is used for stainless steels. Chromium is also used in nonferrous alloys and is essential in the so-called "superalloys' used in jet engines and industrial gas turbines. In 1984, about 3 percent of the ferrochromium and pure chromium metal used for metallurgy was for superalloys; less than 1 percent was used for other nonferrous alloys. Chromium, along with cobalt, nickel, aluminum, titanium, and minor alloying metals, enables superalloy to withstand high mechanical and thermal stress and to resist oxidation and hot corrosion at high operating temperatures.

Chemical Uses.—Chromium-containing chemicals include color pigments, corrosion inhibitors, drilling mud additives, catalysts, etchers, and tanning compounds. Sodium bichromate is the primary intermediate product from which other chromium-containing compounds are produced.

Refractory Uses.—Chromite is used to produce refractory brick and mortar. The major use for refractory brick is for metallurgical furnaces, glassmaking, and cement processing. Use of chromite in refractories improves structural strength and dimensional stability at high temperatures.

National Importance

Chromium is considered to be a strategic material that is critical to national security and potentially very vulnerable to supply interruptions[24] (table 3-1 and 3-3). It is critical because of limitations on substitutes for chromium in the vacuum-melted superalloys needed for hot corrosion and oxidation resistance in high-temperature applications and in its extensive use in stainless steels.

table 3-3.—1986 National Defense Chromium Stockpile Goals and Inventories (as of Sept. 30, 1986)

Material	Goal	Inventory	Inventory as percent of goal
	(thousand	tons)	
Chromite:			
Metallurgical	3,200	1,874	59
Chemical	675	242	36
Refractory	850	391	46
Ferrochromium:			
High-carbon	185	502	271
Low-carbon	75	300	400
Silicon	90	57	63
Chromium metal	20	4	20

SOURCE J Papp, "Chromium," *Mineral Commodity Summaries*– 1987 (Washington, DC: U.S. Bureau of Mines, 1987), p. 35,

The Republic of South Africa accounted for 59 percent of total chromium imports (chromite ore, concentrates, and ferroalloys) between 1982 and 1985. Other suppliers included Zimbabwe, which provided 11 percent, Turkey 7 percent, and Yugoslavia 5 percent.[25] The Republic of South Africa and the U.S.S.R jointly led in world production of chromite in 1986, producing about 3.7 and 3.3 million tons respectively, far ahead of the next largest producer, Albania, with about 1 million tons.[26] Some foreign producing countries, such as Brazil, are producing and exporting ferrochromium from chromite deposits which would not be competitive in the world market if shipped as ore or concentrate. However, by adding the value of conversion to ferroalloy, both the Brazilian and the Zimbabwe deposits remain competitive.

Domestic Resources and Reserves

The United States currently has no chromite *reserves* or *reserve base*. Domestic resources have been mined sporadically when prices are high, or

L+ Office of Technology Assessment, *Strategic Materials: Technologies to Reduce* U.S. *Import* Vulnerability, p. 52.

[25] J. Papp, "Chromium," *Mineral Facts and Problems—1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 141.

[26] J. Papp, "Chromium, *Minerals Yearbook* (Washington DC: U.S. Bureau of Mines, 1985), p. 229.

with the aid of government price supports, or in times of national emergencies. Under normal economic conditions of world trade, U.S. chromite resources are not competitive with foreign sources of supply. There are 43 known domestic deposits estimated to contain approximately 7 million tons of contained chromic oxide as *demonstrated* resources and 25 million tons as identified resources .27 U.S. chromite deposits range between 0.4 percent and 25.8 percent chromic oxide content.

The major known domestic deposits of chromite minerals are the stratiform deposits in the Stillwater Complex in Montana and in small podiform-type deposits in northern California, southern Oregon, and southern Alaska. Placer chromite deposits occur in beach sands in southwest Oregon and stream sands in Georgia, North Carolina, and Pennsylvania.

Although 91 percent of U.S. *demonstrated* chromite resources and 84 percent of identified resources could be converted as low-chromium ferrochromium, the U.S. Bureau of Mines doubts that domestic chromite resources could be produced economically even with much higher market prices than the current $470 per ton for low-chromium ferrochromium and $600 per ton for high-chromium ferrochromium. Most low-chrome ferrochromium could be produced domestically for a little less than about $730 per ton, and high-chrome ferrochromium would cost even more.[28]

With enormous reserves of all grades of chromite in other parts of the world, it is doubtful that the meager chromite resources of the United States could justify the investment needed to rebuild the domestic ferrochromium production capacity that has been lost. In addition, there is currently significant overcapacity in the ferrochromium industry in the market economy countries. Estimates in 1986 showed production capacity of 2.6 million tons compared to demand of 1.9 million tons.[29] There have been no significant shortages of ferrochromium encountered in world markets in the past to indicate that things might change in the future.

Domestic Production

The United States was the world's leading chromite producer in the 1800s, but, since 1900, seldom more than 1,000 tons have been produced annually except for periods of wartime emergencies. During both World Wars and the Korean War, production increased when the Federal Government subsidized domestic chromite production. Domestic production ceased in 1961 when the last purchase contract under the Defense Production Act terminated. Since then, there was one attempt to reopen a mine closed in the 1950s, but, after producing only a small amount of chromite for export in 1976, the mine was again abandoned. There has been no domestic production reported since.

The United States imported and consumed about 512,000 tons of chromite ore and concentrate in 1984, primarily for use in chemicals and refractories. In 1973, the United States ferrochromium capacity was about 400,000 tons (contained chromium); by 1984, domestic capacity had shrunk to about 187,000 tons—a decrease of about 54 percent.[30] U.S. capacity is expected to shrink further, to perhaps 150,000 tons by 1990.[31] Ferrochromium production in 1984 was about 51,000 tons (contained chromium), or approximately 27 percent utilization of installed capacity .32 Production in 1984 was nearly four times that of 1983 as a result of government contracts for the conversion of stockpiled chromite to ferrochromium for the National Defense Stockpile. Once upgrading of the stockpile is completed, ferrochromium production may return to levels at or below 1983 production (13,000 tons—contained chromium). In 1984, only two of the six domestic ferrochromium firms were operating plants, and those only at low production levels or intermittently.

Future Demand and Technological Trends

Commodity analysts differ on the outlook for future chromium demand. One U.S. Bureau of

[27] J. Lemons, Jr., E. Boyle, Jr., and C. Kilgore, *Chromium Availability—Domestic*, IC *8895* (Washington, DC: U.S. Bureau of Mines, 1982), p. 4.

*[*]Ibid., p. 9.

[29] W. Dresler, "A Feasibility Study of Ferrochromium Extraction from Bird River Concentrates in a Submerged-Arc Furnace, *CIM Bulletin, vol. 79* (September 1986), pp. 98-105.

[30] G. Guenther, "Ferroalloys," *The Competitiveness of American Metal Mining and Processing*, ch. VIII (Washington, DC: Congressional Research Service, 1986), p. 127.

[31] Papp, ' 'Chromium, *Mineral Facts and Problems—1985 Edition*, p. 141.

[32] Papp, ' 'Chromium, *Minerals Yearbook—1984,* p, 220.

Table 3-4.–Forecasts for U.S. Chromium Demand in 2000 (thousand tons of contained chromium)

		2000		
End use	1983	Low	Probable	High
Chemical	62	90	110	121
Refractory	20	27	35	47
Fabricated metal products	21	60	80	100
Machinery	18	75	100	130
Transportation	39	80	100	130
Other	169	300	390	500

SOURCE: J, Papp, "Chromium," *Mineral Facts and Problems— 1965 Edition*, Bulletin 675 (Washington, DC: U S. Bureau of Mines, 1986), p. 152

Mines report foresees an increase in domestic chromium demand at a rate of about 6.5 percent per year between 1983 and 2000 (table 3-4),[33] from approximately 329,000 tons in 1983 to between 632,000 tons and about one million tons by 2000, with the most probable estimate being 815,000 tons. About 83 percent of the probable estimated demand in 2000 is expected to be used in metals; 13 percent in chemicals; and 4 percent in refractories.

Based on trends in chromium consumption and use, another Bureau of Mines report, produced in cooperation with basic industry analysts of the Department of Commerce, foresees a different demand scenario. This scenario is based on the theory that demand for ferrochromium is largely determined by the demand for stainless steel. Domestic production of stainless steel has remained relatively stable since 1980 at between 1.7 million and 1.8 million tons per year, with the exception of 1982 when it dipped to 1.2 million tons. Although chromium content of specific alloy and stainless steels remains stable, the use of high-chromium content steels has decreased in volume .34

There is significant potential for reducing the consumption of chromium through substitution by low-chromium steels, titanium, or plastics for stainless steel in less-demanding applications. The National Materials Advisory Board (NMAB) determined that 60 percent of the chromium used in stainless steel could be saved in a supply emergency by the use of low-chromium substitutes or no-chromium materials that either currently exist or could be developed within 10 years.[35] Only 20 to 30 percent of the chromium currently used domestically in stainless steel is considered to be irreplaceable. Substitution may also displace some of the chromite used in refractories with the use of low-chromite bricks or dolomite bricks. Substitutes for chromium in pigments and plating are also available, although at some sacrifice in desirable properties.

Use of chromium in chemicals generally reflects a slow but steady growth in chromium consumption, with expanded capacity of the chemical industry offsetting a decrease in the intensity of use of chromium. The use of chromite-containing refractories has significantly declined as the result of technological improvements in steel furnaces; open hearth furnaces have given way to electric arc furnaces and basic oxygen furnaces (BOF) in the steelmaking process. As a result of these changes in the intensity of use of chromium, the combined Bureau of Mines and Department of Commerce report forecasts a reduction in chromium demand from about 330,000 tons in 1983 to 275,000 tons in 1993.[36]

New technology for processing chromite ores has also increased the world supply of usable chromite reserves. Improvements in technologies to recover chromium from laterite deposits may also make low-grade deposits, some located in the western United States, more desirable for chromium recovery, but probably still not competitive.[37]

[33] Papp, "Chromium," *Mineral Facts and Problems—1985*, p. 152.

[34] *Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for Twelve Major Metals*, Open File Report 27-86 (Washington DC: U.S. Bureau of Mines, 1986), p. 7.

[35] National Materials Advisory Board, *Contingency Plans for Chromium Utilization, NMAB-335* (Washington, DC: National Academy of Sciences, 1978).

[36] Ibid., p. 44.

[37] A. Silverman, J, Schmidt, P, Queneau, et al, *Strategic and Critical Mineral Position of the United States with Respect to Chromium, Nickel, Cobalt, Manganese, and Platinum*, OTA Contract Report (Washington, DC: Office of Technology Assessment, 1983), p. 133; see also, H, Salisbury, M. Wouden, and M, Shirts, *Beneficiation of Low-Grade California Chromite Ores*, RI 8592 (Washington, DC: U.S. Bureau of Mines, 1982), p. 15.

Manganese

Properties and Uses

Manganese plays a major role in the production of steels and cast iron. Originally, manganese was used to control oxygen and sulfur impurities in steel. As an alloying element, it increases the strength, toughness, and hardness of steel and inhibits the formation of carbides which could cause brittleness. Manganese is also an important alloying element for nonferrous materials, including aluminum and copper.

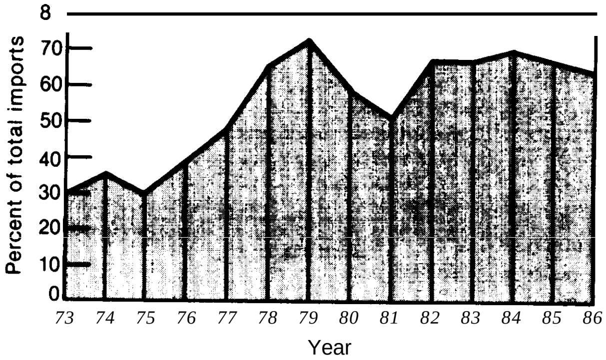
Hadfield steels containing between 10 and 14 percent manganese, are wear-resistant alloys used for certain railroad trackage and for mining and crushing equipment. An intermediate form of manganese alloy—ferromanganese—is usually used in the manufacture of steels, alloys, and castings. Because manganese can exist in several chemical oxidation states, it is used in batteries and for chemicals. Several forms of manganese are used in the manufacture of welding-rod coatings and fluxes and for coloring bricks and ceramics.

National Importance

Demand for manganese is closely related to steel production. Two major trends have combined to lessen domestic consumption of manganese. First, domestic steel production has declined; in 1986, it was at about half of its peak year in 1973, when the U.S. produced 151 million tons of raw steel. Second, developments in steel manufacturing technology have reduced the per-unit quantities of manganese needed. As a result, manganese consumption decreased from 1.5 million tons (contained manganese) in 1973 to 700,000 tons in 1986.

In the early 1970s, the United States was importing about 70 percent of its manganese in the form of ores, a large share of which was processed into ferromanganese by U.S. producers. By 1979, the picture had reversed, with imports of foreign-produced ferromanganese running at about 70 percent and manganese ores at about 30 percent. Since 1983, imports have been about one-third as ore and two-thirds as ferromanganese and metal (figure 3-5). There currently is no remaining domestic capacity for ferromanganese production.

Figure 3-5.—Percentage of Manganese imported into the United States as Ferromanganese, 1973=86



Like chromium and ferrochromium, the proportion of manganese imported by the United States as ferromanganese and manganese metal has increased compared to imported manganese ore. Manganese producing countries find it advantageous to ship processed ferromanganese or metal rather than unprocessed ore to gain the value added for export.

SOURCE: Office of Technology Assessment, 1987,

Today, the United States is highly dependent on foreign sources for manganese concentrates, ores, ferromanganese, and manganese metal. About 30 percent of the imports (based on contained manganese) are from the Republic of South Africa, 16 percent from France (produced largely from ore imported from Gabon), 12 percent from Brazil, 10 percent from Gabon, and 32 percent from diverse other sources.[38]

Manganese is a strategic material which is critical to national security and is potentially vulnerable to supply interruptions (table 3-l). Several forms of manganese are stockpiled in the National Defense Stockpile (table 3-5). However, the diversification of imports among many producing countries tends to somewhat reduce U.S. vulnerability to supply interruptions, although some supplier nations obtain raw material from less-secure African sources,

Domestic Resources and Reserves

Manganese pavements and nodules (approximately 15 percent manganese) on the Blake Plateau in the U.S. EEZ off the southeast coast are

[38]T. Jones, "Manganese," *Mineral Commodity Summaries-1987* (Washington, DC: U.S. Bureau of Mines, 1987), p, 98.

Table 3-5.—Status of Manganese in the National Defense Stockpile— 1986 (as of Sept. 30, 1986)

Material	Goal	Inventory	Inventory as percent of goal
	(thousand tons)		
Battery grade	87	175	201
Chemical ore	170	172	101
Metallurgical ore	2,700	2,235[a]	83
Ferromanganese	439	700	160
Silicomanganese	0	24	—
Electrolytic metal	0	14	—

[a]Stockpiled metallurgical grade ore is being converted to high-carbon ferromanganese which will add about 472,000 tons of ferromanganese to the stockpile and reduces the amount of manganese ore.

SOURCE: T Jones, "Manganese," Mineral *Commodity Summaries–1987*(Washington, DC: U.S Bureau of Mines, 1987), p 99.

estimated to contain as much as 41 million tons of manganese. Similar deposits off Hawaii and the Pacific Islands represent even more manganese on the seafloor within the U.S. EEZ.[39]

At current prices, there are no *reserves* of manganese ore in the continental United States that contain 35 percent or more manganese, nor are there resources from which concentrates of that grade could be economically produced. The 70 million tons of contained manganese *resources* estimated to exist in the United States average less than 20 percent and generally contain less than 10 percent manganese. The U.S. Bureau of Mines estimates that the domestic land-based subeconomic resources would require from 5 to 20 times the current world price of manganese to become commercially viable.[40]

Should an emergency require that economically submarginal domestic deposits be brought into production, the most likely would be in the north Aroostook district of Maine and the Cuyuna north range in Minnesota .[41]

It is unlikely that there will be much improvement in the U.S. manganese supply position. Past efforts to discover rich ore bodies or to improve the efficiency of processing technology have not been successful. What is known about seabed resources of manganese pavement and nodules indicates that manganese content may range between 15 and 30 percent, which makes offshore deposits at least comparable with some onshore deposits. But the uncertainties of offshore mining ventures and their associated costs, coupled with marginal mineral prices, raise doubts as to their economic feasibility as well.[42]

Future Demand and Technological Trends

Future manganese consumption will be determined mainly by requirements for steelmaking. The amount of manganese required for steelmaking depends on two factors: 1) the quantity of manganese used per ton of steel produced, and 2) the total amount of steel produced in the United States. Comparing 1982 with 1977, the intensity of use of manganese in the steel sector was reduced by half, and the total consumption of manganese used for producing steel also dropped around 50 percent .[43]

Although there has been a trend toward the use of higher manganese contents for alloying in high-strength steels and steels needed for cryogenic applications, the reduction in the intensity of use for steels used in large volumes has far exceeded the increases for the high-performance steels. Because manganese is an inexpensive commodity, there is little incentive to develop conservation technologies further.

The U.S. Bureau of Mines expects domestic manganese demand in 2000 to range between 700,000 and 1.3 million tons (manganese content), with probable demand placed at 900,000 tons (table 3-6). With 1986 apparent consumption about 665 million tons, only modest growth in demand is expected through the end of the century.

Nickel

Properties and Uses

Nickel imparts strength, hardness, and corrosion resistance over a wide range of temperatures when

[39]F. Manheim, "Marine Cobalt Resources, " *Science,* vol.232, May 2, 1986, Pp. 600-608.

[40]T. Jones, "Manganese," *Mineral* Facts *and* Problems—19&5 *Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 486.

[41]National Materials Advisor), Board, *Manganese Recovery ~ec~nology*, NMAB-323 (Washington, DC: National Academy of Sciences, 1976).

[42]C. Hillman, *Manganese Nodule Resources of Three Areas in the Northeast Pacific Ocean: With Proposed Mining-Beneficiation Systems and Costs,* IC 8933 (Washington, DC: U.S. Bureau of Mines, 1983).

[43] *Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for Twelve Major Metals*, Open File Report 27-86 (Washington, DC: U.S. Bureau of Mines, 1986), p. 77.

Table 3-6.—Forecast for U.S. and World Manganese Demand in 2000

		2000			Annual growth 1983-2000
	Actual	Low	Probable	High	
			(thousand tons)		(percent)
United States	665[a]	660	920	1,260	1.9
Rest of world	8,132	8,200	10,200	13,900	1.3
Total world	—	8,900	11,100	15,200	1.4

[a]U.S. data for 1988 from T. Jones, "Manganese, " *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 98.

SOURCE: Adapted from T. Jones, "Manganese, " in *Mineral Facts and Problems— 1985 Edition* (Washington, DC: U.S. Bureau of Mines, 1988), p. 495

alloyed with other metals. Approximately 39 percent of the primary nickel consumed in the United States in 1986 went into stainless and alloy steels; 31 percent was used in nonferrous alloys; and 22 percent was used for electroplating. The remaining 8 percent was used in chemicals, batteries, dyes and pigments, and insecticides.

Stainless steels may contain between 1.25 percent and 37 percent nickel, although the average is about 6 percent. Alloy steels, such as those used for high-strength components in heavy equipment and aircraft operations, contain about 2 percent nickel, although the average is less than 1 percent, while superalloy used for very high-temperature and high-stress applications like jet engines and industrial turbines may contain nearly 60 percent nickel. Nickel also is used in a wide range of other alloys (e. g., nickel-copper, copper-nickel, nickel-silver, nickel-molybdenum, and bronze).

National Importance

Most uses for nickel are considered critical for national defense and are generally important to the U.S. industrial economy overall. However, based on criteria that consider supply vulnerability and possible substitute materials, OTA determined in a 1985 assessment that nickel, while economically important, is not a *major "strategic'* material .44 Nickel is stockpiled in the National Defense Stockpile. The stockpile goal is 200,000 tons of contained nickel, and the inventory in 1986 was 37,200 tons—about 20 percent of the goal.

The United States imported about 78 percent of the nickel consumed in 1986.[45] Canada was the major supplier of nickel (40 percent) to the United States; Australia provided 14 percent, Norway 11 percent, Botswana 10 percent, and 25 percent was obtained from other countries, including the Republic of South Africa, New Caledonia, Dominican Republic, Colombia, and Finland. In 1986, the United States consumed 184,000 tons of nickel, compared to 283,000 tons in 1974.

Domestic Resources and Reserves

Domestically produced nickel will probably continue to be a very small part of U.S. total supply in the future. U.S. *demonstrated* resources are estimated to be about 9 million tons of nickel in place, from which 5.3 million tons may be recoverable.[46] *Identified* nickel resources are about 9.9 million tons, which could yield 6 million tons of metal. The domestic *reserve base* is estimated to be 2.8 million tons of contained nickel.[47] Although U.S. resources are substantial, the average grade of domestic nickel resources is about 0.21 percent (ranging from 0.16 percent to 0.91 percent), compared to the average world grade of nearly 0.98 percent. Ferromanganese crusts on Pacific Ocean seamounts are reported to be about 0.49 percent nickel .[48]

Domestic Production

Nickel production from U.S. mines was 1,100 tons in 1986, with about 900 tons of nickel recovered as a nickel sulfate byproduct of two primary

[44]Office of Technology Assessment, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*, p. 52.

[45]P. Chamberlain, "Nickel, *Mineral Commodity Summaries—1987* (Washington, DC: L', S. Bureau of Mines, 1987), p. 108.

[46]D. Buckingham and J. Lemons, Jr,, *Nickel Availability - Domestic*, IC 8988 (Washington, DC: U.S. Bureau of Mines, 1984), p. 25.

[47]Chamberlain, ' 'Nickel, " *Mineral Commodity Summaries—1987*, p. 109.

[48]W. Harvey and P. Ammann, "Metallurgical Processing Component for the Mining Development Scenario for Cobalt-Rich Ferromanganese Oxide Crust, Final Draft Chapter, *Manganese Crust EIS Project* (Arlington, MA: Arlington Technical Services, 1985), pp. 3-2

copper operations.[49] The only domestic mine to metal production came from Hanna Mining Company's Nickel Mountain Mine in Oregon, which produced ferronickel; the mine closed permanently in August 1986. Secondary recovery of nickel from recycled old and new scrap contributed about 39,000 tons in 1986, which was approximately 21 percent of apparent consumption.

Future Demand and Technological Trends

After growing at an average rate of roughly 6 percent per year for most of the century, nickel consumption flattened in the 1970s. From 1978 to 1982, the consumption sharply declined before stabilizing in the mid- 1980s. A major factor in the declining consumption between 1978 and 1982 was the drop in the intensity of nickel use. Less nickel was used per value of Gross National Product and per capita each year during the period. Since 1982, the intensity of use has remained fairly constant.

Much of the decrease in the intensity of use resulted from the substitution of plastics in coatings, containers, automobile parts, and plumbing, and displacement in the use of some stainless steel. Other possible substitute materials include aluminum, coated steel, titanium, platinum, cobalt, and copper. These substitutes, however, can mean poorer performance or added cost. Higher imports of finished goods and the reduced size of automobiles also reduce domestic nickel demand.

Domestic demand for nickel in 2000 is forecast to be between 300,000 and 400,000 tons, with the probable level being about 350,000 tons (table 3-7).[50] The forecast for a 2.6 percent annual growth in domestic nickel demand through 2000 is due to projected growth in total consumption, primarily for pollution abatement **and waste treatment machinery, mass transit systems, and aerospace components.**[51]

Copper

Properties and Uses

Copper offers very high electrical and thermal conductivity, strength, and wear- and corrosion-resistance, and it is nonmagnetic. As a result, copper is valuable both as a basic metal and in alloys (e.g., brass, bronze, copper nickel, copper-nickel-zinc-alloy, and leaded copper), and ranks third in world metal consumption after steel and aluminum. About 43 percent of U.S. copper products are used in building construction, 24 percent in electrical and electronic products, 13 percent for industrial machinery and equipment, 10 percent in transportation, and the remaining 10 percent in general products manufacturing.

In the aggregate, the largest use of copper (65 percent) is in electrical equipment, in the transmission of electrical energy, in electronic and computing equipment, and in telecommunications systems. Because of its corrosion resistance, copper has many uses in industrial equipment and marine and aircraft products. Copper is used extensively for plumbing, roofing, gutters, and other construction purposes. Brass is used in ordnance, military equipment, and machine tools that are important to national security. Copper chemicals are also used in agriculture, in medicine, and as wood preservatives. Once used extensively in coinage, copper has been

[49] Chamberlain, "Nickel," *Mineral Commodity Summaries-1987*, p. 109.

[50] S. Sibley, "Nickel,' *Mineral Facts and Problems—1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 547.

[51] International Trade Administration, *The End- Use Market for 13 Non-Ferrous Metals* (Washington, DC: U.S. Department of Commerce, 1986), p. 32.

Table 3-7.— Forecast of U.S. and World Nickel Demand in 2000

	Actual	2000 Low	2000 Probable	2000 High	Annual growth 1983-2000
			(thousand tons)		(percent)
United States	184a	**300**	**350**	**400**	**2.6**
Rest of world	800	1,000	1,300	1,500	2.9
Total world	—	1,300	1,700	1,900	2.7

aU, S. data for 1986 from P. Chamberlain, "Nickel," *Mineral Commodity Summaries– 1987 Edition* (Washington, DC: U.S. Bureau of Mines, 1987), p 108.

SOURCE Adapted from S. Sibley, "Nickel, " *Mineral Facts and Problems– 1985 Edition* (Washington, DC: U.S. Bureau of Mines, 1986), p. 548.

largely replaced by zinc and zinc-copper alloys in U.S. currency.

National Importance

Copper is a strategic commodity in the National Defense Stockpile. The stockpile goal is one million tons, with an inventory of 22,000 tons in 1986. The United States is the leading consumer of refined copper; it accounted for about 29 percent of world consumption, or 2.2 million tons of copper, in 1986. In 1982 the United States import reliance was 1 percent of the copper it consumed; by 1985, it was importing 28 percent.[52] Imports came largely from North and South America: Chile, 40 percent; Canada, 29 percent; Peru, 8 percent; Mexico, 2 percent. Other sources were: Zambia, 7 percent; Zaire, 6 percent; and elsewhere, 8 percent. Since 1982, Chile has led the world in copper production, followed by the United States, Canada, U. S. S. R., Zambia, and Zaire,

Domestic Resources and Reserves

World copper *reserves* total about 375 million tons, with 80 percent residing in market economy countries. The world's *reserve base* is about 624 million tons of copper, Chile has the largest single share of world *reserves*, accounting for 23 percent; the United States is second with 17 percent.[53]

The United States has a reserve base of about 99 million tons of copper, with *reserves* of 63 million tons. The average grade of domestic copper ore is about 0.5 percent copper, while the world average is close to 0.87 percent.[54] By comparison, copper in some polymetallic sulfide deposits that have been recovered from the seafloor show high variability ranging between 0.5 to 5 percent.[55]

Domestic Production

The United States mined 1.2 million tons of copper in 1986—second only to Chile in world mine production. Domestic mine production peaked in 1970, 1973, and 1981 at about 1.7 million tons each year, but then in response to depressed prices and a worldwide recession, production was cut back. Since then, copper production has recovered slowly to roughly the 1980 level. Copper's recent recovery has benefited from industry-wide cost cutting and improvements in efficiency and productivity resulting from equipment modernizations and renegotiated labor agreements.

The United States is one of the world's largest producers of refined copper, accounting for about 16 percent of world production in 1985. Copper is one of the most extensively recycled of all the common metals. Nearly 22 percent of domestic apparent consumption is recycled from old scrap. Copper prices peaked in 1980 at about $1.00 per pound (current dollars) as a result of high demand and industry labor disruptions, but have since sunk to nearly $0.62 (current dollars) in 1986. With lower prices, there is little incentive to increase efforts to recycle used copper.

Notwithstanding the large *reserve base* of copper in the United States, lower-cost imported copper has displaced appreciable domestic production in recent years. During 1984-85, domestic copper refinery capacity was reduced by about 410,000 tons, and several major mines closed. Between 1974 and 1985, domestic operating refinery capacity declined from 3.4 million tons to about 2 million tons as the result of major industry restructuring and cost reduction.

A number of factors have contributed to the disadvantage that U.S. producers face in meeting foreign competition, e.g., lower ore grade, higher labor costs, and more stringent environmental regulations and until recently, foreign exchange rates. Although significant progress recently has been made by U.S. copper producers to increase productivity and reduce costs at the mine and smelter, there is some doubt whether domestic producers can maintain their market position in the long term.[56]

Future Demand and Technological Trends

Since 1981, worldwide copper production has increased significantly while the rate of demand

[52] J. Jolly and D. Edelstein, "Copper," *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 42.

[53] J. Jolly, "Copper," *Mineral Facts and Problems-1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 203.

[54] L. Sousa, The U.S. Copper Industry (Washington, DC: U.S. Bureau of Mines, 1981), p. 27.

[55] V. McKelvey, *Subsea Mineral Resources*, Bulletin 1689-A (Washington, DC: U.S. Geological Survey, 1986), p. 82.

[56] Commodities Research Unit, *Copper Studies*, vol. 14, No. 4 (New York, NY: CRV Consultants, 1986), p. 7.

growth has been moderated largely by economic conditions and, to a lesser extent, by reduction in the intensity of copper use and substitution of other materials. Thus, today there is the possibility of substantial excess mine capacity in the world copper industry. Overly optimistic forecasts of demand based on consumption trends made in the late 1960s and early 1970s, forecasts of higher real prices, and the unforeseen onset of worldwide recessions beginning in 1975 and 1981 contributed to excess copper production.

The U.S. Bureau of Mines forecasts that domestic demand will increase to between 2.6 tons and 4.5 million tons by 2000, with probable demand about 3.1 million tons of copper (table 3-8). U.S. demand is forecast to increase at an annual rate of approximately 1.9 percent, while the rest of the world is expected to expand copper use at the higher rate of 2.9 percent.

The intensity of copper use fell by about one-fourth between 1970 and 1980.[57] Reductions in use were caused by the reduction in size of automotive and consumer goods, changes in design to conserve materials or increase efficiency, and substitutions of aluminum, plastics, and, to a lesser extent, optical fibers. Although the decline in the intensity of copper use is not expected to continue at the 1970s' rate and even could be offset by gains in other areas, the future of copper demand is uncertain. Moreover, copper is an industrial metal, and its consumption is linked to industrial activity and capital expansion. This makes copper demand very sensitive to general economic activity.

[57] *Domestic Consumption Trends; 1972-82, and Forecasts to 1993 for Twelve Major Metals,* p. 60.

Zinc

Properties and Uses

Zinc is the third most widely used nonferrous metal, exceeded only by aluminum and copper. It is used for galvanizing (coating) steel, for many zinc-based alloys, and for die castings. Zinc is also used in industrial chemicals, agricultural chemicals, rubber, and paint pigments. Construction materials account for about 45 percent of the slab zinc consumed in the United States; transportation accounts for 25 percent; machinery, 10 percent; electrical, 10 percent; and other uses, 10 percent.

National Importance

During the last 15 to 20 years, the United States has gone from near self-sufficiency in zinc metal production to importing 74 percent of the zinc consumed domestically in 1986.[58] Zinc is a component of the National Defense Stockpile; the stockpile goal is 1.4 million tons and the inventory in 1986 was about 378,000 tons—27 percent of the goal.

The United States consumed about 1.1 million tons of zinc in 1986. Between 1972 and 1982, U.S. slab zinc consumption decreased by nearly half,[59] a dramatic drop attributable to the combined effects of the economic recession and a decline in the intensity of use of zinc in construction and manufacturing.

Zinc is imported as both metal and concentrates. Canada provides about half the zinc imported into the United States; Mexico provides 10 percent; Peru, 8 percent; and Australia, 4 percent. All of

[58] J. Jolly, "Zinc," *Mineral Commodity Summaries— 1987* (Washington, DC: U.S. Bureau of Mines, 1987), p, 180

[59] *Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for Twelve Major Metals,* p. 131,

Table 3-8.—U.S. and World Copper Demand in 2000

	Actual	2000 Low	2000 Probable	2000 High	Annual growth 1983-2000
			(thousand tons)		(percent)
United States	2,390"	2,600	3,100	3,900	1.9
Rest of world	8,300	11,700	13,400	15,000	2.9
Total world	—	14,300	16,500	18,800	2.7

[a] U S, data for 1986, J. Jolly, and D Edelstein, "copper," *Mineral Commodity Summaries— 1987* (Washington, DC: U S Bureau of Mines, 1987), p. 42, world data for 1983 from source below

SOURCE Adapted from J Jolly, "Copper," *Mineral Facts and Problems— 1985 Edition* (Washington, DC: Bureau of Mines, 1986), p 219 the major foreign sources of supply are considered to be secure, and there is little risk of supply interruptions.

Domestic Resources and Reserves

The U.S. reserve *base is* estimated to be about 53 million tons of zinc. Domestic *reserves* are nearly 22 million tons. Zinc is generally associated with other minerals containing precious metals, lead, and/or copper. The world *reserve base is* estimated to be 300 million tons of zinc, with major deposits located in Canada, Australia, Peru, and Mexico. World zinc *resources* are estimated to be nearly 2 billion tons,[60] Zinc occurs in seabed polymetallic sulfide deposits along with numerous other metals. The few samples of sulfide material that have been recovered for analysis show wide ranges in zinc content (30-0.2 percent).[61]

Domestic Production

U.S. mine production of zinc in 1986 was about 209,000 tons, down from 485,000 tons in 1976. The decline is attributed to poor market conditions and depressed prices. Some mines shut down in 1986 are expected to reopen in 1987, and new mines will open. Production is then expected to return to around the 1985 level, or about 250,000 tons. Domestic zinc metal production in 1986 also reached lows comparable to those of the depression in the early 1930s. Recycling accounted for 413,000 tons of zinc—about 37 percent of domestic consumption—in 1986.

Future Demand and Technological Trends

The U.S. Bureau of Mines forecasts that both domestic and world zinc demand will increase at the rate of about 2 percent annually through 2000. Probable U.S. demand in 2000 is forecast to be about 1.5 million tons, with possible demand ranging between a low of 1.1 million tons and a high of 2.3 million tons (table 3-9).

A major determinant of future zinc demand will be its use in the construction (galvanized metal structural members) and automotive industries, which together account for about 60 percent of zinc consumption in the U.S. Although use of zinc by the domestic automotive industry has decreased in recent years, this trend is expected to reverse, and manufacturers will again use more electro-galvanized, corrosion-resistant parts as a competitive strategy through extended warranty protection.

Aluminum, plastics, and magnesium can substitute for many zinc uses, including castings, protective coatings, and corrosion protection. Aluminum, magnesium, titanium, and zirconium compete with zinc for some chemical and pigment applications.

It is likely that the U.S. will continue to rely in part on foreign sources of supply; however, domestic resources in Alaska and perhaps Wisconsin might be developed to offset some imports.[62] Secondary sources and recycling of zinc could become more important in the future with improvements in recycling technology and better market conditions.

Gold

Properties and Uses

Gold is a unique commodity because it is considered a measure and store of wealth. Jewelry and art accounted for 48 percent of its use in the United

[60] J. Jolly, "Zinc," *Mineral Commodity Summaries—1987,* p. *181.*
[61] McKelvey, *Subsea Mineral Resources,* p. *82.*

[62] Jolly, "Zinc, *Mineral Facts and Problems—1985 Edition,* Bulletin *675* (Washington, DC: U. S. Bureau of Mines, 1986), p. 939.

Table 3.9.—Forecast of U.S. and World Zinc Demand in 2000

	Actual	2000 Low	2000 Probable	2000 High	Annual growth 1983-2000
			(thousand tons)		(percent)
United States	1,130a	1,100	1,540	2,310	2.0
Rest of world	6,340	7,490	8,820	10,250	2.0
Total	—	8,590	10,360	12,560	2.0

aU.S. data for 1986 from J. Jolly, "zinc," *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 180, world data for 1983 from source below.

SOURCE: Adapted from J. Jolly, "Zinc," Mineral Facts and *Problems—1985 Edition* (Washington, DC: U.S. Bureau of Mines, 1988), p. 938, States in 1986, Gold's resistance to corrosion makes it suitable for electronics uses and dentistry. Gold is also used in the aerospace industry in brazing alloys, in jet and rocket engines, and as a heat reflector on some components. Industrial and electronic applications accounted for about 35 percent of 1986 consumption, dental 16 percent, and investment bars about 1 percent of the gold consumed in 1986. Although gold is exchanged in the open market, about 1.2 billion troy ounces—one-third of the gold mined thus far in the world—is retained by governments.

National Importance

Gold is not a component of the National Defense Stockpile, but the U.S. Treasury keeps a residual stock of about 263 million troy ounces of bullion. Although gold is no longer linked directly to the U.S. monetary system, its value in the world economic equation continues to be a hedge against future economic uncertainties. Should the United States or other major countries return to a regulated gold standard, its price could be affected significantly. Recently the United States issued the Golden Eagle coin for sale as a collector's and investor's item, but gold is not normally circulated as currency.

Apparent U.S. consumption of gold was 3.3 million troy ounces in 1986, whereas about 3.6 million troy ounces were produced by U.S. mines.[63] When U.S. primary industrial gold demand peaked in 1972 at about 6.6 million troy ounces, imports relative to domestic production were about 71 percent. At the lowest primary demand level in 1980 (1 million troy ounces), net imports exceeded primary demand by nearly 2.6 million troy ounces.[64] Canada is the largest single source of imported gold.

Domestic Resources and Reserves

The United States gold reserve base is about 120 million troy ounces. Most of the *reserve base* is in lode deposits. The world *reserve base* of gold is about 1.5 billion ounces, of which about half is located in the Republic of South Africa.[65] Some offshore placer deposits, such as those currently being experimentally dredge mined by Inspiration Mines near Nome, Alaska, maybe considered part of the *reserve base.*

Domestic Production

Domestic gold production was at an all-time high in 1986 with about 3.6 million ounces mined. Lowest production within the last 10 years was 964,000 ounces in 1979. The Republic of South Africa produced about 21 million ounces of gold in 1986—over 40 percent of total world production. Compared to major gold mines in South Africa, the U. S. S. R., and Canada, most existing and potential U.S. gold mines are low-grade, short-life operations with annual outputs between 20,000 and 90,000 troy ounces.[66]

Future Demand and Technological Trends

Generally, domestic primary demand for gold has decreased steadily since its peak at 6.3 million ounces in 1972. Nevertheless, the U.S. Bureau of Mines forecasts that domestic gold demand will increase at an average annual rate of about 2.4 percent through 2000. Domestic primary demand is forecast to be between a low of 2.8 million ounces and a high of 4.6 million ounces in 2000, with the probable demand at 3.7 million troy ounces.[67] Demand in the rest of the world is expected to grow at a slower pace of 1.7 percent annually through 2000.

While other metals may substitute for gold, substitution is generally done at some sacrifice in properties and performance. Platinum-group metals are occasionally substituted for gold but with increased costs and with metals considered to be critical and strategic. Silver may substitute in some instances at lower cost, but it is less corrosion-resistant and involves some compromise in performance and debendability.

[63] J. Lucas, "Gold," *Mineral Commodity Summaries—1987* (Washington, DC: U. S, Bureau of Mines, 1987), p. 62.
[64] J. Lucas, "Gold," *Mineral Facts and Problems— 1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 336,
[65] Lucas, "Gold," *Mineral Commodity Summaries-1987*, p. 63.
[66] P. Thomas and E. Boyle, Jr., *Gold Availability—World*, IC 9070 (Washington DC: U.S. Bureau of Mines, 1986), p. 38.
[67] Lucas, "Gold, ' *Mineral Facts and Problems—198.5 Edition*, p. 335.

Platinum-Group Metals

Properties and Uses

The platinum-group metals (PGMs) consist of six closely related metals that commonly occur together in nature: platinum, palladium, rhodium, iridium ruthenium, and osmium.[68] They are not abundant metals in the earth's crust; hence their value is correspondingly high. At one time, nearly all of the platinum metals were used for jewelry, art, or laboratory ware but during the last 30 or 40 years they have become indispensable to industry, which now consumes 97 percent of the PGMs used annually in the United States.

Industry uses PGMs for two primary purposes: 1) corrosion resistance in chemical, electrical, glass fiber, and dental-medical applications, and 2) a catalysis for chemical and petroleum refining and automotive emission control. About 46 percent of PGMs was used for the automotive industry in 1986, 18 percent for electronic applications, 18 percent for dental and medical uses, 7 percent for chemical production, and 14 percent for miscellaneous uses.[69] Although the importance of platinum for jewelry and art has diminished as industrial uses increase, a significant amount of the precious metal is retained as ingots, coins, or bars by investors.

While the PGMs are often referred to collectively for convenience, each has special properties. For example, platinum-palladium oxidation catalysts are used for control of auto emissions, but a small amount of rhodium is added to improve efficiency. Palladium is used in low-voltage electrical contacts, but ruthenium is often added to accommodate higher voltages.[70]

National Importance

The United States is highly import-dependent for PGMs. About 98 percent of PGMs consumed in 1986 were imported. The Republic of South Africa supplied 43 percent of U.S. consumption, United Kingdom 17 percent, U.S.S.R. 12 percent, and Canada, Colombia and other sources 28 percent. Because nearly all of the PGMs imported from the United Kingdom originated in South Africa prior to refining, the Republic of South Africa actually provides the United States with approximately 60 percent of its platinum imports.

Potential instability in southern Africa, dependence on the U.S.S.R. for a portion of U.S. supply, scarcity of domestic resources, and the importance that PGMs have assumed in industrial goods and processes make platinum metals a first tier critical and strategic material.[71] Platinum, palladium, and iridium are retained in the National Defense Stockpile (table 3-10).

Domestic Resources and Reserves

There are several major areas with PGM deposits that are currently considered to be economic or subeconomic in the United States. The domestic reserve *base is* estimated to be about 16 million troy ounces.[72] Of that, however, only 1 million ounces are considered to be *reserves.*[73] Most of the PGM reserves are byproduct components of copper reserves. *Demonstrated* resources may contain 3 million ounces of platinum of which 2 million ounces are gauged to be recoverable.[74] Some estimates place *identified* and *undiscovered* U.S. resources at 300 million ounces.[75]

[68] The disparities in demand among PGMs and the variance in proportion and grade of individual metals recovered from PGM mineral deposits complicate the assessment of supply-demand for this metal group. For simplicity, the PGMs are discussed as a unit,

[69] J. Loebenstein, "Platinum-Group Metals, " *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 118.

[70] J. Loebenstein, "Platinum-Group Metals, " *Mineral Facts and Problems—1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 599.

[71] Office of Technology Assessment, *Strategic Materials: Technologies to Reduce U.S. Vulnerability,* p. 52.

[72] Loebenstein, "Platinum-Group Metals, " *Mineral Commodity Summaries—1987,* p. 119.

[73] 1 bid., p. 21.

[74] T. Anstett, D, Bleiwas, and C. Sheng-Fogg, *Platinum Availability—Market Economy Countries,* IC 8897 (Washington, DC: U.S. Bureau of Mines, 1982), p. 4.

[75] 1 bid., p. 6.

Table 3-10.—Platinum. Group Metals in the National Defense Stockpile (as of Sept. 30, 1986)

Material	Goal	Inventory	Inventory as percent of goal
	(thousand	troy ounces)	
Platinum	1,310	440	34
Palladium	3,000	1,262	42
Iridium	98	30	30

[a] The Stockpile also contain 13,043 troy ounces of nonstockpile-grade Platinum and 2,214 ounces of palladium.

SOURCE: J.R. Lobenstein, "Platinum-Group Metals, " *Mineral Commodity Summaries — 1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 119.

The PGM potential of the Stillwater Complex in Montana is higher than that of the other known domestic deposits. Stillwater PGMs are found in conjunction with nickel and copper. The Stillwater Mining Company, which is capable of producing 500 tons of ore per day, began producing PGMs in March 1987, but the mineral concentrates are being shipped abroad for refining to metal. Nearly 80 percent of the PGMs in Stillwater ores is palladium, and the remainder is mostly platinum. Platinum generally brings several times the price of palladium. The Salmon River deposit in Alaska is an alluvial gravel placer that is estimated to contain about 500,000 troy ounces of recoverable platinum. The Ely Spruce and Minnamax deposits in northeastern Minnesota are estimated to contain less than 800,000 troy ounces of platinum at the *demonstrated* level.[76]

World resources are estimated to be about 3.3 billion troy ounces of PGMs. The world *reserve base* is about 2.1 billion troy ounces, with the Republic of South Africa controlling 90 percent of the reserves. Other major reserves are found in the U.S.S.R. and Canada, The United States has less than 10 percent of the world's total PGM resources.

Domestic Production

Domestic firms produced approximately 5,000 troy ounces of PGMs in 1986, all as byproducts from copper refining. The Republic of South Africa and the U.S. S. R. dominate world production of PGMs; in 1986 South Africa's mine production was 4 million ounces and the Soviet Union's was 3,7 million ounces of PGMs. Together they accounted for 95 percent of world production. It is expected that existing world reserves will have no problem in meeting cumulative demand through 2000.

Future Demand and Technological Trends

U.S. demand for PGMs in 2000 is expected to be between 2 million ounces and 3.3 million ounces (table 3-1 1) with the probable demand at about 2.9 million ounces. Domestic demand is forecast to grow at a rate of 2.5 percent annually between 1983 and 2000. Demand in the rest of the world is expected to increase more rapidly—perhaps 3 percent annually— due to the introduction of catalytic auto emission controls in Europe and Australia, and to the Japanese and U.S. emphasis on developing fuel cell technology as an alternative power source.

For most PGM end uses, the intensity of use has diminished since 1972.77 Although intensity of use has declined, consumption has generally increased as a result of the growth of the automotive, electronic, and medical industries that consume platinum, palladium, and iridium. Since 1982, investors and speculators have been purchasing large quantities of platinum coins, bars, and ingots.

There are opportunities to reduce imports by improved recycling and substitution. About 97 percent of the PGMs used for petroleum refining and 85 percent of the catalysts used for chemicals and pharmaceutical manufacturing are recycled. Automobile catalysts are recycled much less frequently,

[76]Ibid., p. 7.

[77]*Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for Twelve Major Metals*, p. 96.

Table 3-11.– Forecast of Demand for Platinum-Group Metals in 2000

Material	1983	2000 Low	2000 Probable	2000 High
		(thousand troy ounces)		
Platinum	797	900	1,300	1,400
Palladium	922	1,000	1,400	1,500
Rhodium	44	50	70	80
Ruthenium	145	140	210	230
Iridium	5	5	10	20
Osmium	1	1	2	4
Total platinum-group	1,914	2,000a	2,900	3,300

aTotal differs from individual forecasts due to rounding.

SOURCE: J. Loebenstein, "Platinum-Group Metals," *Mineral Facts and Problems— 1985* (Washington, DC: U.S Bureau of Mines, 1966), p. 611.

but recycling could increase if PGM prices escalate and if collection and waste disposal costs are reduced. It may be possible to reprocess as much as 200,000 troy ounces of PGMs annually from used automotive catalysts (about 3 percent of 1986 U.S. consumption).[78] Recycling of electronic scrap has collection and processing problems similar to recycling of automotive catalysts.

Substitution opportunities for PGMs in automotive catalysts are limited. Moreover, there is little incentive to seek alternatives for catalysts in the petroleum industry because a high proportion of PGMs used is currently recycled. Similarly, in the chemical and pharmaceutical industry, the value of the product far exceeds the return on investment for developing non-PGM substitutes, which usually are less efficient. It is possible to reduce the amount of PGMs used for electrical and electronic applications by substituting gold and silver for platinum and palladium.

Titanium (Ilmenite and Rutile)

Properties and Uses

Titanium is used as a metal and for pigments. Ninety-five percent of world production is used for white titanium dioxide pigment. Its high light reflectivity makes the pigment valuable in paints, paper, plastics, and rubber products. About 65 percent of the titanium pigments used domestically are for paint and paper.

Titanium alloys have a high strength-to-weight ratio and high heat and corrosion resistance. They, therefore, are well-suited for high technology applications, including high performance aircraft, electrical generation equipment, and chemical processing and handling equipment.

Although only 5 percent of all titanium goes into metal, it is an important material for aircraft engines. About 63 percent of the titanium metal consumed in the United States in 1985 was for aerospace applications. The remaining 37 percent was used in chemical processing, electric power generation, marine applications, and steel and other alloys. Titanium carbide is used in commercial cutting tools in combination with tungsten carbide. Organotitanium compounds are used as catalysts in polymerization processes, in water repellents, and in dyeing processes.

National Importance

Over 80 percent of the titanium materials used in the United States are imported. The major sources of U.S. raw material imports are Canada and Australia. Other suppliers include the Republic of South Africa and Sierra Leone. The United States also imported about 5,500 tons of titanium metal in 1984 (about 5 percent of consumption), mainly from Japan, Canada, and the United Kingdom. Titanium's importance to the military and to the domestic aerospace industry makes this metal a second-tier strategic material ('strategic to some degree' with some small measure of potential supply vulnerability.[79] The current National Defense Stockpile goal for titanium sponge is 195,000 tons, and the current inventory is about 26,000 tons. The stockpile goal for rutile (used for metal production as well as pigments) is 106,000 tons, with the current inventory at 39,186 tons.

Domestic Resources and Reserves

The United States has *reserves* of about 7.9 million tons of titanium in the form of ilmenite and 200,000 tons in the form of rutile, both located mainly in ancient beach sand deposits in Florida and Tennessee and in ilmenite rock (table 3-12). The domestic *reserve base* of 23 million tons of titanium contains 15.5 million tons of ilmenite, 6,5 million tons of perovskite (not economically minable), and 900,000 tons of rutile. Total *resources* (including *reserves* and *reserve base)* are about 103 million tons of titanium dioxide, made up of 13 million tons of rutile, 30 million tons of ilmenite, 42 million tons of low-titanium dioxide ilmenite, and 18 million tons of perovskite.[80] These resources include large quantities of rutile at concentrations of about 0.3 percent in some porphyry copper ores and mill tailings.[81]

[78] *Platinum*, MCP-22 (Washington, DC: U.S. Bureau of Mines, 1978), p. 13.

[79] Office of Technology Assessment, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*, p. 52.

[80] E. Force and L. Lynd, *Titanium Mineral Resources of the United States—Definitions and Documentation*, Geological Survey Bulletin 1558-B (Washington, DC: U.S. Government Printing Office, 1984), p. B-1.

[81] E. Force, "Is the United States of America Geologically Dependent on Imported Rutile?," *Proceedings of the 4th Industrial Minerals International Congress*, Atlanta, GA, 1980.

Table 3-12.—U.S. Titanium Reserves and Reserve Base

	Reserves			Reserve bse[a]		
	Ilmenite	Rutile	Total	Ilmenite[b]	Rutile	Total
	(thousand tons of contained titanium)					
Arkansas	—	—	—	—	100	100
California	—	—	—	400	—	400
Colorado	—	—	—	6,500	—	6,500
Florida	5,000	200	5,200	5,400	200	5,600
New York	2,700	—	2,700	5,300	—	5,300
Tennessee	200	10	210	3,700	600	4,300
Virginia	—	—	—	500	—	500
Total	7,900	210	8,110	22,000	900	23,000

[a]The reserve base includes demonstrated resources that are currently economic reserves, marginally economic reserves, and Some that are currently subeconomic resources.
[b]Ilmenite except for 6,5 million tons in Colorado perovskite.

SOURCE: L. Lynd, "Titanium," *Mineral Facts and Problems— 1985 Edition* (Washington, DC: US. Bureau of Mines, 1986), p. 663.

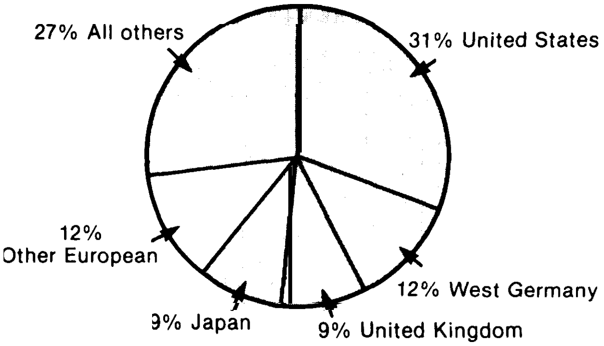
Domestic Production

The United States is the world leader in titanium pigment production, with 31 percent of the world's pigment capacity, far ahead of the Federal Republic of Germany in second place with 12 percent (figure 3-6). There were 11 U.S. titanium pigment plants operated by 5 firms in production in 1986. Their combined capacity was about 919,000 tons of pigment per year. Production in 1986 was about 917,000 tons, with nearly all of the plant capacity being utilized.

The United States accounts for about 25 percent of the world's titanium sponge production capacity, third behind the U.S.S.R. (39 percent) and Japan (28 percent). In 1985, total U.S. sponge capacity was about 33,500 tons annually, the Soviet capacity was about 53,000 tons, and the Japanese 38,000 tons. U.S. production of sponge in 1985 was about 23,000 tons, indicating that domestic producers were then operating at about 70 percent of capacity.

When demand peaked in 1981 due to rapid increases in aerospace use, the U.S. consumed about 32,000 tons of titanium metal. This surge in demand, which resulted in a temporary titanium shortage, prompted both the United States and Japan to increase their titanium metal production capacity. However, in 1982 the recession and overstocked inventories forced a cutback in sponge production in both countries to below 50 percent of capacity. Since then, the economic recovery and expansion of the U.S. military and commercial air fleets has increased domestic demand for titanium

Figure 3-6.—World Titanium Pigment Manufacturing Capacity



Titanium dioxide is the major form of titanium used in the United States. It is primarily used for manufacturing pigments for paints and whiteners. The United States currently leads the world in pigment production.

SOURCE: Office of Technology Assessment, 1987

metal, but significant U.S. production capacity remains idle.

Production of titanium heavy minerals is driven primarily by demand for titanium dioxide pigments. E.I. du Pont de Nemours & Co., Inc., the world's largest titanium dioxide producer, obtains raw materials from its own mines in Florida and from a partially owned Australian subsidiary.

Currently, there are only two deposits producing heavy minerals from titaneous sands in the United States. Both are in northeastern Florida, Trail deposit near Starke, Florida (du Pent), and the Green Cove Springs deposit (Associated Minerals (U.S.A.), Ltd.) near the community of the same name.[82] The six U.S. titanium sponge producers import rutile, the raw material now used for metal production in the market economy countries,[83] primarily from Australia, Sierra Leone, and the Republic of South Africa. Associated Minerals (U.S.A.), Ltd., is the sole domestic producer of natural rutile concentrate, although Kerr-McGee Chemical Corp. produces about 100,000 tons of synthetic rutile[84] from high-grade ilmenite through the removal of iron at its Mobile, Alabama, plant.

Future Demand and Technological Trends

Projected total titanium demand in 2000 is estimated at 750,000 tons, an increase of 43 percent from 1983; however, demand could range from a low of 600,000 tons to a high of 1 million tons (table 3-1 3).[85] The greatest *percentage* increase in titanium demand is expected to occur in the use of metals, which is projected to increase over five-fold, from 8,000 to 45,000 tons (this appears to be an optimistic estimate). Nevertheless, non-metal uses will continue to dominate the titanium market, probably approaching 700,000 tons by 2000, up from 515,000 tons in 1983.

In contrast, domestic titanium mine production in 2000 is projected at about 210,000 tons, an annual growth rate of about 4.6 percent from the 1982 level of 98,000 tons. Cumulative domestic mine production from the period 1983 to 2000 is projected to be 2.6 million tons titanium, significantly less than the probable cumulative primary non-metal demand of 10.5 million tons. Most of the future 7.9-million-ton shortfall is expected to be supplied by imports, even though domestic reserves of 7.8 million tons of ilmenite (contained titanium equivalent) and 199,000 tons of rutile (contained titanium equivalent) are considered sufficient to meet about 80 percent of expected U.S. non-metal demand in 2000.

Although a major proportion of future U.S. mine production is considered suitable for conversion to metal with intermediate processing,[86] nearly all of the titanium concentrates used for domestic metal production are expected to come from cheaper im-

[82] W. Harvey and F. Brown, *Offshore Titanium Heavy Mineral Placers: Processing and Related Considerations,"* OTA Contract Report, November 1986, p. 3.

[83] Although the free market countries prefer to produce titanium metal from rutile, the U. S.S. R and People's Republic of China—which collectively produce 63 percent of the world titanium metal—manufacture metal from high-grade titanium oxide slag made from ilmenite. The process involves chlorination, purification, and reduction of titanium chloride. The U.S. could probably also use the same process to produce titanium metal feedstock, or synthetic rutile could be used,

[84] Synthetic rutile is often referred to in the trade as " beneficiated'' ilmenite. A natural analogue of this material is "Ieucoxene. Slagging processes are also used elsewhere to produce high-titanium dioxide, low-iron products from ilmenite.

[85] Although titanium demand is equated to elemental titanium content, the major proportion of domestic demand will be for titanium dioxide.

[86] These include intermediate products such as synthetic rutile and/or high-titanium slags. Such slags have been made from American ores. See G Elger, J. Wright, J. Tress, et al., *Producing Chlorination-Grade Feedstock from Domestic Ilmenite—Laboratory and Pilot Plant Studies, RI-9002* (Washington, DC: U.S. Bureau of Mines, 1985), p. 24.

Table 3.13.—Forecast for U.S. Titanium Demand in 2000

		2000		
End use	1983	Low	Probable	High
	(thousand tons contained titanium)			
Nonmetal:				
Paints	246	270	320	400
Paper products	137	160	200	280
Plastics and synthetics	66	80	100	140
Other	66	57	85	116
Total	515	570	700	940
Metal:				
Aerospace	4	15	23	29
Industrial equipment	2	7	13	20
Steel and alloys	2	5	9	13
Total	8	27	45	62
Grand total	523	600	750	1,000

SOURCE: L. Lynd, "Titanium," *Mineral Facts and Problems— 1985 Edition* (Washington, DC: U.S. Bureau of Mines, 1988), p. 875.

ports. U.S. ilmenite reserves that *could* be used for metal production are estimated to contain about 10 times the probable forecast of metal cumulative demand of 490,000 tons by 2000.

Titanium Metal.—Titanium is one of only three metals expected to increase significantly in consumption and intensity of use; its demand is closely related to requirements for the construction of military and civilian aircraft. The outlook for titanium mill products through 1990 will depend primarily on military aircraft procurement and on the rate at which commercial air carriers replace aging fleets. The intensity of use (ratio of use to shipments) in the aerospace industry remained unchanged during the period 1972 to 1982. It is expected that significant replacement of titanium by carbon-epoxy composite materials-titanium's major competitor for lightweight, high-strength aircraft construction—will not occur before at least 1994. Titanium can be effectively used in conjunction with composite materials because their coefficients of thermal expansion match closely. Selection of titanium alloys over other materials for aerospace applications generally is based on economics and their special properties.

Because of its corrosion resistance and high-strength, titanium is likely to be increasingly used in industrial processes involving corrosive environments, although price has been somewhat of a deterrent to expanded commercial use. Non-aircraft industrial demand is currently showing strong growth in intensity of use of titanium. Automotive uses may also increase in the future. Currently, however, the use of titanium metal represents a relatively small amount of materials, and titanium dioxide for use in pigments and chemicals remains the major use in the United States.

Titanium Pigments.—Demand for paint pigments is projected to increase from 246,000 tons of titanium in 1983 to a probable level of 320,000 tons of titanium by 2000, but may range as low as 270,000 tons or as high as 400,000 tons. By 2000, metal and wood products precoated with durable plastic or ceramic finishes could be used in the construction industry, which would reduce or eliminate the need for repainting, thus adversely affecting demand growth of conventional coatings.

Paper products are projected to consume about 200,000 tons of titanium by 2000, up from 137,000 tons in 1983. The United States is the world's largest producer of paper, accounting for 35 percent of total world supply. The industry seems assured of continued growth, which should also be reflected in increased demand for titanium pigment.[87]

Some substitution by alternative whiteners and coloring agents may be developed in the future which could slightly offset growth of titanium pigment usage, but it is projected that total pigment consumption will probably reach 640,000 tons of titanium by 2000.

Because production of titanium dioxide pigment by the chloride process results in fewer environmental problems than does the sulfate process, future trends are likely to be toward the development of concentrates that are suited as chlorination feed materials and for making metals. Future commercial applications for utilizing domestic ilmenite to produce high-titanium dioxide concentrates may have the potential to make the United States self-sufficient in supplying its titanium requirements, should they prove economically competitive. Technically, such concentrates can be produced from rutile, high-titanium dioxide ilmenite sands, leucoxene, synthetic rutile, and low-magnesium, low-calcium titaniferous slags. Perovskite found in Colorado also might be convertible to synthetic rutile or titanium dioxide pigment.

Phosphate Rock (Phosphorite)

Properties and Uses

Over 90 percent of the phosphate rock (a sedimentary rock composed chiefly of phosphate minerals) mined in the United States is used for agricultural fertilizers. Most of the balance of phosphate consumed domestically is used to produce sodium tripolyphosphate —a major constituent of household laundry detergents—and other sodium phosphates that are used in cleaners, water treatment, and foods. Phosphoric acid is also used in the manu-

[87]US. Department of Commerce, 1986 *U.S. Industrial Outlook* (Washington, DC: U.S. Government Printing Office, 1986), p. 5-5.

facture of calcium phosphates for animal feeds, dentifrices, food additives, and baking powder. Technical grades of phosphoric acid are used for cleaning metals and lubricants. Food-grade phosphoric acid is used as a preservative in processed foods.

National Importance

There is no substitute for phosphorus in agricultural uses; however, its use in detergents has been reduced by the substitution of other compounds to reduce environmental damage in lakes and streams partially caused by phosphorus enrichment (eutrophication).

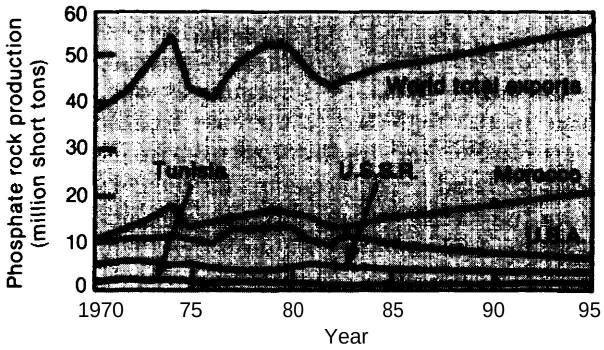
The United States leads the world in phosphate rock production (table 3-14), but it is likely to be challenged by Morocco as the world's largest producer in future years. Domestic production supplies nearly all of the phosphorus used in the United States, except for a small amount of low-fluorine phosphate rock imported from Mexico and the Netherlands Antilles and high-quality phosphate rock for liquid fertilizers from Togo. The United States is currently a major exporter of phosphate rock and phosphate chemicals but is facing increased price competition from foreign sources (figure 3-7). Producers in the Middle East and North Africa may continue to encroach on U.S. export markets as new phosphorus fertilizer plants begin operation and U.S. production continues to shut down.

Table 3-14.—World and U.S. Phosphate Rock Production

Year	World Production	Us. Production	US. production
	(million	tons)	(percent)
1977	130	52	41
1978	138	55	40
1979	147	57	39
1980	173	60	34
1981	161	60	37
1982	136	41	30
1983	149	47	32
1984	166	54	32
1985	168	56	33
1986	154	44	29

SOURCE: Adapted from W. Stowasser and R. Fantel, "The Outlook for the United States Phosphate Rock Industry and its Place In the World," Society of Mining Engineers of AIME, Society of Mining Engineers, Inc., Reprint 65-116, 1965.

Figure 3.7.—Major World Exporters of Phosphate Rock Since 1975, With Projections to 1995



The United States is currently a major exporter of phosphate rock and phosphate chemicals but is facing increased price competition from foreign sources, principally Morocco. Domestic mines are shutting down, and some analysts believe that the U.S. industry is in danger of collapsing in the future.

SOURCE: W. Laver, "Phosphate Rock: Regional Supply and Changing Pattern of World Trade," Transactions *of the Institution of Mining and Metallurgy, Sec. A–Mining Industry,* July 1966, Transactions Vol. 95, p. Al 19.

Domestic Resources and Reserves

Phosphorus-rich deposits occur throughout the world, but only a small proportion are of commercial grade. Igneous phosphate rock (apatites) are also commercially important in some parts of the world. Commercial deposits in the United States are all marine phosphorites that were formed under warm, tropical conditions in shallow plateau areas where upwelling water could collect. U.S. phosphate rock reserves are estimated to be 1.3 billion tons at costs of less than $32 per ton.[88] The *reserve base is* about 5.8 billion tons (at costs ranging from less than $18 per ton to $91 per ton), with total *resources* estimated at 6.9 billion tons, Over 70 percent of the U.S. *reserve base is* located in Florida and North Carolina. There are also large phosphate deposits in some Western States.

Although the United States has potentially vast *inferred* and hypothetical resources (7 billion tons and 24 billion tons of phosphate rock respectively), economic production thresholds for these resources have not been calculated. Other deposits probably

[88] W. Stowasser and R. Fantel, "The Outlook for the United States Phosphate Rock Industry and its Place in the World, paper presented at the SME-AIME Annual Meeting, New York, NY, Feb. 24-28, 1985, Society of Mining Engineers Reprint No. 85-116, p. 5.

will likely be discovered. Deep phosphate rock deposits may also hold promise if economically acceptable means for recovering them without excessive surface disturbance can be developed. Hydraulic borehole technology may be adapted for this purpose, but very little is known about its economic feasibility and environmental acceptability.[89]

The United States is a distant second in world *demonstrated* phosphate resources (19 percent) behind Morocco, whose enormous resources account for over 56 percent of the total *demonstrated* resources of the market economy countries, the U.S.S.R, and the Federal Republic of China[90] (table 3-1 5). Morocco alone may have sufficient resources to supply world demand far into the future.[91]

Domestic Production

The United States produced 44 million tons of phosphate rock in 1986, which accounted for about one-third of total world production. U.S. production of rock phosphate peaked in 1980-81 at approximately 60 million tons each year,[92] Twenty-three domestic companies were mining phosphate rock in 1986, with an aggregate capacity of about 66 million tons. Of the domestic phosphate rock that was mined in 1984, 84 percent came from Florida and North Carolina.

The domestic phosphate industry is vertically integrated and highly concentrated.[93] Most of the phosphate rock produced in the United States is used to manufacture wet-process phosphoric acid, which is produced by digestion with sulfuric acid. Elemental phosphorus is produced by reducing phosphate rock in an electric furnace. About half the elemental phosphorus produced is converted to sodium tripolyphosphate for use in detergents.

Table 3-15.—World Phosphate Rock Reserves and Reserve Base

	Reserves[a]	Reserve base[b]
	(million tons)	
North America:		
United States	1,543	5,951
Canada		44
Mexico		12
Total	1,543	6,127
South America:		
Brazil	44	386
Colombia		110
Peru		154
Total	44	650
Europe:		
U. S.S.R	1,433	1,433
Other		154
Total	1,433	1,587
Africa:		
Algeria		276
Egypt		871
Morocco	7,604	22,040
Western Sahara	937	937
South Africa	2,865	2,865
Other	264	231
Total	11,670	27,220
Asia:		
China	231	231
Jordan	132	562
Syria		198
Other	55	485
Total	418	1,449
Oceania:		
Australia		551
Nauru	11	11
Total	11	561
World total	15,119	37,594

[a]Cost less than $32 per ton. Cost includes capital, operating expenses, etc. and a 15 percent rate of return on investment. Costs and resources as of January 1983, f.o.b. mine.
[b]Cost less than $91 per ton.

SOURCE: Adapted from W. Stowasser, "Phosphate Rock," *Mineral Facts and Problems—1985 Edition* (Washington, DC: U.S. Bureau of Mines, 1986), p. 582.

Future Demand and Technological Trends

Demand for phosphate rock is closely linked to agricultural production. Domestic primary demand for phosphate rock (including exports) grew from 31.2 million tons in 1973 to 45 million tons in 1980. The global recession that followed, coupled with agricultural drought conditions and government agricultural policies aimed at reducing excessive domestic grain inventories, reduced phosphate rock consumption to 31.7 million tons in 1982. Domestic consumption rebounded in 1984 to 46 million tons

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[89] J. Hrabik and D. Godesky, *Economic Evaluation of Borehole and Conventional Mining Systems in Phosphate Deposits,* IC 8929 (Washington, DC: U.S. Bureau of Mines, 1983), p. 34.

[90] R. Fantel, G. Peterson, and W. Stowasser, "The Worldwide Availability of Phosphate Rock, *Natural Resources Forum* vol. 9, No. 1 (New York, NY: United Nations, 1985), pp. 5-23.

[91] R, Fantel, T. Anstett, G, Peterson, et al. , *Phosphate Rock Availability— World,* IC 8989 (Washington, DC: U.S. Bureau of Mines, 1984), p. 12.

[92] W. Stowasser, "Phosphate Rock, " *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 116.

[93] R. Fantel, D. Sullivan, and G, Peterson, *Phosphate Rock Availability-Domestic,* IC 8937 (Washington, DC: U.S. Bureau of Mines, 1983), p. 5.

as the world economy improved and U.S. grain production increased.[94] But depressed agricultural prices and increased operating costs have tended to stabilize demand growth as domestic farmers continue to struggle with the cost-price squeeze.

Probable domestic demand for phosphate rock is projected to be 52 million tons by 2000, with the low forecast at 50 million tons and the high at 55 million tons (table 3-1 6).[95] However, these forecasts are very uncertain due to global changes taking place in agricultural production. End uses in 2000 are expected to remain in about the same proportion as current uses.

From the mid-1970s, when exports represented about 40 percent of domestic production, the proportion of exported phosphate rock, fertilizers, and chemicals increased slowly through 1982 but decreased to its 10-year low by 1985. In 1983, fertilizer and chemicals slightly exceeded phosphate rock as export commodities (in terms of contained phosphorus pentoxide).[96]

Competition for international market share is expected to increase. Economics favors the conversion of phosphate rock to higher valued chemicals and fertilizers for export. There is currently a trend in phosphate rock producing countries to expand facilities for processing raw material into intermediate or finished products, particularly among Middle Eastern and North African nations.

The U.S. share of world markets is expected to continue to decline in the future. Probable annual growth rate for phosphate fertilizer exports through 2000 is forecast to be 2 percent, with a low of 1.5 and a high of 3 percent.[97] Exports of phosphate rock are projected to decline at an annual rate of about 1 percent through 2000. In summary, the annual growth rate is expected to approach 0.8 percent from 1983 through 2000.

Future export levels of phosphate rock and phosphate fertilizer will be largely determined by the availability of resources from Florida and North Carolina, competition from foreign producers, and an increase in international trade of phosphoric acid rather than phosphate rock. U.S. phosphate rock supply is likely to be sufficient to meet demand through 1995, but demand could exceed domestic supply by 2000 if U.S. producers reduce domestic capacity as a result of foreign competition.

In addition to the domestic industry's problems with foreign competition and diminishing ore quality and quantity, problems associated with the environment affect phosphate rock mining and beneficiation. Environmental concerns include disposing of waste clay (slimes) produced from the beneficiation of phosphate ores, disposing of phosphogypsum from acid plants, developing acceptable reclamation procedures for disturbed wetlands, and operating with reduced water consumption.

Industry analysts think the phosphate industry's problems will grow with time. It is likely that the price will not increase enough to justify mining higher-cost deposits, and that the public will continue to oppose phosphate mining and manufacturing phosphatic chemicals. In that event, the remaining low-cost, high-quality deposits will continue to satisfy demand until they are exhausted or until the markets for phosphate rock or fertilizer become unprofitable. If domestic phosphate rock

[94] W. Stowasser, "Phosphate Rock," *Mineral Facts and Problems—1985 Edition,* Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 585.

[95] Stowasser, "Phosphate Rock," *Mineral Facts and Problems—1985 Edition,* p. 591.

[96] Stowasser and Fantel, "The Outlook for the United States Phosphate Rock Industry," pp. 85-116.

[97] Stowasser, "Phosphate Rock," *Mineral Facts and Problems—1985 Edition,* p. 590.

Table 3-16.– Forecasts of U.S. and World Phosphate Rock Demand in 2000

		2000			Annual growth
	Actual	Low	Probable	High	1983-2000
			(million tons)		(percent)
United States.	44[a]	50	50	60	1.8
Rest of world.	110	220	220	230	4.2
World total ., ...		270	270	290	3.6

[a] U.S. data for 1986, from W. Stowasser, "Phosphate Rock," *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1987), p. 116.

SOURCE: Adapted from W. Stowasser, "Phosphate Rock," *Mineral Facts and Problems—1985 Edition* (Washington, DC: U.S. Bureau of Mines, 1966), p 592.

production costs continue to rise and investment in new mines is not justified, the shortfall between domestic supply and domestic demand will have to come from imports of lower-cost phosphate rock. 98

Sand and Gravel

Properties and Uses

Sand and gravel is a nationally used commodity which is an important element in many U.S. industries and is used in enormous quantities. Sand and gravel can be used for industrial purposes such as in foundary operations, in glass manufacturing, as abrasives, and in infiltration beds of water treatment facilities.

Most sand and gravel, however, is used in construction. Much of the aggregate is used in concrete for residential housing, commercial buildings, bridges and dams, and in concrete or bituminous mixes for highway construction. A large percentage of sand and gravel is also used without binders as road bases, as road coverings, and in railroad ballast.

National Importance

Generally, there is an abundance of sand and gravel in the United States. Even though these materials are widely distributed, they are not universally available for consumptive use. Some areas are devoid of sand and gravel or may be covered with sufficient material to make surface mining impractical. In some areas, many sand and gravel sources do not meet toughness, strength, durability, or other physical property requirements for certain uses. Similarly, many sources may contain mineral constituents that react adversely when used as concrete aggregate. Furthermore, even though an area may be endowed with an abundance of sand and gravel suitable for the intended purpose, existing land uses, zoning, or regulations may preclude commercial exploitation of the aggregate.

Domestic Resources and Reserves

Sand and gravel resources are so extensive that resource estimates of total reserves are probably not obtainable. Mineable resources occur both onshore and in coastal waters. Large offshore deposits have been located in the Atlantic continental shelf and offshore Alaska.[99] The availability of construction sand and gravel is controlled largely by land use and/or environmental constraints. Local shortages of sand and gravel are becoming common, especially near large metropolitan areas, and therefore onshore resources may not meet future demand. Crushed stone is being used often as a substitute, despite its higher price.

Domestic Production

In 1986, about 837 million tons of construction sand and gravel were produced in the United States, industrial sand and gravel production approached 28.5 million tons[100] and about 2.5 million tons of construction and industrial sand and gravel were exported.[101] The domestic industry is made up of many producers ranging widely in size. Most produce materials for the local market. The western region led production and consumption of sand and gravel, followed by the east north-central, mountain, and southern regions.

Future Demand and Technological Trends

Demand forecasts for U.S. construction sand and gravel for 2000 range between a low of 650 million tons and a high of 1.2 billion tons, with the demand probably about 1 billion tons. Average annual growth in demand is expected to be about 2.9 percent annually through 2000.[102] Apparent consumption in 1986 was about 836 million tons.

Offshore resources may find future markets in certain urban areas where demand might outpace onshore supply because of scarcity or limited production due to land use or environmental con-

'* Ibid., p. 593.

[99] J. Williams, "Sand and Gravel Deposits Within the United States Exclusive Economic Zone: Resource Assessment and Uses, OTC 5197, Proceedings of the 18th Annual Offshore Technology Conference, Houston, Texas, May 5-8, 1986, p. 377.

[100] V. Tepordei, "Sand and Gravel, " *Mineral Commodity Summaries— 1987* (Washington, DC: U.S. Bureau of M incs, 1985), pp. 136-137.

101 V. Tepordei and L. Davis, " Sand and Gravel, *Minerals Yearbook—1984* (Washington, DC: U.S. Bureau of Mines, 1985), p. 775.

[102] V. Tepordei, "Sand and Grave l," *Miner-al Facts and Problems-198.5 Edition*, Bulletin 675 (Washington, DC: L'. S. Bureau of Mines, 1986), p. 695.

straints. Such areas include New York, Boston, Los Angeles, San Francisco, San Juan, and Honolulu.

Garnet

Garnet is an iron-aluminum silicate used for high-quality abrasives and as filter media. Its size and shape in its natural form is important in determining its industrial use. The United States is the dominant world producer and user of garnet, accounting for about 75 percent of the world's output and 70 percent of its consumption. In 1986, the U.S. produced about 35,000 tons of garnet and consumed about 28,000 tons.[103] Domestic demand is expected to rise only modestly to about 38,000 tons per year by 2000.[104] World resources are very large and distributed widely among nations.

Monazite

Monazite is a rare-earth and thorium mineral found in association with heavy mineral sands. It is recovered mainly as a byproduct of processing titanium and zirconium minerals, principally in Australia and India. Domestic production of monazite is small relative, to demand. As a result, the United States imports monazite concentrates and intermediates, primarily for their rare-earth content.

The rare earths are used domestically in a wide variety of end uses including: petroleum fluid cracking catalysts, metallurgical applications in high-strength low-alloy steels, phosphors used in color television and color computer displays, high-strength permanent magnets, laser crystals for high-energy applications such as fusion research and special underwater-to-surface communications, electronic components, high-tech ceramics, fiber-optics, and superconductors. It is estimated that about 15,400 tons of equivalent rare-earth oxides were consumed domestically in 1986.[105]

Substitutes for the rare earths are available for many applications, but are usually much less effective. The United States imported 3,262 tons of monazite concentrates in 1986, representing about 12 percent of the total estimated domestic consumption of equivalent rare-earth oxides.

World resources of the rare-earth elements are large, and critical shortages of most of the elements are not likely to occur. Because domestic demand for thorium is small, only a small amount of the thorium available in monazite is recovered. It is used in aerospace alloys, lamp mantles, welding electrodes, high-temperature refractory applications, and nuclear fuel.

Zircon

Zircon is recovered as a byproduct from the extraction of titanium minerals from titaneous sands. Zirconium metal is used as fuel cladding and structural material in nuclear reactors and for chemical processing equipment because of its resistance to corrosion. Ferrozirconium; zircon and zirconium oxide, is used in abrasives, refractories, and ceramics. Zircon is produced in the United States with about 40 to 50 percent of consumption imported from Australia, South Africa, and France.

Domestic consumption of contained zirconium was about 50,000 tons in 1983.[106] The United States is estimated to have about 14 million tons of zircon, primarily associated with titaneous sand deposits. It is expected that domestic contained zirconium demand may reach about 116,000 tons by 2000, an annual growth of nearly 6 percent. Substitutes for zirconium are available, but at a sacrifice in effectiveness. Domestic reserves are gauged to be adequate for some time in the future although the United States imports much of that consumed from cheaper sources.

[103] G. Austin, "Garnet, Industrial," *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1986), p. 56.

[104] J. Smoak, "Garnet," *Mineral Facts and Problems—1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 297.

[105] J. Hedrick, "Rare-Earth Metals, *Mineral Commodity Summaries—1987* (Washington, DC: U.S. Bureau of Mines, 1986), p. 126.

[106] W. Adams, "Zirconium and Hafnium," *Mineral Facts and Problems—1985 Edition*, Bulletin 675 (Washington, DC: U.S. Bureau of Mines, 1986), p. 941.