CHAPTER 2

An Introduction to Materials Import Vulnerability

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The United States, despite its wealth of resources, is a substantial importer of materials for industry. To some observers, the Nation's reliance on these imports constitutes a dangerous dependency, threatening a "materials crisis" more devastating than the recent energy crisis, Others see the U.S. position as quite manageable, though not without dangers and difficulties.

U.S. reliance on foreign sources for a number of important nonfuel minerals is not new nor, in itself, a cause for alarm. What really matters is whether import dependence makes the United States vulnerable to a cutoff of supply and whether that cutoff could have very damaging effects. In the past few years, these possibilities have raised a wave of concern. Undoubtedly, one factor in the crescendo of concern was the success of the OPEC cartel in controlling oil production during the 1970s, raising the world oil price to unheard of heights, and—at least temporarily—reducing oil exports to the United States for political reasons.

Today, many people believe that the United States is vulnerable to disruptions at least as serious as the oil crisis because of the nature, level, and sources of U.S. materials imports. Some fear that worse times are in store: they are persuaded that the Soviet Union is conducting a "resource war" against the United States and its allies, with the threat of shutting off supplies of minerals from central and southern Africa that are vital to U.S. national defense and basic industries.

Others familiar with minerals issues believe, on the contrary, that the interdependence policy for minerals supply has served the Nation well over the years and that the costs of self-sufficiency would be extremely high. Those who take this view concede that the supply of some imported materials could be interrupted, but count on flexible responses of the market economy—e.g., alternate suppliers, substitutions in use, and shifts from less to more essential uses—to compensate tolerably well for supply cutoffs or dislocating price increases.

There is some common ground in the opposing views. Both sides favor stockpiling imported materials that are vital to national defense and essential supporting industries as an insurance against supply interruptions. Both agree that, for at least a few imported minerals, continuity of supply is a serious question deserving a carefully considered government response.

The short list of these generally agreed upon "strategic" materials includes chromium, cobalt, manganese, and the platinum group metals (which comprise platinum, palladium, rhodium, iridium, osmium, and ruthenium). All of the four have essential uses, including military uses, for which there are no readily available substitutes—or in some cases, no substitutes even in sight, For all of them, production from domestic mines is negligible at best. Instead, these minerals are imported, mainly from a very few countries in the politically unstable region of central and southern Africa, an area that, along with the Soviet Union, holds most of the world's known resources of these important minerals.

Thus, for a few specific materials at least, most observers agree that the United States is in a vulnerable position. To shed light on the dimensions of this vulnerability, this chapter looks at the significance of imported materials in general to the United States and its allies and discusses those factors that led to the selection of chromium, cobalt, manganese, and the platinum group metals for in-depth assessment in this report.

The Importance of Nonfuel Minerals Imports

In terms of dollar value in world trade, U.S. reliance on imports of nonfuel minerals is moderate. The United States is still a leading world minerals producer as well as the world's largest minerals consumer. In 1981, as the dollar rose against other currencies, U.S. imports of nonfuel minerals (raw and processed) amounted to $17.6 billion, exports were $28.8 billion, and thus net imports were $11.2 billion, a moderate sum when compared to U.S. net energy imports, which were $75 billion.[1]

The overall figures, however, aggregate a great many unlike materials, from scrap steel to gem and industrial diamonds to fertilizers. It is particular kinds of minerals—materials needed for basic industry and vital ingredients for military hardware—that are the center of concern, Figure 2-1 shows the extent of U.S. reliance on imports of 34 important nonfuel minerals and metals as of 1980. Nearly all of the manganese, bauxite, cobalt, tantalum, and chromium used in the United States is mined in foreign countries. Imports of other important minerals—the platinum metals group, asbestos, tin, nickel, zinc, cadmium, and tungsten—range from 85 to 50 percent of U.S. consumption.[2] Even iron ore, once supplied wholly by domestic mines, now comes in substantial amounts from foreign mines. As table 2-1 shows, import dependence was high 30 years ago for much the same list of minerals that is the focus of concern today: In 1952, foreign mines provided 70 to 80 percent of the Nation's bauxite, manganese, and tungsten, and 90 to 100 percent of its platinum, cobalt, nickel, and chromium. a

Table 2-1.–U.S. Dependence, Selected Minerals, 1950-82 (net imports as percent of apparent consumption)

	1950	1970	1979	1980	1981	1982
Bauxite [a]	71	80	93	94	94	96
Chromium	100	100	90	91	90	85
Cobalt	92	96	94	93	92	92
Copper	35	8	13	16	6	1
Iron ore	5	30	25	25	22	34
Lead	59	40	5	O [b]	1	3
Manganese	77	94	98	98	99	99
Nickel	99	91	75	76	75	76
Platinum	91	98	89	88	84	80
Tungsten	80	40	58	53	50	46
Zinc	37	60	63	60	64	58

[a] 1979-82, Includes alumina
[b] Net export
NOTE: Net imports = imports exports + adjustments for government and industry stock changes
SOURCE 1950, 1970: *Report of National Commission on Material Policy*, June 1973, pp 2-23 1979-82: U S Department of the Interim Bureau of Mines, *Mineral Commodity Summaries 1984*

It is worth noting the modest dollar value of many of the materials for which the United States is most import dependent. For example, the entire year's bill for 1981 imports of cobalt, chromium, and manganese was between $230 million and $300 million apiece—equivalent to 1½ days (at most) of oil imports. The fact that the quantities involved are relatively small and total costs low does not imply that imports of these materials are insignificant; some are vital. It does imply that even a sharp rise in price for the materials might have no great effect on the economy as a whole (a point to keep in mind later, in the discussion of possible cartel control). It also indicates that stockpiling these materials, as a way of assuring a reliable supply, can be practical and relatively inexpensive.

Changes in Amount of Imports

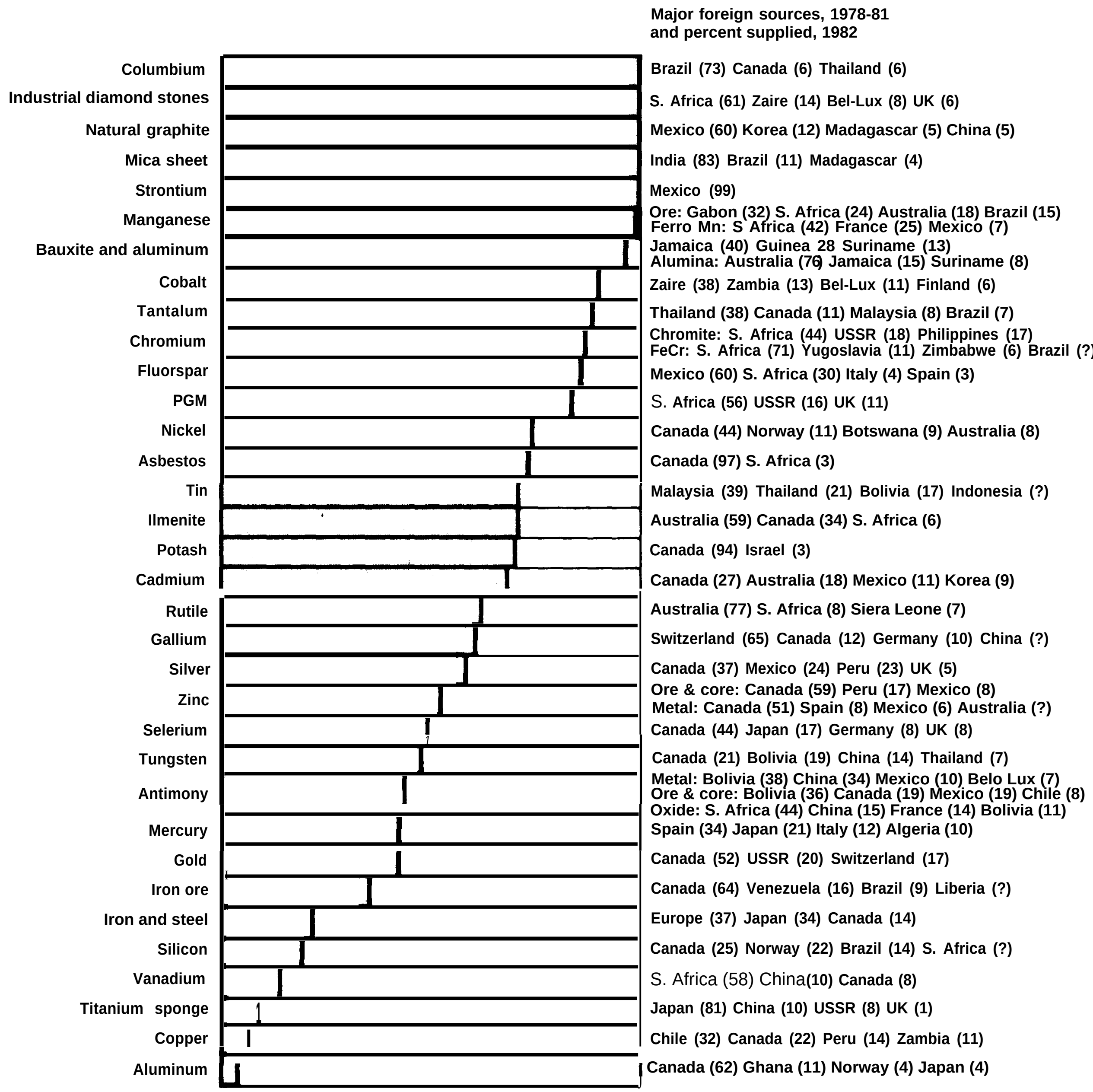
U.S. minerals imports increased from 1950 to the 1980s, but at a modest pace overall, and not uniformly for all minerals, (Import dependence as a percentage of U.S. consumption for platinum, nickel, and chromium declined, mostly because of recycling.) In general, the gradually rising flow of imported minerals into the United States reflects lower prices of foreign materials, often because the ores being

[1] Unless otherwise noted, data on production, consumption, and imports of nonfuel minerals comes from the Bureau of Mines, Department of the Interior. Energy data was provided by the Department of Energy.

[2] "'Consumption" here means apparent consumption, which is domestic primary production, plus recycled materials and net imports, adjusted to reflect releases from or additions to industry or government stocks.

[3] The President's Materials Policy Commission, Resources for Freedom (Washington, DC: U.S. Government Printing Office, 1952), vol. 1, pp. 6 and 157.

Figure 2-1.— Net Import Reliance As a Percent of Consumption, 1982



NOTES Net import reliance is figured as percent of apparent consumption, except for rutile, for which net import reliance is figured as percent of reported consumption
Net Imports = import exports + adjustments for government and industry stock changes
Apparent consumption = U S primary and secondary production + net imports

SOURCE: U S Department of the Interior, Bureau of Mines mined abroad are richer, although other factors such as lower labor costs or government subsidies may also be important. The U.S. minerals economy is managed, on the whole, by a great many private businesses looking for the best deal they can get.

Changes in Use of Imports

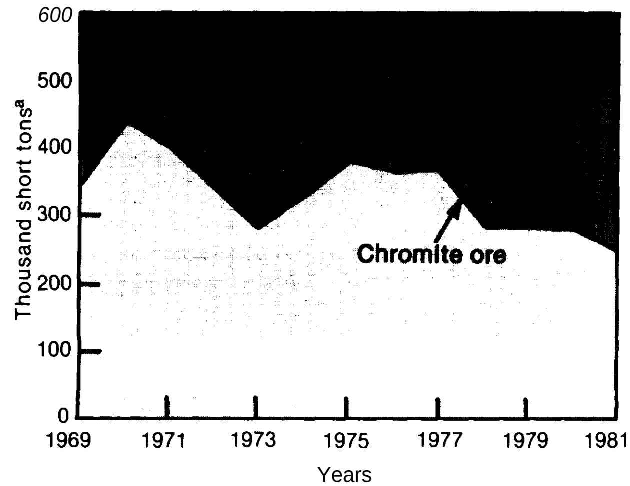
While nonfuel minerals imports of the United States have slowly risen, significant changes in the uses of imports have taken place. Growth has occurred in selective demand for specialty steels using chromium, for high-strength, high-temperature superalloy using cobalt and chromium, and for cobalt catalysts. Also, in the 10 years from 1970 to 1980, annual consumption of cobalt for superalloy (which are particularly important for aerospace applications, military and civilian) roughly tripled, rising from about 2 million to over 6 million pounds. Use of cobalt in catalysts quadrupled. Platinum group consumption jumped from 1.4 million troy ounces in 1970 to 2,2 million in 1980, of which more than 700,000 troy ounces went for catalytic converters to control pollution from automobile exhausts. Use of platinum as a catalyst in petroleum refining has also grown, rising from less than 40,000 troy ounces in 1960 to 171,000 in 1980. In the severe worldwide 1981-83 recession, U.S. consumption of all these metals declined, but recovery is now in evidence.

Changes in Form of Imports

Nonfuel mineral imports are no longer mostly in the form of raw ores. Instead, minerals-producing countries like South Africa are now taking advantage of their lower wages, proximity to raw materials, cheaper energy, and modern new processing facilities, to export processed materials such as ferroalloys[4] rather than chromite and manganese ores, Figures 2-2 and 2-3 show how rapid this change to importation of ferroalloys has been. The United States now imports 35 to 50 percent of its chromium in ferroalloy form, compared with 8 to 12 percent a decade ago. Ferromanganese and refined manganese metal now account for 60 to 75 percent of manganese imports; at the beginning of the 1970s they amounted to only 20 percent of the total. As part of the same process, the domestic ferroalloy industry has shrunk remarkably, from production levels of 2.6 million to 2.8 million tons in the peak years of 1965 to 1970, to 1.5 million tons in 1981 and an estimated 800,000 tons in the recession year of 1982.

[4]Alloys of iron and other elements, used as raw material in the production of steel; e.g., ferromanganese and ferrochromium.

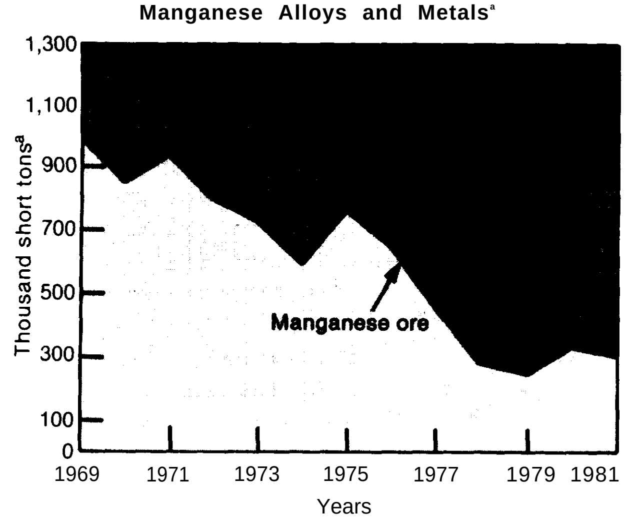
Figure 2-2.—U.S. Imports of Chromite Ore and Chromium Alloys[a]



[a]Tons of contained chromium.

SOURCE: U.S. Bureau of Mines data.

Figure 2-3.—U.S. Imports of Manganese Ore and Manganese Alloys and Metals[a]



[a]Tons of contained manganese.

SOURCE: U S Department of the Interior, Bureau of Mines data

This has led to concern that if international trade were restricted or disrupted, it might be difficult to replace lost supplies of ferroalloys with imports of chromium or manganese ores from other sources, because of the lack of U.S. facilities to process the ore into ferroalloys. Similarly, if a major high-grade deposit of chromium or manganese were discovered, we might not have the production capacity to produce ferroalloys until facilities were expanded, which could take several years.

Definition and Selection of Strategic Materials

One of the greatest difficulties in assessing import vulnerability lies in defining what materials are strategic. There is no fixed, universally accepted definition of the term "strategic material, " Much depends on the purpose of the definition. For purposes of a national stockpilers present U.S. law defines "strategic and critical materials" in the context of a hypothetical, complete cutoff of foreign supplies during a 3-year national emergency, The Strategic and Critical Materials Stock Piling Revision Act of 1979 (Public Law 96-41) says:

> The term "strategic and critical materials" means materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and (B) are not found or produced in the United States in sufficient quantities to meet such need. The term "national emergency" means a general declaration of emergency with respect to the national defense made by the President or by the Congress.

In the context of broader materials policy, former Secretary of the Interior James B. Watt gave the term "strategic" a more elastic meaning. In 1981 testimony before the House Subcommittee on Energy and Mineral Resources, he said:

> It is not my intention to limit the word "strategic" to its former definition of minerals wholly or substantially from foreign sources. We must acknowledge, as an element of minerals policy, that all minerals are strategically important in a complex industrial society, B

By this definition, however, every element of production—land, energy, labor, capital, technology—is also essential and therefore strategic, and the term becomes so broad as to lose any practical meaning. Moreover, a definition of strategic materials as all those that are "wholly or substantially from foreign sources" is not widely accepted, First, it leaves out the element of critical needs for particular materials. Then, it seems automatically to equate import dependence with vulnerability. Many materials analysts do not accept this equation as a guide to policy decisions.[7] Moreover, it runs counter to a major shared conclusion of the materials commissions that have reported to three American Presidents over the past 30 years; that is, that the Nation should seek materials wherever they may be found, at the least cost and consistent with national security and the welfare of friendly nations,

[5] Current stockpile planning is based on the military, industrial, and essential civilian requirements of the first 3 years of a major conflict, assuming that austerity measures are taken to sustain defense production.

[6] U. S. Congress, Senate Committee on Energy and Natural Resources, Subcommittee on Energy and Mineral Resources, Hearings on Strategic Minerals and Materials Policy, 97th Cong., 1st sess., Apr. 1, 1981, p. 4.

[7] See, for example, Congressional Research Service, A Congressional Handbook on U.S. Materials Import Dependency/Vulnerability, Report to the Subcommittee on Economic Stabilization, Committee on Banking, Finance, and Urban Affairs, House of Representatives, 97th Cong., 1st sess., September 1981, p. 7, p. 341 ff; Hans Landsberg and John E. Tilton, "Nonfuel Minerals, " in Current Issues in Natural Resource Policy, Paul R. Portney with Ruth B. Haas (eds.) [Baltimore: The Johns Hopkins University Press, 1982); Robert Legvold, "The Strategic Implications of the Soviet Union's Nonfuel Minerals Policy, " paper prepared for the School of Advanced International Studies, The Johns Hopkins University, May 1981.

In its 1981 Preliminary Assessment of strategic metals, the Materials Forum of the United Kingdom discussed the term "strategic" in this way:[8]

> The term "strategic minerals" has traditionally been used in the United Kingdom to refer to those minerals which are vital to the national defense and yet have to be procured entirely or in large part from foreign sources. However, in this country, "strategic" no longer has a mere defense connotation when attached to minerals; it has come to have a wider meaning, somewhat obscure, and A. A. Archer of the Institute of Geological Sciences in London has recently shown how this can be clarified.
>
> He believes it is useful to distinguish some minerals from others by disengaging two main strands. One is, that some minerals are more important, vital, essential or critical than others because they make a demonstrably greater contribution to the national well-being, so that interruption or cessation of supplies, from whatever source, would have graver consequences. This can be described as the degree of "criticality" of a mineral. The other strand is the "vulnerability y" of supplies to interruption; some minerals have sources which may be judged to be more vulnerable than others. Although the concept of vulnerability is mainly linked with imports, the possibility of the disruption of domestic supply cannot be entirely overlooked.

The concepts set forth above are used in this report as the basis for a definition and selection of strategic materials,

Not surprisingly, both the selection of criteria and the screening of materials against the criteria involve a good deal of qualitative judgment. OTA's assessment uses quantitative measures as much as possible. Also, it builds on the earlier efforts of others to define and list strategic materials. (See app. A.) In the end, however, any list of strategic materials must reflect the judgment of its authors.

[8]The Materials Forum, Strategic Metals and the United Kingdom: A Preliminary Assessment, published by the Institution of Mechanical Engineers, July 1981, p. 3.

Criticality

The criticality of materials has to do with how they are used. Three main factors are part of the concept:

- Essential use for national defense.
- Essential use for industry.
- Lack of suitable substitutes.

Essential use for national defense means that, without the material, the Nation's capacity to defend itself could be seriously compromised. Examples of material uses that are vital to national defense are cobalt in superalloy for jet engine turbine blades and discs, where resistance to heat under conditions of high stress is necessary; or chromium for jet engines, to withstand hot corrosion and oxidation; or the manganese used industrywide in steelmaking to eliminate faults in steel that arise from sulfur content.

Essential use for industry is another main factor. Use of the materials must fill such an important need that without it, industries that are basic to the Nation's economic well-being and to military production could be crippled.

Materials vital to national defense are likely to be essential for industry, as well, in the same or other applications, Industrial machinery is a prime example. The machine tools that shape, stamp, cut, and drill all metal goods, military and civilian, are made of manganese-bearing steel. The best binder for carbide cutting tools and drill bits is cobalt, Another example is in the aerospace industry, where jet airplanes for civilian use have much the same material requirements as do military planes.

Industrial uses for some critical materials cover a broad spectrum, ranging from virtually indispensable to nonimportant. Chromium is an example: stainless steel cannot be made without it. Of the hundreds of industrial uses for stainless steel, some—e.g., automobile bumpers or hub-caps—are easily replaceable; for others—e.g., corrosion-resistant pipes in oil refineries—nothing else now available serves as well.

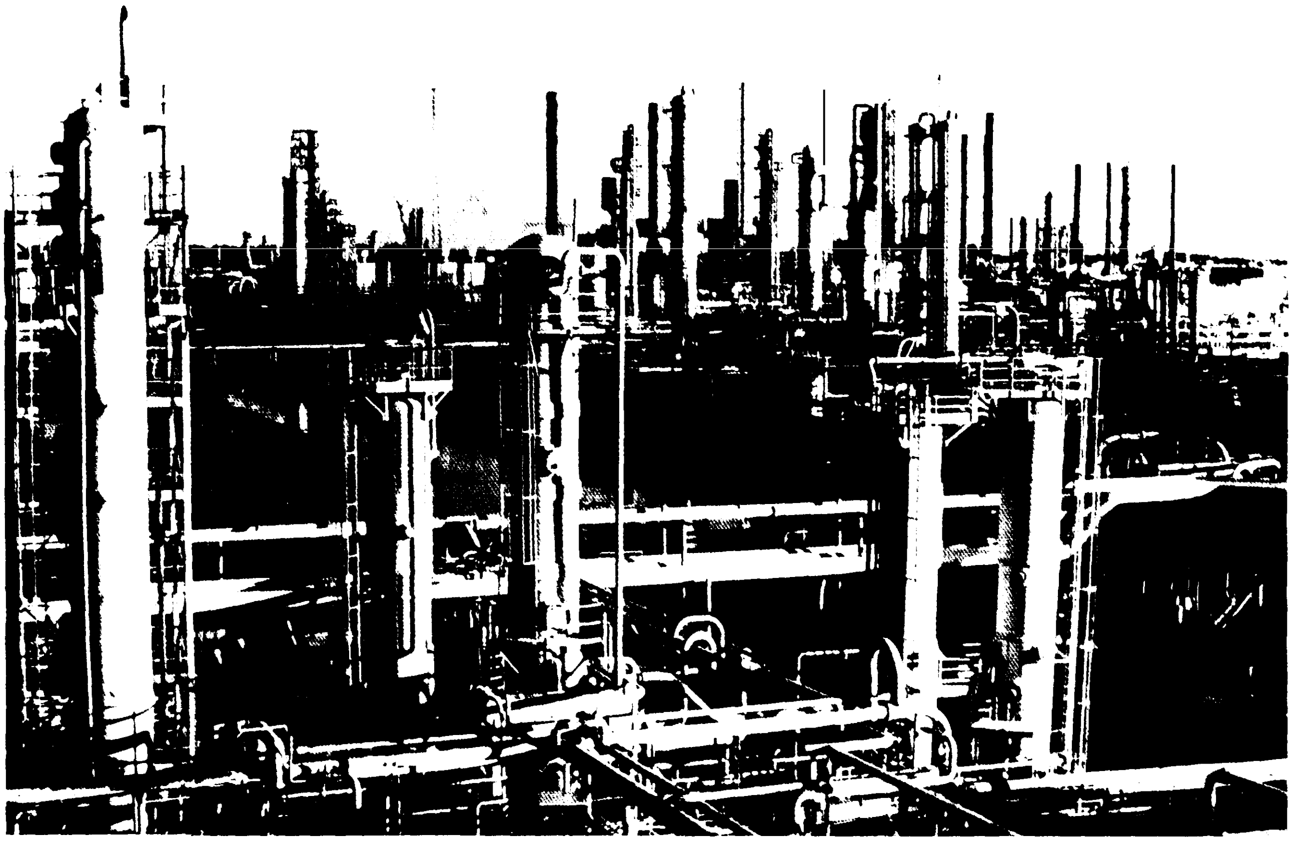


Photo credit American Petroleum Institute and Exxon Corp

Petroleum refiners are major consumers of strategic materials in steel, stainless steel, and processing catalysts

Closely related to the concept of essential use is the lack of suitable substitutes. This implies that substitutes, if available at all, either cost much more or involve important sacrifices of properties or performance. In a few cases (e.g., chromium for corrosion resistance) there may be no real alternative at present levels of technology in some critical industrial and defense applications.

One aspect of substitution is simply the replacement of one material for another—nickel for cobalt, for example, in some superalloys. Some of these substitutions replace one critical metal with another. Of obviously greater value is the replacement of a scarce material with an abundant one—advanced ceramics for instance, may be a long-term replacement for metal superalloys.

The economic dependence of the Nation on particular materials is sometimes mentioned as a factor in criticality. One of the conventional measures of economic importance—the dollar value of the material consumed or imported per year—is not a useful criterion for critical function. Several materials that have essential uses but no substitutes readily available are quite low in dollar value; for example, net imports of cobalt, chromium, and manganese each ran about $230 million to $300 million in 1981–a drop in the bucket in a $3 trillion-per-year economy. Yet even a partial loss of supplies of these materials could have serious effects on production, jobs, and the survival of business firms in the many industries where their uses are essential (e. g., steel, aerospace, and automotive industries).

Exactly how much the economy as a whole would suffer from a sudden drop in the supply of specific critical materials is hard to calculate. Cranking figures on supply loss through an economic input-output model may appear to be systematic and objective, But such models can produce highly unrealistic results if they make no allowance for compensatory moves by users of the material in question.[9] Studies of chromium and cobalt shortages are worth noting at this point.

The National Materials Advisory Board (NMAB) (of the National Academies of Science and Engineering) in its 1978 study of chromium conservation opportunities, concluded that about one-third of U.S. chromium use could be quite promptly replaced in an emergency. Without specifying any dollar figures, the study observed that replacing a chromium shortfall of this magnitude would "not have serious economic consequences on industrial dislocations."[10] The study also refrained from estimating the economic costs of a greater shortfall cutting into uses which could not be quickly replaced; obviously the effects of such a shortfall would be greater.

In its 1982 study of cobalt, the Congressional Budget Office reported cost estimates of a cobalt supply cutoff that took into account the buffering effects of private stocks, materials substitution, scrap recovery, and alternative suppliers.[11] The Department of the Interior provided a range of cost estimates, depending on various political assessments. The most extreme case (considered highly improbable) involved a 2-year shortfall (in 1985-86) from both Zaire and Zambia. In this extreme case, U.S. cobalt consumption was expected to drop 20 percent in 1985 and 35 percent in 1986—but with little loss in economic output, mainly because of substitution. Extra costs to the economy (in terms of higher prices) were estimated as $1 billion for 1985 and $1.8 billion for 1986 (in 1980 dollars). A Commerce Department study, which assumed a 75-percent reduction in output in Zaire and Zambia in 1985, came to similar conclusions: 23 percent lower cobalt consumption, forced substitution, little lost output, Extra cost to the economy of high cobalt prices was estimated at $2.5 billion—assuming a cobalt price of $112 per pound (more than twice as high as the top price during the cobalt price spike of 1978-79, and over 20 times the 1982 price). The inflationary pressure of this price increase was reckoned as no more than 0.1 percent in the economy as a whole,

Analysis of the effect of material shortfalls on the economy as a whole is at an early, unrefined stage.[12] In addition, because these economic effects are a reflection of the essential nature of the material's uses and the lack of substitutes, it seems needlessly complex to add "economic effects" as another criterion of criticality. Thus, for the purpose of this chapter, which is to select a list of strategic materials for study, no attempt was made to quantify the economic effects of losing a part or all of the supply of candidate materials. Rather, economic effects were simply kept in mind as a part of the meaning of criticality,

Vulnerability

Among the conditions that affect supply vulnerability, a most important factor is lack of diversity of supply. Reliance on a sole supplier, even a highly reliable one, can be risky. Of the few significant interruptions in U.S. materials supply in the past 30-odd years (described in ch. 4), the most disruptive was probably the loss of nickel from Canada during the 4-month nickel strike in 1969. Canada was at that time the source of 90 percent of new (nonrecycled) U.S. nickel supplies.

[9] Hans H. Landsberg, "Minerals in the Eighties: Issues and Policies: An Exploratory Survey," paper prepared for the Oak Ridge National Laboratory, Oak Ridge, TN, 1982, pp. 30-31.

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

[11] Congressional Budget Office, Cobalt: Policy Options for a Strategic *Mineral* (Washington, DC: U.S. Government Printing Office, 1982), pp. 21-24.

[12] A recent attempt to quantify economic effects Of materials supply disruptions, using a neoclassical econometric model of the primary metals industry is reported by Michael Hazilla and Raymond J. Kopp, "Assessing U.S. Vulnerability to Mineral Supply Disruptions, An Application to Strategic Nonfuel Minerals," paper prepared for Resources for the Future, Washington, DC, draft May 5, 1982.

U.S. imports of critical minerals are part of the nexus of world trade in these commodities. If one of its usual suppliers fails for some reason to produce, the United States can buy elsewhere as long as alternate producers exist (although probably with some shortage and delay, since mining companies often commit supplies to their customers considerably in advance and it takes time to expand capacity). Thus, the total number of producers in the world for particular minerals is important, and so are their relative shares of production. If one or two countries dominate (as South Africa and the Soviet Union do for PGM), the potential for disruption is greater than if there were a number of substantial producers.

In the same way, diversity in the location of mineral reserves is important for the future. Since reserve estimates change dramatically over time with new technology, new discoveries, and price changes, they are a rough indicator of where to expect minerals production.[13]

By the measure of reserve location, it appears that world production of certain important minerals could become more concentrated than it is now. For example, South Africa and the Soviet Union produced 64 percent of the world's manganese in 1982; they own 77 percent of the reserves. South Africa today produces 22 percent of the world's chromite ore, but holds 91 percent of the reserves (see ch. 5 for further discussion).

In general, reliance on one or a very few suppliers creates the potential at least for cartel action to limit supplies and raise prices, for politically inspired embargoes, or for a cutoff of supply due to local disturbances in the producer countries. Of these possibilities, discussed in some detail in chapter 4, the last appears most likely.

Instability in foreign sources of supply is certainly an element in vulnerability. The only way to evaluate instability in particular countries is by qualitative judgment, and opinions differ, For example, some consider South Africa a risky source because they see an inherent instability in minority rule by 4.5 million whites of 20 million blacks.[14] Some of those concerned about a "resource war" fear that the Soviets or Soviet-backed forces may seize power in South Africa, and the Soviet Navy interdict shipments of critical materials from South African ports.[15] Others see such an interdiction of trade as virtually an act of war, and do not consider it likely, short of a shooting war.[16] A quite different point of view is that South Africa has proved to be one of the world's most reliable suppliers, with a record of long-range planning and steady production, and a conservative commercial approach that rules out political embargoes,

There is greater consensus that production of minerals in the relatively new African nations could be disrupted by local wars, insurrection, or civil disorder, or by inexperienced management of complex minerals enterprises—regardless of the part the Soviet Union might play in aggravating these dangers (see ch. 4 for a discussion of these possibilities).

Other developing countries also may be subject to political instability, thus affecting minerals production. Indonesia (a significant supplier of tin) was governed less than *20* years ago by the strongly anti-Western Sukarno, and Thailand (an important source of tantalum and tin) is under some pressure from its revolutionary neighbors. In Latin America, too, political upheavals have, on occasion, interfered with

[13] "Reserves" comprise only part of a country's mineral wealth. They are deposits which are known and are technically and economically feasible to mine at a profit at the time the data is analyzed. "Resources" include reserves and all other deposits that are known but are not economic to mine, as well as deposits that are merely inferred to exist from geologic evidence. "Reserve base" includes resources that are currently economic ("reserves"), those that are considered marginally' economic plus a portion of the subeconomic resources. Throughout this study, reserve data has been used for comparison purposes, unless otherwise noted.

14 Robert E. Osgood, "The Security Implication of Dependence on Foreign Non fuel Minerals, paper prepared for the School of Adva need International Studies, The Johns Hopkins University.

"Rear Adm. William C. Mott, "Introduction: What 1s the Resource War?' *Strategic Minerals:* A Resource Crisis [Washington. DC: The Council on Economics and National Security, **1981]**, **pp.** 20-29.

16 Osgood, **op.** c **it.;** I, egvol d, op. c it.

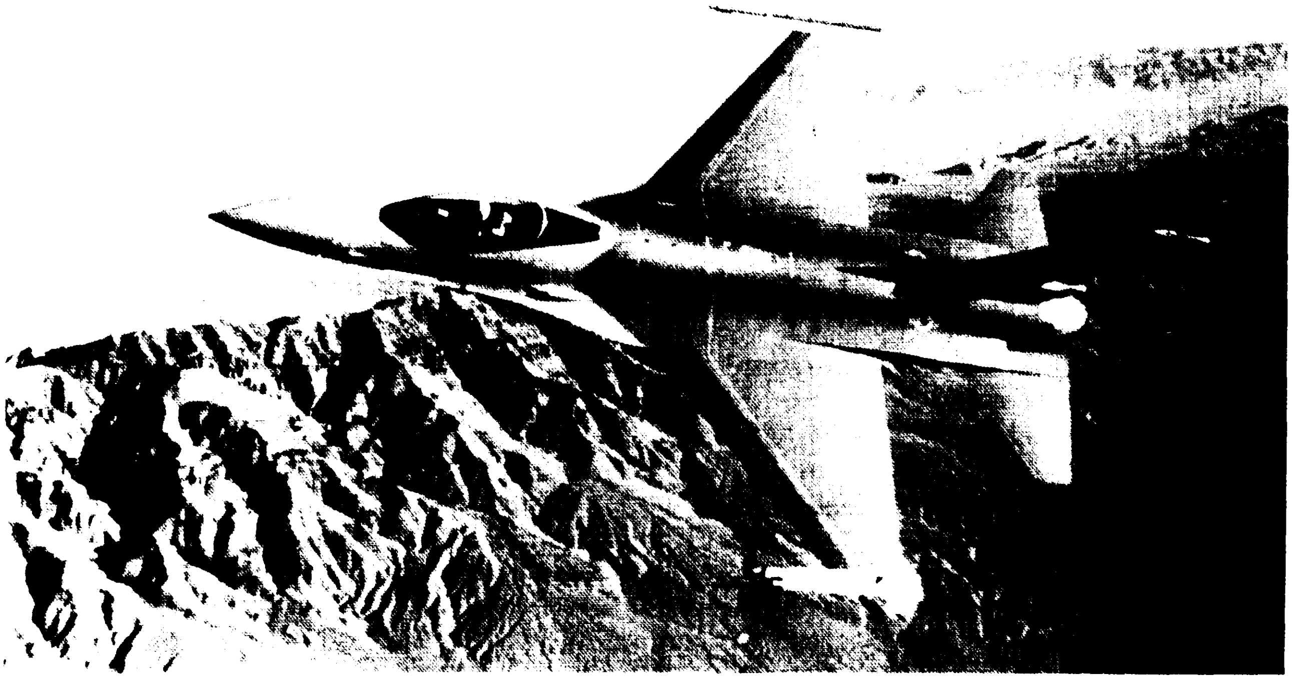


Photo credit U S Air Force

Chromium and cobalt are essential in jet engines of high-performance military aircraft such as this U.S. Air Force F-16

minerals production and export, Cuba, for example, was considered a potential supplier of nickel for the United States, as a supplement to Canadian supplies. When the Communist government was installed in Cuba, access to this source was lost due to a U.S.-imposed embargo.

Another possible source of vulnerability is long-distance transportation by sea. The United States imports large tonnages of a number of important materials from distant countries by sea, For example, in 1981 the United States imported 3 million tons of alumina from Australia; some 640,000 tons of manganese ore, mainly from Gabon, South Africa, and Australia; and 800,000 tons of ferromanganese and ferrosilico-manganese, largely from South Africa, France, and Brazil. If sea lanes were blocked in a war, it is difficult to conceive how these large tonnages could be airlifted to the United States from the producer countries.[17]

Although import dependency does not equate with vulnerability, and domestic supplies are not an ironclad guarantee against disruption, the lack of adequate domestic supplies counts as a most important factor in vulnerability. Lagging investment and labor troubles have, on occasion, limited production from U.S. mines. Yet, at the very least, domestic supplies can be relied on in a national emergency, to meet part of domestic requirements, assuming the government would exercise special powers to keep production going.

“Lack” of domestic supply can be a relative term, ranging from resources that look prom-

17 The payload of a C5A, our largest cargo aircraft, is about 100 tons. At that payload, it has a range of 2,500 miles.

ising now or in the near future (platinum in the Stillwater Complex in Montana) to subeconomic deposits (cobalt in the Blackbird deposit of Idaho) to resources of such poor quality (manganese in Minnesota and Maine) that they may never be economical to mine.

Combining Both Strands: Defining "Strategic"

When the strands of criticality and vulnerability are combined, a definition something like this emerges: If a material's essential uses, for which there are no available economic substitutes, exceed the reasonably secure sources of supply, the material is "strategic. " However, neither "essential uses" nor "reasonably secure sources of supply" can be defined with quantitative precision. The following section screens particular materials against the criteria described in this section, with the aim of selecting a few materials that nearly everyone can agree are "strategic" and that exemplify the problems and opportunities presented by these materials.

Selecting Strategic Materials

The group of materials chosen for screening for this report included the 86 nonfuel minerals for which the Bureau of Mines regularly publishes statistics.[18] The Bureau reports data for each material on the structure of the domestic industry; consumption (overall and by end use or industry); imports and exports, including sources of imports and how much each source supplies; purchased scrap recycling; events, trends, and issues relevant to the material; world production, reserves, and resources; and substitutes and alternatives. These kinds of data (drawn from the Bureau of Mines and other sources) were the basis for fitting materials against the criteria described earlier, defining which materials are strategic, and selecting them for further study. Table 2-2 lists the 86 materials that comprised the group chosen for screening,

[18] Unless otherwise noted the i n formation presented is from the Bureau of Mines.

Table 2-2.—Materials To Be Screened

Aluminum	Manganese
Antimony	Mercury
Arsenic	Mica (natural), scrap and flake
Asbestos	Mica (natural), sheet
Barite	Molybdenum
Bauxite	Nickel
Beryllium	Nitrogen (fixed) ammonia
Bismuth	Peat
Boron	Perlite
Bromine	Phosphate rock
Cadmium	Platinum group metals
Cement	Potash
Cesium	Pumice and volcanic cinder
Chromium	Quartz crystal (industrial)
Clays	Rare-earth metals
Cobalt	Rhenium
Columbium	Rubidium
Copper	Rutile
Corundum	Salt
Diamond (industrial)	Sand and gravel
Diatomite	Selenium
Feldspar	Silicon
Fluorspar	Silver
Gallilum	Sodium carbonate
Garnet	Sodium sulfate
Gem stones	Stone
Germanium	Strontium
Gold	Sulfur
Graphite (natural)	Talc and pryophyllite
Gypsum	Tantalum
Hafnium	Tellurium
Helium	Thallium
Ilmenite	Thorium
Iridium	Tin
lodine	Titanium dioxide
Iron ore	Titanium sponge
Iron and steel	Tungsten
Iron and steel scrap	Vanadium
Kyanite and related materials	Vermiculite
Lead	Yttrium
Lime	Zinc
Lithium	Zirconium
Magnesium metal	
Magnesium compounds	

SOURCE Off Ice of Technology Assessment, drawn from U S Department of the Interior Bureau of Mines data

One of the leading criteria for vulnerability was the sufficiency of domestic supplies of a material. The United States is a net exporter or is self-sufficient for 22, or approximately one-quarter, of the materials on the list (table 2-3), As a first cut in the screening, all these materials were eliminated from further consideration as strategic. In addition, 50 of the 86 materials on the original list are imported mostly from countries judged to be stable sources of supply—i.e., countries presently free

Table 2.3.—Materials for Which the United States is Self-Sufficient or a Net Exporter

Boron	Magnesium compounds
Bromite	Mica (natural), scrap and flake
Clays	Molybdenum
Diatomite	Perlite
Feldspar	Phosphate rock
Garnet	Quartz crystal (industrial)[a]
Helium	Sand and gravel
Iron and steel scrap	Sodium carbonate
Kyanite and related minerals	Stone
Lithium	Talc and pyrophyllite
Magnesium metal	Vermiculite

[a]Lasca is one of the three commodities reported in this category It is imported, but the net import reliance is not available

SOURCE Office of Technology Assessment, based on U.S Department of the Interior, Bureau of Mines data

from threats of internal disturbances or outside pressure from forces hostile to the United States. These "stable" sources range from industrialized countries such as Canada and Australia to advanced developing nations, particularly Latin American ones such as Brazil, Chile, and Mexico. For most of the 50 materials in this group, there was either considerable diversity in sources of supply, or stability, or both. For these reasons, the vulnerability of the United States to disruption of the supply of these materials was judged to be relatively low, However, dependable allies or even the United States itself cannot be considered totally immune from interruption in minerals and metal production, as shown by the previously mentioned Canadian nickel strike.

The primary end uses of this group of materials were also scrutinized, to see whether the uses should be considered critical. For materials with significant military or important industrial uses, the availability of substitutes to replace these uses was checked. Combining qualitative judgments with quantitative information on both the vulnerability and criticality factors, it appeared that the critical uses of materials in this group did not exceed the amount imported from stable sources. Thus, they were screened out of the list of strategic materials candidates, Appendix B shows these 50 materials and their import sources.

It was not possible to eliminate as a group the remaining 14 materials. They required more detailed individual scrutiny. As the following discussion shows, at least four of them–chromium, cobalt, manganese, and the platinum group metals—clearly met all of the criteria set forth in the first part of this chapter and were definitely strategic:

- They are essential for the national defense and other important industries.
- For some of their essential uses no satisfactory substitutes are available,
- There is little or no production of any of these materials in the United States (although for some, recycling is significant).
- They are supplied largely by a very few countries in a politically unsettled region (central and southern Africa), and this same region, plus the Soviet Union, holds most of the world's known resources.

These four minerals form a "first tier" of strategic materials that have been selected for detailed treatment in this report. The remaining 10 materials share some characteristics of criticality and vulnerability with the first tier (as detailed in the discussion below), but in less definitive ways. While the materials in this second tier may be thought of as strategic to some degree, they are less so than those in the first tier. Table 2-4 shows the 14 materials grouped by first and second tiers.

Table 2-4.—U.S. Strategic Materials

First tier	Second tier
Chromium	Bauxite/alumina
Cobalt	Beryllium
Manganese	Columbium
Platinum group metals	Diamond (industrial)
	Graphite (natural)
	Rutile
	Tantalum
	Tin
	Titanium sponge
	Vanadium

SOURCE: Office of Technology Assessment

Overview of Selected Strategic Materials

Agreement that chromium, manganese, cobalt, and the platinum group metals are strategic materials is widespread. The selections of strategic materials made by other authors, as described in the first part of this chapter, all include these metals. A brief explanation of the reasons for selecting these four materials follows, with an emphasis on the vulnerability strand. Chapter 3 summarizes in more detail the essential uses of the first-tier materials, probable trends in their consumption over the next 10 to 25 years, and the current status of substitutes for their uses. The discussion below presents data for each of the materials on U.S. consumption over the past 5 years and on several factors related to vulnerability: U.S. net import reliance, import sources, world production and reserves. Similar information about second-tier materials can be found in appendix C.

Chromium

Chromium (Cr) is a lustrous, hard, steel-gray metallic element found primarily in chromite, a black to brownish-black chromium ore ($FeCr_2O_4$). It imparts unique properties of corrosion resistance, oxidation resistance at high temperatures, and strength to other metals. An important ingredient in many steels and alloys, chromium is irreplaceable (at present levels of technology) in stainless steels and high temperature-resistant superalloys. And many of the uses of stainless steels and superalloy are essential, such as in jet engines, in other military applications, and in vital nondefense production.

Besides its metallurgical uses, chromium is essential in the chemicals industry, where it is used in making pigments and chromium chemicals. Chromite is used in making refractory bricks to line metallurgical furnaces; such bricks retain their strength and stability even when subjected to rapid, extreme changes in temperature, and are resistant to acid and alkali environments. Additional uses of chromium are in leather tanning, in wood treatment, and as additives to oil-well drilling mud.

Table 2-5 shows chromium consumption in the United States from 1978 to 1982, including the chromium contained both in chromite ore and in the semi-processed alloy ferrochromium. The sharp decline in 1982 reflects that year's recession, with the steel industry especially hard hit.

In the 1979-82 period, imports accounted for 85 to 91 percent of U.S. chromium consumption, Recycling of scrap amounted to 12 percent of apparent consumption in 1982. As table 2-6 shows, the largest supplier to the United States for both chromium ore and ferrochromium is South Africa. The Soviet Union is actually the world's largest producer of chromium, and once played a significant role in supplying the United States with chromium ore. Since the mid-1970s, however, its contribution to U.S. supplies has declined significantly. Other U.S. suppliers of chromium ore—e.g., the Philippines, Finland, and Turkey—have limited production capacity compared to South Africa's,

The recent trend among a number of ore producers has been to process the ore into ferrochromium. Zimbabwe presently exports most of its chromium as ferrochromium.

U.S. chromium resources are mostly in the Stillwater Complex in Montana, podiform de-

Table 2-5.–U.S. Consumption of Chromium, 1978.82

Year	Apparent consumption (thousand short tons chromium content)	Net import reliance[b] (percent)
1978	590	91
1979	610	90
1980	587	91
1981	510	90
1982	319	85

[a]Apparent consumption = u s primary and secondary (recycled) production and net import reliance
[b]Net import reliance = (imports exports + changes in government and industry stocks) apparent consumption

SOURCE U S Department of the Interior, Bureau of Mines, *Mineral Commodity Summaries*, 1983 and 1984

Table 2-6.—Sources of U.S. Chromium Imports

Country	1979-82 (percent)	1982 (percent)
Chromite: [a]		
South Africa	**48**	**59**
Soviet Union	**17**	**6**
Philippines	**13**	**11**
Turkey	**7**	**6**
Albania	**6**	**1**
Finland	**5**	**7**
Madagascar	**4**	**9**
Ferrochromium:		
South Africa	61	35
Zimbabwe	12	25
Yugoslavia	12	12
Brazil	4	11
Sweden	4	4
Turkey	2	4
West Germany	2	3
Japan	1	—
China	1	4
Other	1	2

[a]Chromite = chromium ores

NOTE: Major world producers of chromite and their contribution to world supplies in 1982 were" Soviet Union (34 percent), South Africa (22 percent); Albania (12 percent); Brazil (10 percent), Zimbabwe, Philippines, Turkey, and Finland (4 percent each), India (3 percent). See table 5-4 of ch 5 for more detail, and for Information on reserves

SOURCE U S Department of the Interior, Bureau of Mines, *Minerals* Yearbook, 1980, 1981, 1982, and 1983

posits in California and Alaska, and beach sands in Oregon. These deposits are not considered close to being economically mineable at present. Some chromium would be produced as a co-product of nickel and cobalt at Gasquet Mountain in northern California, according to the plans of the developer. However, startup of this mine in the near future seems highly unlikely without either Government subsidies or substantially higher world prices for these metals. (Detailed information on domestic and world chromium production is covered in ch. 5.)

Cobalt

Cobalt (Co) is a hard, brittle metallic element found in association with nickel, silver, lead, copper, and iron ores. It resembles nickel and iron in appearance.

The largest and most critical end use of cobalt is in superalloys, used mainly in gas turbines (aircraft and land and marine-based) that require high strength at very high temperatures, Cobalt has no satisfactory substitute as a binder in carbide tools. It is a preferred ingredient in other steels and alloys as a hardening agent, Another application is in electrical equipment, where cobalt's strong magnetic properties make small, powerful, and long-lasting magnets. Cobalt is also used as a catalyst, especially in petroleum refining, to remove sulfur and heavy metals. Spurred by high cobalt prices in the 1978-80 period, considerable substitution for cobalt has occurred—e.g., ceramics in permanent magnets. But cobalt is still considered essential in many of its applications, especially in many superalloys.

Table 2-7 shows total annual consumption of cobalt. Quantities used are relatively small compared to materials such as chromium and manganese. A trend toward declining cobalt consumption is apparent since the price hike and fears of shortage in 1978 (see ch. 4).

The United States is highly import-dependent (92 percent) for cobalt, with the rest of demand supplied by recycling. The largest sources of supply, both for the United States and the rest of the free market countries, are Zaire and Zambia (see table 2-8). In the past 4 years, world supplies have been expanded and diversified; other countries such as New Caledonia, the Philippines, and Australia now make a greater contribution to world supply. This expansion was also induced by the cobalt price spike in the wake of the Katanga invasion of Zaire's mining belt in 1978. Zairian cobalt currently accounts for about 43 percent of U.S. imports, compared with 53 percent before the 1978 cobalt panic. Despite the considerable number of suppliers at present, Zaire and Zambia have

Table 2-7.—U.S. Consumption of Cobalt, 1978.82

Year	Apparent consumption (short tons cobalt content)	Net import reliance[b] (percent)
1978	10,182	95
1979	9,403	94
1980	8,527	93
1981	6,266	92
1982	5,592	92

[a]Apparent consumption = U S primary and secondary (recycled) production and net import reliance

[b]Net import reliance = (imports exports + changes in government and industry stocks) apparent consumption

SOURCE U S Department of the Interior, Bureau of Mines, *Mineral Commodity Summaries, 1983* and 1984

Table 2-8.—Sources of U.S. Cobalt Imports

Country	1979-82 (percent)	1982 (percent)
Zaire	37	39
Zambia	13	9
Canada	8	12
Belgium-Luxembourg [a]	8	5
Finland	7	6
Japan [a]	7	8
Norway [a]	7	7
Botswana	3	3
France [a]	3	3
Other	7	8

[a] Processes cobalt ore originating from other countries

NOTE Major world producers of primary cobalt and their contribution to world supplies in 1982 were Zaire (45 percent), Zambia (13 percent), Australia (9 percent), Soviet Union (9 percent), and Canada (6 percent) See table 5-16 of ch 5 for more detail and for information on reserves

SOURCE U S Department of the Interior, Bureau of Mines, *Minerals Yearbook. 1980 1981 1982,* and 1983

substantially the largest and richest cobalt ore deposits. Due to these reserves, these two countries promise to continue to dominate cobalt supply far into the next century.

The United States has sizable cobalt deposits, particularly at the Blackbird Mine in Idaho, the Madison Mine in Missouri, and Gasquet Mountain in California. Substantial cobalt is also associated with copper-nickel deposits in the Duluth Gabbro of Minnesota. But the world price of cobalt (except during the panic) has been significantly less than what is needed to make U.S. cobalt mining economically feasible without government assistance.

Manganese

The dominant critical use of manganese, a gray-white or silver metallic element, is in steelmaking which accounts for about 90 percent of domestic manganese consumption. The addition of manganese prevents steel from becoming brittle. Normally, iron and sulfur compounds in steel tend to form at grain boundaries and weaken the steel at high temperatures. When manganese is added, the sulfur bonds with it instead of the iron, forming a stable compound and avoiding weakness at grain boundaries. Manganese also has uses as an alloying element to impart strength and hardness to all grades of steel. For example, manganese-alloy steel is used for armored vehicles that withstand impacts.

Only 10 percent of U.S. manganese consumption goes into nonsteel applications. Manganese dioxide is used *in* batteries for *its oxygen* content, wherein the oxygen combines with hydrogen, which would otherwise slow the cell's action. Manganese dioxide is also used in making chemicals, in the leaching of uranium ores, and in the electrolytic production of zinc.

For these smaller uses, manganese has some substitutes. Although no satisfactory material replacements for manganese exist in iron and steel production (see ch. *6),* there are functional substitutes for manganese in steelmaking: external desulfurization is reducing the manganese requirement for sulfur control and several other process modifications in steelmaking also reduce manganese requirement or improve manganese recovery.

Domestic consumption of manganese has declined slightly in recent years (table *2-9).* The big drop in *1982* is due to the recession in the steel industry.

There is no domestic production of "manganese ore" (defined as ores containing more than 35 percent manganese). The United States relies on import sources for *99* percent of its supply, with the remaining *1* percent recovered from domestic production of manganiferous ores that contain less than 35 percent manganese.[19] Ferromanganese and silicomanganese—alloys used in steelmaking—are also highly imported.

The largest suppliers of manganese materials to the United States are Gabon and South Africa, as shown in table *2-10.* The U.S.S.R. and South Africa have by far the largest manganese deposits in the world. However, Australia and Gabon are well-endowed with reserves which could last a century or more at

[19] The iron and steel industry derives a significant quantity of manganese from iron ores charged to the blast furnace, This input accounts for approximately one-third of total consumption, but it is not included in manganese import statistics. The quantity of manganese contained in these iron ores has been declining. **Based** on George R, St, Pierre, et al., Use *of* Manganese in *Steelmaking and Steel* Products and Trends in the Use *of Manganese as an Alloying Element in Steels,* report prepared for the Office of Technology Assessment, **1983.**

Table 2-9.–U.S. Consumption of Manganese, 1978-82

Year	Apparent consumption (thousand short tons manganese content)	Net import reliance[b] (percent)
1978	1,363	97
1979	1,250	98
1980	1,029	98
1981	1,027	99
1982	672	99

[a]Apparent Consumption = U.S primary and secondary (recycled) production and net import reliance
[b]Net import reliance . (imports exports + changes in government and industry stocks) apparent consumption

SOURCE: U S Department of the Interior, Bureau of Mines, *Mineral Commodity Summaries, 1983* and 1984

Table 2-10.—Sources of U.S. Manganese Imports

Country	1979-82 (percent)	1982 (percent)
Manganese ore:		
South Africa.	30	52
Gabon	27	21
Australia	22	17
Brazil	13	3
Mexico	4	1
Morocco	4	4
Other	—	2
Ferromanganese:		
South Africa	43	49
France[a].	26	21
Mexico	6	7
Brazil	3	6
Australia	2	1
Other[a].	20	16

[a]Processes manganese ore originating from other countries.

NOTE Major world producers of primary manganese ores and their contribution to world supplies in 1982 were: Soviet Union (41 percent); South Africa (23 percent); Gabon (7 percent); China (7 percent), Brazil (6 percent), Australia (5 percent); Mexico (2 percent). See table 5-22 of ch 5 for further details, and for information on reserves.

SOURCE U S Department of the Interior, Bureau of Mines, *Minerals Yearbook, 1980, 1981, 1982,* and 1983.

the current rate of production, and other countries also have significant reserves—all of which perhaps implies that supply vulnerability for manganese is somewhat less than that for other materials in the first tier. Nonetheless, the only large manganese reserve in the Americas is in Brazil. All sources of U.S. manganese imports (except a small amount coming from Mexico) require long-distance transportation by sea, which adds an element of vulnerability to U.S. supply. The tonnages required by U.S. industry rule out any other method of transport. Unclaimed resources are the manganese nodules which are found in large areas of the ocean floor (see ch. 5).

Platinum Group Metals

Platinum group metals (PGMs) refer to six metals which have similar properties: platinum, palladium, rhodium, iridium, osmium, and ruthenium. They have the ability to catalyze many chemical reactions and withstand chemical attack, even at high temperatures. Their leading use in the United States is in automobile catalytic converters, which use small amounts of platinum, palladium, and rhodium in each car, At present, there is no satisfactory substitute for this use of platinum group metals. Other catalytic applications are in petroleum refining, to produce high-octane gasoline, and in chemical manufacture of acids (e. g., nitric acid for fertilizer) and other organic chemicals.

The great strength, high melting points, and resistance to corrosion and oxidation of PGMs make them the material choice for electrical contacts and relays in telephone systems. PGM alloys are also used as crucible materials (e. g., for the growth of single crystals of oxide compounds, used for semiconductor substrates), in glass fiber manufacture, in dental and medical applications, and in jewelry. Most uses of PGMs as catalysts and in electronics are highly important to U.S. industry. [20]

U.S. consumption of PGMs declined in the 1981-83 recession but is now recovering (table 2-11),

[20]National Materials Advisory Board, *Supply and Use* Patterns for the Platinum-Group Metals, NMAB-359 (Washington, DC: National Academy of Sciences, 1980).

Table 2-11. —U.S. Consumption of Platinum Group Metals, 1978-82

Year	Apparent consumption (thousand troy ounces)	Net import reliance[b] (percent)
1978	2,635	90
1979 ... , . . .	2,995	89
1980	2,859	88
1981	2,411	84
1982	1,787	80

[a]Apparent Consumption = u s primary and secondary (recycled) production and net import reliance,
[b]Net import reliance . (imports exports + changes in government and industry stocks) apparent consumption

SOURCE: U S Department of the Interior, Bureau of Mines, *Mineral Commodity Summaries, 1983* and 1984

The United States is highly import-dependent (85 percent) for PGMs. There is a small amount of domestic production (less than 1 percent of apparent consumption), The remaining 15 percent of demand is supplied by purchased secondary materials. Actually, this figure understates the amount of PGM recycling. If consumption is defined to include the PGM catalysts which are owned by refiners and chemical manufacturers, sent out for "toll refining,"[21] and then reused, recycling accounts for about 40 percent of total consumption. Chapter 6 discusses further recycling possibilities.

The Stillwater Complex in Montana is the most significant known U.S. deposit of PGMs. Development of an underground mine has been proposed for this site, with the decision on whether to develop the property scheduled for mid-1985. Small amounts of PGMs were recovered from placer deposits at Goodnews Bay in Alaska as recently as 1975. Chapter 5 has more details regarding PGM mineral deposits,

The largest source of PGM supply for the United States is South Africa. As table 2-12 shows, the South African deposits of the Bushveld Igneous Complex dwarf those of the United States and Canada. In fact, the U.S. and Canadian reserves combined would satisfy U.S. demand at the current level for only about 10 years. The Soviet Union is presently the world's largest producer of PGMs; its reserves are substantial but only about one-fifth the size of South Africa 's.

PGMs are mined in South Africa for their own sake, while in the Soviet Union and Canada they are coproducts or byproducts of nickel and copper. Thus, South Africa has the advantage of responding directly to the PGM market in making production decisions. Moreover, the combination of PGMs in the ores is more favorable in South Africa than anywhere else, with a greater proportion of higher value platinum in the mix.

[21]The term "toll refining" denotes the recycling of metals for a fee in which ownership of the metals does not change hands.

Table 2-12.—Sources of U.S. Platinum Group Metal Imports

Country	1979-82 (percent)	1982 (percent)
South-Africa . . . , ... , .,	56	48
U.S.S.R.	16	16
United Kingdom. ., ...	11[a]	13
Other	17	23

[a]PGM production from the United Kingdom is from ores originating in South Africa and Canada and from secondary materials

NOTE Major world producers of PGM and their contribution to world supplies in 1982 were Soviet Union (54 percent) South Africa (40 percent) and Canada (4 percent) See table 5-33 of ch 5 for further details and for information on reserves

SOURCE U S Department of the Interior, Bureau of Mines *Minerals Commodity Summaries* 1983 and 1984

A Perspective on Strategic Materials Selection

For many reasons, no list of strategic materials can be the last word. It cannot be exhaustive: the cutoff point at the end of the list is bound to be somewhat arbitrary, separating materials which are "more" strategic from those that are "less," rather than representing ones that "are" strategic as opposed to those that "are not. " Nor can the list be final. Conditions change. Take copper, for example. In *1952,* the Paley Commission selected copper as a "key commodity, " for which world consumption and U.S. net imports were rapidly rising.[22] The commission projected that by 1975, the United States would be able to supply only about **60** percent of its copper needs through domestic mine production and recycling. Thus, copper, which had a number of important industrial uses, might have been considered at that time as a good candidate for a strategic materials list. In fact, domestic cop-

[22]The President's Materials Policy Commission, *Resources for Freedom* (Washington, DC: U.S. Government Printing Office, 1952), vol. 2.

per production rose so much over 25 years that net imports fell to about 10 percent of consumption in the 1970s, rather than to the projected 40 percent, and were well below the 35 percent of 1950.[23]

The position of copper may change again in the future, American mines were closing in large numbers in the recession year of 1982, with some industry officials predicting that the mines would never reopen because high wages and pollution control costs had made the American copper mining industry—the world's largest—uncompetitive with foreign producers. Even if this prediction proves true, copper's designation as a strategic material will depend on many factors, including the nature of its use, the availability of substitutes, and the number and character of foreign suppliers.

The continual development of new materials and uses also tends to make lists of strategic materials out of date. For example, natural rubber was a strategic material of great concern to the United States before World War II. But during the war, when imports of natural rubber from Southeast Asia were cut off, U.S. production of synthetic rubber expanded enormously. The displacement of natural rubber for most uses proved to be permanent.

[23]Data on production, reserves, and imports of minerals come from the Bureau of Mines, Department of the Interior.

Perhaps it is most useful to look at the strategic materials selected for careful analysis herein as indicative of a set of problems and possible solutions, not as fixed or exhaustive.

The brief discussion above—much amplified in chapters 3 and 4—indicate why cobalt, chromium, manganese, and PGMs are judged to be highly strategic materials. Because they meet all, or nearly all, of the criteria for critical uses and vulnerability of supply, they have been selected for detailed examination in this report. The essential functions of these materials, present and anticipated, potential substitutes, and technologies that can reduce dependence on uncertain supplies are discussed at length in the chapters that follow.

The second-tier materials, which share some strategic characteristics with those of the first tier, are described in appendix C. These materials, though judged to be less strategic than the first four, are still worthy of attention and study. As a practical matter, this report must confine its assessment to a manageable number of materials. The four first-tier materials are judged to be most strategic, and they present the problems of import vulnerability and possible solutions in the most striking way, Thus, the assessment here may serve as a useful model for studying other materials which, though judged less strategic, may be of some concern because of combined factors of vulnerability and criticality,