UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

ENERGY AND MINERALS DIVISION

B-203767

June 25, 1981

The Honorable Henry M. Jackson
Ranking Minority Member
Committee on Energy and Natural Resources
United States Senate

Dear Senator Jackson:

Subject: Minerals Critical to Developing Future Energy Technologies, Their Availability, and Projected Demand (EMD-81-104)

The next 20 to 30 years are expected to be a period of transition from major dependence on conventional energy sources such as oil and natural gas to an era more dependent on nonconventional renewable and virtually inexhaustible sources of energy. The viability of these future alternative energy sources is contingent, in part, on future materials and minerals availability, technology, and cost.

On June 20, 1980, you asked GAO to identify minerals critical to developing future energy technologies, their availability, and projected demand. In your letter, you stated that strategic and critical minerals constraints on the United States capability to meet expected requirements of future major alternative energy technologies represent a critical consideration in formulating a national energy policy and, as such, are of immediate interest to the Committee. From GAO's effort, you stated that the Committee should be able to "identify whether legislation is needed to develop new alloys or substitutes; increase domestic, foreign, and undersea supplies; develop new technologies; promote recycling; augment stockpiles, etc."

Our initial effort found that no Federal agency collects data in a form that can be used to show how much of any given mineral goes to the energy industries or to project demand for minerals by the various energy technologies. Further, a capability for providing valid, reasonably reliable projections of demand for and supply of minerals by the energy technologies had not been developed within either the public or private sector.

As agreed with your office, GAO and the Lawrence Berkeley Laboratory developed a methodology to evaluate projected energy-related demand for nonfuel minerals. The methodology modified

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and interlinked two accepted computer models to provide projected demand for 25 nonfuel minerals in 5-year intervals to the year 2000 under four technology scenarios. The Department of Energy has used the scenarios to formulate national energy policy. Since the output from the methodology was limited to energy-related demand for nonfuel minerals, the Department of the Interior's Bureau of Mines provided projections of total U.S. and world primary demand, mine production capacity, and level of production for each mineral evaluated. The energy technology scenarios selected and the methodologies used to project energy-related and total U.S. and world demand for the 25 nonfuel minerals together with related caveats are explained in the enclosure. (See p. 6.)

As further agreed with your office, because of the time required to develop the modeling methodology, this interim report is limited to identifying minerals critical to developing future energy technologies, their availability and projected demand, and our conclusions relative to these issues. We are in the process of evaluating the need for legislative and/or administrative actions to help mitigate the adverse impact of potential future supply disruptions or sharp price increases in critical mineral markets. As requested, a second, more comprehensive report including the results of our evaluation together with a complete technical report on our modeling methodology will be made available to the 97th Congress for use in formulating energy-related minerals policy legislation. Any recommendations we may ultimately have will be contained in our second report.

ENERGY WILL BE A MAJOR CONSUMER OF NONFUEL MINERALS, BUT MINERAL EXHAUSTION DOES NOT APPEAR TO BE A PROBLEM

Our projections indicated that implementing a national energy program to replace or supplement conventional oil, natural gas, and coal with energy sources that are either renewable or available on a scale sufficient for centuries could require large increases in the supply and availability of certain nonfuel minerals. The four energy technology scenarios evaluated required an average of between 17 percent and 23 percent of total projected U.S. demand for the 25 minerals to the year 2000. However, the percentage for each mineral varied sharply from a low of 3 percent for molybdenum to a high of 75 percent for tantalum. (See p. 15.)

Demand for the 25 nonfuel minerals by the conventional oil, gas, and coal technologies remained relatively constant among the four energy scenarios averaging between 8 percent and 9 percent of total projected U.S. demand. Conversely, demand by the alternative solar, synfuel, and nuclear technologies varied from 8 percent to 15 percent depending primarily on the amount of energy in the scenario provided by the solar and other renewable technologies. (See pp. 15 to 19.) However, physical or "crustal" exhaustion of world mineral resources did not appear to be a problem through the remainder of this century. Further, world reserves of most minerals, defined as that portion of resources which are located in identified deposits and can be economically extracted given current technology and mineral prices, also appeared to be adequate despite the increased demand generated by the alternative energy technologies. (See p. 20.)

ALTERNATIVES ARE AVAILABLE TO MITIGATE MOST POTENTIAL CONSTRAINTS

Our modeling methodology and analytical efforts did, however, identify nine minerals--aluminum ores, chromium, cobalt, columbium, gold, manganese, nickel, the platinum group metals, and tantalum--that appear to be both strategic and critical to implementing a national energy program. These minerals are "strategic" in that the United States is vulnerable to contingencies that might either seriously disrupt supplies or cause sharp increases in price (see p. 21) and implementing a national energy program may intensify this vulnerability. (See p. 26.) They are "critical" in that they appear to be essential for future energy technology development. These minerals are concentrated primarily within the steel industry and are capable of tolerating high stress and temperature and/or severe corrosive and erosive environments. (See p. 26.)

Our findings must be tempered by the fact that high U.S. import reliance is _not_ synonomous with vulnerability and does _not_ necessarily present a high risk to the U.S. economy or a national energy program. Other factors, such as the probability of a supply disruption or sharp price increase in a given mineral market and its expected duration, concentration of mine production in one or several foreign countries, the cost of the potential loss to the U.S. economy or to a national priority such as an energy program, and the availability of alternatives to mitigate any adverse impacts must also be considered.

The concensus among most risk assessments we reviewed is that the probability of prolonged periods of physical supply stringency or sharp price increases in any given nonfuel mineral market appears remote for the remainder of this century and the economic impact of most nonfuel mineral supply disruptions or price increases, if they did occur, appears minimal.

These assessments have found that political, military, and economic ties between the mineral producing countries and the industrialized consuming countries including the United States appear to substantially reduce the probability of long-term supply disruptions or sharp price increases and that the chance of a nonfuel mineral cartel successfully controlling the market price is low. (See p. 29.)

A national energy program may be subject to short-term contingencies in certain mineral markets such as actions by foreign governments or other entities intended to disrupt supplies or raise prices, civil or military conflicts in producing areas, generalized demand surges, and natural disasters. However, most of these short-term contingencies which could last for several years fall within the bounds of normal business risks and do not require Federal attention. Further, a national energy program is not subject to the same stringent time frames as are defense-related needs during periods of national emergency. Within each energy program time frame, opportunities appeared available to mitigate most adverse impacts through incidential, market-related incentives such as

--shifting emphasis among competing energy technologies,

--substituting technological designs that are less mineral intensive or utilize different minerals in both energy and nonenergy applications,

--substituting other minerals in applications where cost and preferred use are the key criteria,

--reducing consumption through conservation,

--expanding domestic and foreign supplies,

--increasing recycling, and

--drawing down industry stocks. (See p. 33.)

These and other measures indicate a multitude of alternatives are available to mitigate the adverse impact of supply disruptions or sharp price increases in most mineral markets, but the availability of many of these alternatives is uncertain due primarily to the lead time associated with their implementation. Further, not all alternatives are available for a specific strategic and critical mineral. For example, the

United States currently has no known reserves of chromium, columbium, manganese, or tantalum. Thus, domestic mine production is not feasible without improvements in extraction and mining technology and/or increased market prices.

Our analysis indicated that each mineral may have to be analyzed and evaluated on its own merits before comparative analysis can be performed. It also indicated that generalizations concerning the availability of nonfuel minerals are difficult, if not impossible, to make. Therefore, we must caution that our analysis was not exhaustive, in part because all the significant problems connected with the minerals may not have been identified. Further, there may be significant problems of different types associated with other minerals. However, we believe the potential problems and solutions addressed are sufficiently representative of those relating to implementing a national energy program.

As agreed with your office, we did not obtain official agency comments on this report. Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of its issuance. At that time we will send copies to interested parties and make copies available to others upon request.

Sincerely yours,

J. Dexter Peach
Director

Enclosure

 ENCLOSURE I

MODELING METHODOLOGY AND ANALYSES EMPLOYED TO IDENTIFY ENERGY-CRITICAL AND STRATEGIC NONFUEL MINERALS

SELECTING THE ENERGY FUTURES

To provide a range of U.S. energy-related demand for nonfuel minerals, we selected four technology scenarios used by the Department of Energy to formulate national energy policy. (See p. 7.) Two were developed by the Department of Energy's Office of Policy and Evaluation based on the May 1979 National Energy Plan II modified to reflect the high (NEP-2 High) and the low (NEP-2 Low) oil price cases in the Energy Information Administration's 1979 Annual Report to the Congress. The two other scenarios were developed in 1979 for Energy's Technology Assessment of Solar Energy. These scenarios--TASE 6 and TASE 14--reflect 6 quads 1/ and 14 quads of solar energy and together with other renewable technologies comprise 10 quads and 18 quads or about 8 percent and 15 percent, respectively, of the total projected energy supply by the year 2000. They were also based on the Energy Information Administration's high and low oil price cases with 1978 Domestic Policy Review of Solar Energy projections embedded in them.

All four scenarios show similar growth in energy consumption, reaching between 123 and 129 quads in the year 2000. By comparing the mineral requirements among the four scenarios, we were able to determine the effects of different growth rates and mix of technologies on energy-related demand for nonfuel minerals.

More recent energy forecasts have significantly reduced the growth in energy consumption. For example, the high and low oil price cases in the Energy Information Administration's 1980 Annual Report to the Congress show energy growth reaching only 97 and 107 quads, respectively, in the year 2000. These reductions, averaging about 20 percent, could, in turn, significantly reduce energy-related demand for nonfuel minerals. Therefore, the projections based on the four energy technology scenarios above should be viewed as high in light of the current era of energy austerity.

1/One quad is equal to 10^{15} British thermal units (Btu). A Btu is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

SCHEDULE OF FOUR ENERGY TECHNOLOGY SCENARIOS

BY AGGREGATED TECHNOLOGY GROUP

Technology group by scenario	Quads of energy supplied (note a) 1975	1985	1990	2000
NEP-2 High:				
Coal	15	23	29	38
Synfuels	0	0	0	6
Oil	33	40	38	33
Gas	20	20	20	19
Solar and other renewables	4	5	7	12
Nuclear	2	6	10	16
Total	74	94	104	124
NEP-2 Low:				
Coal	15	22	28	33
Synfuels	0	0	0	4
Oil	33	42	44	48
Gas	20	20	20	19
Solar and other renewables	4	6	6	10
Nuclear	2	6	9	15
Total	74	96	107	129
TASE 6:				
Coal	15	22	29	37
Synfuels	0	0	0	9
Oil	33	40	38	33
Gas	18	18	18	18
Solar and other renewables	5	6	7	10
Nuclear	2	6	9	16
Total	73	92	101	123
TASE 14:				
Coal	15	22	28	33
Synfuels	0	0	0	9
Oil	33	40	38	32
Gas	18	18	17	17
Solar and other renewables	5	6	9	18
Nuclear	2	6	9	14
Total	73	92	101	123

a/One quad is equal to 10^{15} British thermal units (Btu). A Btu is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

METHODOLOGY DEVELOPED TO PROJECT ENERGY-RELATED DEMAND FOR NONFUEL MINERALS

The modeling methodology developed by GAO and the Lawrence Berkeley Laboratory merged these qualitative judgments by energy experts with available quantitative tools of supply and demand analysis to formulate energy-related nonfuel mineral forecasts. The methodology modified and interlinked two accepted computer models and provided demand for 46 nonfuel mineral sectors in 5-year intervals to the year 2000 under each of the four energy technology scenarios.

The energy technology scenarios provided detailed specifications of the amount of energy to be supplied by each energy technology group. These data were disaggregated (broken out) to provide geographic and technical detail. Then, the Energy Supply Planning Model, originally developed in 1973 by the Bechtel Group of Companies for the National Science Foundation and updated from time-to-time, translated each scenario into the number of 74 nominal energy supply facilities and 27 energy transportation and transmission facilities to be constructed to meet the specified levels of energy supply. Bechtel developed the data characterizing the facilities based primarily on in-house engineering estimates relying on past construction experience, literature, and industry contacts. The model then generated a year-by-year schedule of the capital investment for 24 categories of materials, equipment, and labor needed to construct each type of energy and transportation facility. To this was added the materials and engineering cost requirements for 20 model or nominal solar and other renewable systems developed by the Department of Energy's national laboratories and the MITRE Corporation as part of the Technology Assessment of Solar Energy or TASE study.

A nominal facility represents a "future average" facility in that its resource requirements are intended to be typical of requirements for a facility of that kind and size likely to be under construction through the year 2000. This definition implies that a nominal facility may not be identical to any existing or planned facility but can yield reasonably accurate results over a future time period.

The modified Energy Supply Planning Model's capital investment output was linked directly to a U.S. input-output (I/O) model derived from a 496-sector national table for 1972 prepared by the Department of Commerce's Bureau of Economic Analysis. The I/O model was used to project the impact of the Energy Supply Planning Model's capital investment on other sectors of the national economy, including the minerals industries. However, the Bureau of Economic Analysis' U.S. national I/O table showed only 7 minerals industry sectors in its most disaggregated 496-sector table.

For purposes of expanding the national I/O table for analysis of U.S. mining activities, the Dry Lands Research Institute, under a grant from Interior's Bureau of Mines, disaggregated the 7 minerals industry sectors to show detail for 38 mineral industries. Lawrence Berkeley Laboratory further disaggregated 6 of the 38 sectors to show detail for 20 mineral industries or a total of 52 sectors, 46 of which were nonfuel minerals.

To project the minerals demand by the alternative energy technologies, Lawrence Berkeley Laboratory collapsed the I/O table to 178 industry sectors but kept the detail in the mineral producing and using sectors. The Energy Supply Planning Model capital investment output was then deflated to 1972 dollars, aggregated for 5-year periods, and distributed to the proper I/O sectors with labor costs deflated to 78 percent to reflect only the fraction that went to personal consumption expenditures in 1972. The model then calculated the direct or primary demand as well as the indirect or secondary gross output for each mineral industry required to construct the energy facilities called for in the scenario. Finally, the I/O model output in monetary values for ores and concentrates was converted to physical units and to total demand for the minerals through the primary stage of production (e.g. ferroalloys). For metallic minerals, the physical quantities represent the metal content to eliminate the need to differentiate between grades of ore, concentrates, and ferroalloys.

Several important caveats should be noted. First, limitations exist in both the accuracy and availability of data. The accuracy of the Energy Supply Planning Model's capital investment is limited by several considerations. These are primarily gaps in the available information base, metallurgical uncertainties associated with the alloy content and design flexibility, and the imprecision induced by disaggregating complex assemblies into their various components. Bechtel considers the output to be reasonably accurate for "nominal" or model facilities as precisely defined, but no better than rough estimates for more generalized facility definitions or for situations in which material supplies are tightly constrained. The level of confidence in these data range from $\pm$ 10 percent to $\pm$ 50 percent. Data on the Technology Assessment of Solar Energy model systems are even less reliable since they are based primarily on engineering estimates or experience with pilot plants and are, therefore, speculative to a large degree. However, as time passes, plans for these systems will become clearer and more accurate and detailed data on the materials and minerals needed to expand energy production will be available.

Secondly, the I/O model is based on the structure of the U.S. economy in 1972 and thus cannot account for structural changes that could take place to the year 2000. Further, since most of the minerals do not appear explicitly in the 1972 U.S. table, they had to be broken out of the larger and less detailed aggregated sectors in which they were originally included. However, information was available from the 1972 Census of Mining and Census of Manufactures supplemented by worksheets supplied by the Bureau of Mines to minimize the potential for errors in disaggregation.

Finally, projected demand should be considered as minimum requirements for the scenarios analyzed. Although they include both direct and indirect gross output for each mineral industry, the projections are limited primarily to ores, concentrates, and primary metals. Thus, demand for imported semifinished and finished products (e.g. steel and valves) are not included.

BUREAU OF MINES' METHODOLOGY TO PROJECT TOTAL DEMAND AND SUPPLY

Since the output from the methodology developed by GAO and the Lawrence Berkeley Laboratory was limited to energy-related demand for nonfuel minerals, the Department of the Interior's Bureau of Mines was requested to provide projections of total U.S. and world primary demand, mine production capacity, and level of production for each mineral analyzed.

The Bureau's projections of U.S. demand consisted of both statistical and contingency analyses. First, a 20-year least-squares regression analysis on each end use of a mineral was performed using the following U.S. economic indicators as explanatory variables--the gross national product, Federal Reserve Board index of industrial production, gross private domestic investment, construction, and population. Projections were then extrapolated for each end use to the years 1990 and 2000 based on a macroeconomic model which forecasts gross national product and detailed Federal Reserve Board industrial production indexes. Among the resulting regression lines for a particular end use of a given mineral, the line (estimated equation) that best explained the variation in the dependent variable was chosen. After the forecast bases had been established for each end use, a contingency analysis was performed which took into account judgmental factors such as technological advances, environmental issues, Federal and State policies and regulations, consumer tastes, new and obsolete uses, changes in availability of reserves and resources, substitutes and competitive commodities, price trends, world political developments, sources of minerals as byproducts and coproducts, and recycling. These mitigating factors were used to determine a high and low range and a probable forecast for each end use. The cumulative forecasts for all end uses of a mineral constituted the projection for total U.S primary demand.

Future primary production and capacity from domestic mines was estimated by a method of contingency analysis similar to that used for the U.S. demand forecasts. Projections made by regression analysis of 20-year production trends for each mineral were used as a basis for contingency analysis taking into account such judgmental factors as the geographic location of reserves and resources, land ownership, energy requirements, capital investment, existing capacity and production, and labor availability.

"Rest-of-the-world" demand, capacity, and production are often much less reliable than U.S. projections because data for many countries simply do not exist. When available, historical world consumption and production data, together with three economic indicators--world population, gross domestic product, and gross domestic product per capita--served as guides in making forecasts for nations other than the United States. However, in many instances, considerable judgment by Bureau specialists was used based on experience and knowledge of the mineral in question.

The Bureau of Mines performed a least-squares regression analysis to determine primary demand, mine production, and capacity for the intermediate years 1985 and 1995. The Lawrence Berkeley Laboratory then applied straight-line interpolation to compute demand, production, and capacity during each 5-year period between 1976 and 2000 using the Bureau's projections.

Several caveats, in addition to the questionable reliability of the rest-of-the-world projections, should be noted. First, historical end-use trends are developed through canvasses of the U.S. minerals industry, but response is voluntary. While Bureau officials consider their figures reasonable, they agree that they are not perfect. Secondly, although the Bureau forecasts of future supply and demand are tempered by contingency analysis and are not simply statistical projections of the past, radical changes in mineral markets cannot always be foreseen. Bureau specialists are often unable to foresee new uses or the impact of technological changes. Further, since forecasts of primary demand, capacity, and production were not available prior to 1975 for most of the minerals selected for analysis, we could not determine a level of confidence for the Bureau's projections.

METHODOLOGY DEVELOPED TO COMPARE ENERGY-RELATED DEMAND TO TOTAL U.S. AND WORLD DEMAND AND SUPPLY

For purposes of our analysis, total demand was derived by adding projected demand for a mineral by the synthetic fuel, nuclear, and solar and other renewable technologies to the combined total of the Bureau's forecast of U.S. and rest-of-the-world demand. Demand for a given mineral by the conventional oil, gas, and coal technologies as well as electric power transmission and energy transportation were assumed to have been included in the Bureau's projections.

We selected 25 of the 46 nonfuel mineral sectors for projection. The remaining 21 sectors were excluded because (1) the United States is a net exporter with adequate reserves and resources, (2) there are readily available, geographically dispersed, and virtually inexhaustible world resources, (3) the mineral sector included two or more minerals, or (4) the sector was not applicable to any given mineral. (See p. 13.)

Domestic energy-related and total U.S. and world primary demand, together with U.S. and world mine production capacity, were projected in 5-year periods to the year 2000. U.S. energy-related demand was then expressed as a percentage of U.S. and world demand and capacity for both the alternative and conventional energy technologies under each scenario. The primary demand for the 25 minerals was also projected in 5-year periods to the year 2000 for each group of technologies--coal, oil, gas, solar and other renewables, nuclear, and synfuels. A similar run was made for the TASE 6 and TASE 14 scenarios substituting a different technological design for the solar heating and cooling of buildings.

Our modeling methodology could not provide energy-related demand for cobalt. However, a 1976 U.S. Geological Survey study which projected demand for nonfuel minerals for the U.S. energy industry from 1975 to 1990 based on a Project Independence scenario indicated that energy-related demand for cobalt would amount to a little more than 1 percent of annual domestic consumption. According to the study, cobalt will be primarily used in fossil fuel powerplants with small amounts also being required for coal mines and transport and uranium mining and processing. Cobalt was included in our analysis because of U.S. vulnerability to both serious supply disruptions and sharp price increases in this mineral market and the lack of adequate mineral substitutes for some energy-related uses.

ENERGY WILL BE A MAJOR CONSUMER OF NONFUEL MINERALS

Our projections indicated that implementation of any of the four previously proposed national energy programs to replace or supplement conventional oil, natural gas, and coal with energy sources that are either renewable or available on a scale sufficient for centuries could require large increases in the supply and availability of certain nonfuel minerals. The four energy technology scenarios evaluated required an average of between 17 percent and 23 percent of the total projected U.S. demand for the 25 minerals to the year 2000. However, the percentage for each mineral varied sharply from a

MINERAL SECTORS EXCLUDED FROM PROJECTION

Reason for exclusion	Mineral sector
Net exporter, adequate reserves and resources	Construction sand and gravel Industrial sand Bentonite Fire clay Fuller's earth Kaolin and ball clay Other clay, ceramic, and refractory minerals, except feldspar Phosphate rock Talc, soapstone, and pyrophyllite
Inexhaustible world resources	Dimension stone Limestone Granite Other stone (marble, sandstone, etc.) Rock salt
Could not be disaggregated	Potash, soda, and borate minerals Other chemical and fertilizer minerals (lithium, strontium, etc.) Ferroalloys, including cobalt, except chromium, columbium, manganese, molybdenum, nickel, tantalum, tungsten, and vanadium Other metallic minerals including beryllium, ilmenite, rare earths, rutile, thorium, tin, and zirconium Other nonmetallic minerals including corundum, industrial diamonds, gem and precious stones, graphite, mica, and pumice
Not applicable to any given mineral	Metal mining services Nonmetallic minerals services

low of 3 percent for molybdenum to a high of 75 percent for tantalum. (See p. 15.)

Demand for the 25 nonfuel minerals by the conventional oil, gas, and coal technologies remained relatively constant among the four energy scenarios averaging between 8 percent and 9 percent of total projected U.S. demand. Conversely, demand by the alternative solar, synfuel, and nuclear technologies varied from 8 percent to 15 percent depending primarily on the amount of energy in the scenario provided by the solar and other renewable technologies. (See pp. 15 to 19.)

MINERAL EXHAUSTION DOES NOT APPEAR TO BE A PROBLEM, BUT POTENTIAL CONSTRAINTS EXIST

The concensus among the scientific community supported by current geologic, economic, and demographic evidence is that physical or "crustal" exhaustion of world mineral resources is not likely to be a problem through the remainder of this century. World reserves of most minerals, defined as that portion of resources which are located in identified deposits and can be economically extracted given current technology and mineral prices, are also expected to be adequate. Our analysis resulted in similar findings, despite the increased demand generated by the alternative energy technologies.

Bureau of Mines' estimates of reserves and resources for the minerals included in our analysis have been historically very conservative. Increases over the 20-year period 1960 to 1980 ranging between 200 percent and 300 percent were not uncommon for the minerals we analyzed due to major new deposit discoveries, technological advances in recovery processing permitting inclusion of lower grade ores, and an upward movement in prices.

Of the 26 minerals analyzed, 8 presented no long-range supply problems in the form of either U.S. or world mineral exhaustion, using a conservative 200 percent criterion for the 25-year period. Further, of the remaining 18 minerals for which the United States has no or inadequate reserves or resources, world reserves and resources appeared adequate. (See p. 20.)

While world supplies appeared adequate to meet U.S. energy-related demand, the uncertain availability of some pose potential constraints to a smooth transition from major dependence on oil and natural gas to alternative sources of energy. This uncertainty stems primarily from an undue U.S. vulnerability for some minerals to contingencies that might either seriously disrupt supplies or cause sharp increases in price. Either could delay implementing a national energy program. In this sense, "strategic" refers to the relative

SCHEDULE OF DEMAND BY THE CONVENTIONAL AND ALTERNATIVE ENERGY TECHNOLOGIES AS A PERCENT OF TOTAL U.S. DEMAND (1976 - 2000) (note a)

	Percent of U.S. demand					
	Conventional		Alternative		Total	
Mineral	High	Low	High	Low	High	Low
Aluminum ores	5	5	10	6	15	11
Antimony	12	12	22	14	34*	26*
Asbestos	8	8	14	11	22	19
Barite	5	5	5	3	10	8
Chromium	19	20	30	22	49*	42*
Cobalt	b/	b/	b/	b/	b/	b/
Columbium	13	15	30	15	43*	30*
Copper	4	4	5	3	9	7
Feldspar	4	4	11	6	15	10
Fluorspar	8	8	8	5	16	13
Gold	7	8	22	10	29*	18
Gypsum	6	8	26	8	32*	16
Iron ore	10	10	8	5	18	15
Lead	5	6	15	5	20	11
Manganese	30	31	25	17	55*	48*
Mercury	4	4	11	5	15	9
Molybdenum	3	2	2	1	5	3
Nickel	10	10	16	8	26*	18
Platinum Group	2	2	7	3	9	5
Silver	5	5	14	6	19	11
Sulfur	3	3	5	2	8	5
Tantalum	23	32	52	31	75*	63*
Titanium	4	4	10	6	14	10
Tungsten	5	5	6	4	11	9
Vanadium	9	9	15	12	24	21
Zinc	4	4	9	4	13	8
Cumulative Average	8	9	15	8	23	17

a/By GAO definition, demand by the alternative synfuel, nuclear, and solar and other renewable technologies was added to Bureau of Mines total projected demand. Since demand by these alternative technologies varied in each of the four energy scenarios, the highest and lowest total demands were used for analytical purposes.

b/Not available.

SCHEDULE OF DEMAND FOR NONFUEL MINERALS

BY ENERGY TECHNOLOGY GROUP UNDER THE

NEP-2 HIGH SCENARIO (1976 - 2000)

Mineral	Technology group (%) Coal	Oil	Gas	Solar	Nuclear	Synfuels	Electric Power Transmission (%)	Energy Trans-portation (%)	Total (%)
Aluminum ores	10	11	4	42*	11	6	10	6	100
Antimony	6	16	7	49	6	3	8	5	100
Asbestos	13	9	4	39	18	5	7	5	100
Barite	2	29	16	44	3	3	1	2	100
Chromium	6	19	9	46*	6	5	3	6	100
Cobalt	a/	a/	a/	a/	a/	a/	a/	a/	a/
Columbium	9	16	8	40*	9	4	6	8	100
Copper	11	11	5	27	12	5	23	6	100
Feldspar	1	16	8	65	2	6	1	1	100
Fluorspar	10	22	11	29	9	5	4	10	100
Gold	8	13	6	46*	9	4	8	6	100
Gypsum	1	10	6	78	2	1	1	1	100
Iron ore	11	24	13	21	10	5	4	12	100
Lead	9	15	7	38	10	5	8	8	100
Manganese	11	24	12	23*	10	5	4	11	100
Mercury	7	16	7	45	7	3	9	6	100
Molybdenum	11	23	12	23	10	6	4	11	100
Nickel	10	19	9	33*	10	5	5	9	100
Platinum Group	8	13	6	46*	9	4	7	7	100
Silver	8	13	6	46	9	4	8	6	100
Sulfur	7	16	7	47	7	3	8	5	100
Tantalum	9	16	8	40*	9	4	6	8	100
Titanium	6	13	6	53	6	3	7	6	100
Tungsten	11	19	9	24	12	12	4	9	100
Vanadium	26	10	3	23	22	12	1	3	100
Zinc	11	13	6	36	11	5	11	7	100
Cumulative Average	9	16	8	40	9	5	6	7	100

a/Not available.

ENCLOSURE I

SCHEDULE OF DEMAND FOR NONFUEL MINERALS

BY ENERGY TECHNOLOGY GROUP UNDER THE

NEP-2 LOW SCENARIO (1976 - 2000)

Mineral	Technology group (%) Coal	Oil	Gas	Solar	Nuclear	Synfuels	Electric Power Transmission (%)	Energy Transportation (%)	Total (%)
Aluminum ores	9	14	5	38*	12	5	10	7	100
Antimony	6	19	8	44	7	2	8	6	100
Asbestos	12	12	5	34	20	4	7	6	100
Barite	2	32	18	40	3	2	1	2	100
Chromium	6	22	11	41*	7	4	3	6	100
Cobalt	a/	a/	a/	a/	a/	a/	a/	a/	a/
Columbium	8	18	9	36*	10	4	6	9	100
Copper	10	13	5	25	13	4	23	7	100
Feldspar	1	20	10	61	2	4	1	1	100
Fluorspar	9	24	13	25	10	4	4	11	100
Gold	8	15	7	43*	9	3	8	7	100
Gypsum	1	12	7	75	2	1	1	1	100
Iron ore	10	28	15	18	10	4	3	12	100
Lead	9	17	8	35	10	4	8	9	100
Manganese	10	27*	13	20	11	4	4	11	100
Mercury	6	18	8	43	7	3	8	7	100
Molybdenum	10	25	13	21	11	5	4	11	100
Nickel	9	21	11	30*	10	4	5	10	100
Platinum Group	8	15	7	43*	9	3	7	8	100
Silver	8	15	7	43	9	3	8	7	100
Sulfur	6	18	8	45	7	2	8	6	100
Tantalum	9	18	9	35*	10	4	6	9	100
Titanium	6	15	7	50	6	2	7	7	100
Tungsten	10	21	11	21	13	10	4	10	100
Vanadium	23	13	4	21	24	10	1	4	100
Zinc	10	16	7	31	12	4	11	9	100
Cumulative Average	8	19	9	37	10	4	6	7	100

a/Not available.

SCHEDULE OF DEMAND FOR NONFUEL MINERALS

BY ENERGY TECHNOLOGY GROUP UNDER THE

TASE 6 SCENARIO (1976 - 2000)

Mineral	Technology group (%) Coal	Oil	Gas	Solar	Nuclear	Synfuels	Electric Power Transmission (%)	Energy Transportation (%)	Total (%)
Aluminum ores	12	13	5	29*	13	9	13	6	100
Antimony	8	22	8	36	7	4	10	5	100
Asbestos	16	12	4	24	21	8	9	6	100
Barite	3	39	20	25	4	5	2	2	100
Chromium	8	25	11	29*	8	9	4	6	100
Cobalt	a/	a/	a/	a/	a/	a/	a/	a/	a/
Columbium	10	16	7	38*	9	6	7	7	100
Copper	12	11	5	20	13	7	26	6	100
Feldspar	2	25	12	44	3	12	1	1	100
Fluorspar	12	25	12	19	10	7	5	10	100
Gold	9	13	6	45*	8	5	8	6	100
Gypsum	3	28	14	43	5	3	2	2	100
Iron ore	13	26	13	14	11	8	4	11	100
Lead	10	16	7	35	10	6	9	7	100
Manganese	13	26*	12	16	11	7	5	10	100
Mercury	8	19	7	38	8	4	10	6	100
Molybdenum	13	25	12	16	11	8	5	10	100
Nickel	11	20	9	30*	10	6	6	8	100
Platinum Group	9	13	6	46*	8	5	7	6	100
Silver	9	13	6	43	9	5	9	6	100
Sulfur	9	21	8	32	8	5	11	6	100
Tantalum	10	17	8	36*	9	6	7	7	100
Titanium	8	17	7	41	7	4	9	7	100
Tungsten	12	20	9	16	13	17	5	8	100
Vanadium	29	11	3	14	23	17	1	2	100
Zinc	12	14	6	29	12	7	13	7	100
Cumulative Average	10	20	9	30	10	7	8	6	100

a/Not available.

SCHEDULE OF DEMAND FOR NONFUEL MINERALS

BY ENERGY TECHNOLOGY GROUP UNDER THE

TASE 14 SCENARIO (1976 - 2000)

Mineral	Technology group (%) Coal	Oil	Gas	Solar	Nuclear	Synfuels	Electric Power Transmission (%)	Energy Trans-portation (%)	Total (%)
Aluminum ores	7	10	4	52*	7	7	9	4	100
Antimony	5	15	6	57	4	3	7	3	100
Asbestos	11	10	4	43	14	7	7	4	100
Barite	2	29	14	47	2	4	1	1	100
Chromium	5	19	8	50*	4	7	3	4	100
Cobalt	a/	a/	a/	a/	a/	a/	a/	a/	a/
Columbium	5	11	5	62*	5	4	4	4	100
Copper	8	9	4	43	7	5	20	4	100
Feldspar	1	16	7	64	2	8	1	1	100
Fluorspar	8	21	10	38	6	6	4	7	100
Gold	5	9	4	67*	4	3	5	3	100
Gypsum	1	13	6	75	2	1	1	1	100
Iron ore	9	24	11	30	7	7	3	9	100
Lead	5	9	4	65	4	4	5	4	100
Manganese	9	23	10	33*	7	6	4	8	100
Mercury	4	11	4	66	3	3	6	3	100
Molybdenum	9	22	10	33	7	7	4	8	100
Nickel	7	15	7	52*	5	5	4	5	100
Platinum Group	5	9	4	67*	4	3	5	3	100
Silver	5	8	4	68	4	3	5	3	100
Sulfur	5	15	6	56	4	3	7	4	100
Tantalum	6	11	5	61*	5	4	4	4	100
Titanium	4	11	4	64	4	3	6	4	100
Tungsten	8	18	8	34	7	15	4	6	100
Vanadium	22	10	3	28	17	17	1	2	100
Zinc	6	9	4	60	5	4	8	4	100
Cumulative Average	6	14	6	53	6	6	5	4	100

a/Not available.

SCHEDULE OF HIGHEST ENERGY-RELATED AND TOTAL U.S. DEMAND AS A PERCENT OF U.S. AND WORLD RESERVES AND RESOURCES AND HIGHEST WORLD DEMAND AS A PERCENT OF WORLD RESERVES AND RESOURCES (1976 - 2000) (note a)

Mineral	Highest energy-related demand				Highest total U.S. demand				Highest total world demand	
	% of reserves		% of resources		% of reserves		% of resources		% of reserves	% of resources
	US	World	US	World	US	World	US	World	World	World
Aluminum ores	381*	b/	51	b/	2487*	4	332*	2	14	6
Antimony	244*	6	209*	5	733*	17	628*	16	49	46
Asbestos	99	3	40	b/	452*	13	181	7	137	79
Barite	27	7	8	b/	265*	68	85	4	167	10
Chromium	c/*	1	502*	b/	c/*	2	1028*	b/	11	1
Cobalt	d/*	d/	d/	d/	c/*	12	37	5	32	14
Columbium	c/*	2	22	b/	c/*	5	52	1	14	3
Copper	6	1	2	b/	67	12	16	3	60	13
Feldspar	2	b/	b/	b/	14	b/	3	b/	d/	d/
Fluorspar	49	2	4	b/	297*	12	25	6	47	22
Gold	87	4	16	4	300*	14	56	13	147	132
Gypsum	42	12	b/	b/	130	38	b/	b/	111	d/
Iron ore	4	b/	b/	b/	23	2	4	b/	10	3
Lead	12	4	b/	b/	61	19	b/	b/	81	b/
Manganese	c/*	2	41	b/	c/*	4	75	2	25	12
Mercury	57	4	25	1	378*	29	165	8	118	32
Molybdenum	1	b/	b/	b/	24	13	14	11	44	37
Nickel	594*	3	14	b/	2345*	14	55	4	51	14
Platinum Group	517*	b/	2	b/	5629*	5	19	2	16	6
Silver	60	11	16	4	315*	59	83	19	149	49
Sulfur	6	1	3	b/	87	15	46	2	88	13
Tantalum	c/*	49	2354*	13	c/*	65	3125*	17	86	22
Titanium	16	1	3	b/	117	7	20	3	23	9
Tungsten	32	b/	9	b/	297*	14	81	5	58	22
Vanadium	74	b/	8	b/	307*	2	35	1	7	2
Zinc	32	3	7	2	238*	22	55	12	120	66

a/By GAO definition, demand by the alternative synfuel, nuclear, and solar and other renewable technologies was added to Bureau of Mines total projected demand. Since demand by these alternative technologies varied in each of the four energy scenarios, the highest demand was used for analytical purposes.

b/Less than 1 percent.

c/The U.S. has no known reserves.

d/Not available.

availability of a mineral, while "critical" refers to its essentiality for energy-related uses.

Our analysis identified nine energy-critical and strategic minerals based on the following problems:

Mineral	Excessive U.S. import dependence	Potentially unreliable foreign source(s)	Few foreign sources	Inadequate domestic mine capacity	Energy intensified U.S. vulnerability	Energy Essential
Aluminum ores	x		x	x		x
Chromium	x	x	x	x	x	x
Cobalt	x	x	x	x		x
Columbium	x	x	x	x	x	x
Gold	x		x	x	x	x
Manganese	x	x	x	x	x	x
Nickel	x		x	x	x	x
Platinum group	x	x	x	x		x
Tantalum	x	x	x	x	x	x

Strategic equates to U.S. vulnerability, not import reliance

Any analysis of strategic minerals must first appraise present and likely future U.S. import reliance. If low, the United States faces no substantial threat. However, when a large percentage of a mineral originates outside of the United States the uncertainty surrounding future price and availability is increased.

Of the 26 minerals analyzed, the United States is projected to be greater than 50 percent import reliant on 17 to the year 2000. (See p. 22.) This is not to imply, however, that high U.S. import reliance is synonomous with vulnerability or necessarily presents a high risk to the U.S. economy. Other factors, such as the probability of a supply disruption or sharp price increase (e.g. the political and economic stability of the major suppliers) and its expected duration, concentration of mine production in one or several foreign countries, the cost of the potential loss to the U.S. economy or to a national priority such as an energy program, and the availability of alternatives to mitigate any adverse impacts must also be considered.

U.S. vulnerability due to import reliance is often based on the political and economic stability of our major suppliers. Of the 17 minerals for which the United States is projected to be greater than 50 percent import reliant to the year 2000,

SCHEDULE OF U.S. NET IMPORT RELIANCE

AND IMPORT VULNERABILITY FACTORS

Mineral	% U.S. net import reliance '80 (note a)	% U.S. net import reliance '76-00 (note b)	Major U.S. supplier (1976-1979) Commodity	Major U.S. supplier (1976-1979) Country	Major U.S. supplier (1976-1979) %	% of total world mine production by largest foreign supplier(s) Country	% of total world mine production by largest foreign supplier(s) %(1980)
Aluminum ores	94	96*	bauxite	Jamaica	42	Australia*	32
				Guinea	32	Guinea	15
			alumina	Australia	78	Jamaica	13
Antimony	53	95*	metal	China	37	Bolivia	19
			ores	Mexico	35	S. Africa	14
			oxide	S. Africa	46		
Asbestos	76	81*		Canada	96	Canada	26
Barite	38	44		Peru	26	Peru	6
Chromium	91	100*	chromite ore	S. Africa*	40	S. Africa*	35
			ferrochromium	S. Africa	62		
Cobalt	93	72*		Zaire*	42	Zaire*	50
						Zambia	11
Columbium	100	100*		Brazil*	66	Brazil*	79
						Canada	17
Copper	14	20		Chile	27	Chile	14
				Canada	23	Soviet Union	12
						Canada	10
Feldspar	0	5		Sweden	50	W. Germany	13
Fluorspar	84	92*		Mexico	62	Mexico	17
Gold	28	63*		Canada	41	S. Africa*	56
				Soviet Union	27		
Gypsum	38	37		Canada	74	Canada	11
Iron ore	22	25		Canada	54	Soviet Union	42
						Canada	14
						Brazil	10
Lead	0	32	ore	Honduras	34	Australia	12
				Peru	25		
			metal	Mexico	35	Canada	9
				Canada	34		
Manganese	97	99*	ore	Gabon*	44	Soviet Union*	43
			ferromanganese	S. Africa	38	S. Africa	20
Mercury	49	68*		Spain	25	Spain	16
						Algeria	16
Molybdenum	0	0		Canada	92	Canada	12
						Chile	12
Nickel	73	82*		Canada	52	Canada*	40
						New Caledonia	11
Platinum Group	87	99*		S. Africa*	53	S. Africa*	48
						Soviet Union	47
Silver	0	68*		Canada	42	Mexico	15
						Canada	12
						Peru	12
Sulfur	13	1		Canada	55	Canada	13
				Mexico	44		

SCHEDULE OF U.S. NET IMPORT RELIANCE

AND IMPORT VULNERABILITY FACTORS (Continued)

Mineral	% U.S. net import reliance '80 (note a)	% U.S. net import reliance '76-00 (note b)	Major U.S. supplier (1976-1979) Commodity	Major U.S. supplier (1976-1979) Country	Major U.S. supplier (1976-1979) %	% of total world mine production by largest foreign supplier(s) Country	% of total world mine production by largest foreign supplier(s) %(1980)
Tantalum	97	100*		Thailand*	35	Canada*	34
Titanium	c/	65*	ilmenite	Austrailia	56	Australia	26 d/
				Canada	32		
			rutile	Australia	84	Australia	69 d/
			sponge metal	Japan	72		
			dioxide	W. Germany	35		
Tungsten	54	75*		Canada	24	China	26
						Soviet Union	18
Vanadium	15	45		S. Africa	55	S. Africa	31
						Soviet Union	27
Zinc	58	63*	ore	Canada	55	Canada	19
			metal	Canada	45		

a/U.S. net import reliance as a % of apparent consumption. Net import reliance equals imports less exports plus adjustments for Government and industry stock changes. Apparent consumption equals U.S. primary and secondary production plus net import reliance.

b/Projected U.S. net import reliance equals U.S. primary demand less U.S. production assuming secondary demand equals recycling and 1976 Government and industry stocks would not affect the 25-year average.

c/Withheld.

d/1980 mine production.

Mineral	Australia		World	
Ilmenite	1370		5230	
Rutile	325		472	
	1695	(30%)	5702	(100%)

only six--chromium, cobalt, columbium 1/, manganese, the platinum group metals, and tantalum--are supplied by sources considered by most risk analysts to be politically and/or economically unstable. (See p. 22.)

Another consideration in determining U.S. vulnerability is concentration of mine production. If no single country has a substantial market share of world mine production and if supply is not concentrated in a small group of countries, then concerted restrictions or price increases are unlikely.

Of the 17 minerals for which the United States is projected to be greater than 50 percent import reliant to the year 2000, 9 markets--aluminum ores, chromium, cobalt, columbium, gold, manganese, nickel, the platinum group metals, and tantalum--are controlled by one country (greater than 33 percent) or a few countries (greater than 50 percent). (See p. 22.) These nine markets include the six minerals identified above as being imported from politically and/or economically unstable countries.

Although imports claim a large percentage of the domestic market for the nine minerals, the United States may not be as dependent on imports as the percentages suggest if the projected amount of domestic mine production capacity is nearly equal to total U.S. demand. However, since mineral extractive operations generally require lead times of from 5 to 20 years and are very capital intensive, domestic mining industries may experience great difficulty if demand requires large increases in capacity. Maximum projected total U.S. demand for any 5-year period to the year 2000 and for the entire 25-year period of the energy technology scenarios exceeded 150 percent of projected U.S. mine capacity for all nine minerals indicating that a large percentage of future demand for these minerals will have to be met by imports. (See p. 25.)

In summary, it appears that of the 17 minerals for which the United States is projected to be greater than 50 percent import reliant to the year 2000, the relative availability of 9--aluminum ores, chromium, cobalt, columbium, gold, manganese, nickel, the platinum group metals, and tantalum--is the most uncertain. This uncertainty stems primarily from an undue U.S. vulnerability in these strategic mineral markets to contingencies that might either seriously disrupt supplies or cause sharp increases in price.

1/ Although the official name of this mineral is niobium, the older name, columbium, is still in general use in the mining and metallurgical industries.

SCHEDULE OF MAXIMUM U.S. TOTAL AND ENERGY-RELATED

DEMAND AS A PERCENT OF PROJECTED U.S. MINE CAPACITY

(1976 - 2000) (note a)

Mineral	Total U.S. Demand: For any 5-year period to 2000	Total U.S. Demand: For entire 25-year scenario	Energy-related Demand: For any 5-year period to 2000	Energy-related Demand: For entire 25-year scenario
Aluminum ores	3,300*	1,881*	446*	289*
Antimony	790*	617*	277*	205*
Asbestos	504*	449*	111*	99
Barite	167*	141	21	14
Chromium	b/*	b/*	b/*	b/*
Cobalt	1,823*	542*	c/	c/
Columbium	b/*	b/*	b/*	b/*
Copper	117	111	12	11
Feldspar	104	98	19	15
Fluorspar	1,107*	813*	178*	135*
Gold	274*	257*	96	74
Gypsum	218*	180*	98	58
Iron ore	135	124	25	22
Lead	157*	143	42	30
Manganese	b/*	6,276*	b/*	3,429*
Mercury	b/*	205*	b/*	31
Molybdenum	45	45	2	2
Nickel	1,052*	578*	238*	147*
Platinum Group	10,000*	9,963*	1,503*	916*
Silver	312*	283*	77	54
Sulfur	94	87	10	6
Tantalum	b/*	b/*	b/*	b/*
Titanium	244*	221*	42	31
Tungsten	516*	349*	49	37
Vanadium	128	110	30	26
Zinc	232*	228*	40	30

a/By GAO definition, demand by the alternative synfuel, nuclear, and solar and other renewable technologies was added to Bureau of Mines total projected demand. Since demand by these alternative technologies varied in each of the four energy scenarios, the highest demand was used for analytical purposes.

b/The U.S. has no mine capacity.

c/Not available.

A national energy program may intensify an already recognized undue U.S. vulnerability for certain minerals

Excessive U.S. import reliance coupled with concentration of mine production in one or several foreign countries and/or the political and economic instability of our major suppliers make minerals availability a potential problem. However, if maximum energy-related demand for a strategic mineral is relatively small compared to total U.S. demand, U.S. import reliance and vulnerability to contingencies become issues of general economic concern and not necessarily related to any specific national energy program under consideration. But, if an energy supply system may substantially intensify an already recognized undue U.S. import reliance for certain strategic minerals, then it may have to be considered in any vulnerability assessment. Similarly, a national energy program may become a market driver perhaps bringing about significantly higher prices and/or adversely impacting on other segments of the economy demanding the same mineral.

For the four energy technology scenarios, maximum projected energy-related demand for the 25-year period exceeded 25 percent of total U.S. demand for 6 of the 9 minerals--chromium (49 percent), columbium (43 percent), gold (29 percent), manganese (55 percent), nickel (26 percent), and tantalum (75 percent)--imported from sources considered politically and/or economically unstable and/or for which world mine production is concentrated in one or a few foreign countries. (See p. 15.)

Maximum projected energy-related demand for any 5-year period to the year 2000 and for the entire 25-year period of the energy technology scenarios exceeded projected U.S. mine capacity for seven of the nine minerals indicating that imports may be required to meet energy goals. (See p. 25.) Similarly, maximum energy-related demand for both the 5-year and 25-year periods was equal to or exceeded 10 percent of projected world mine capacity for chromium, columbium, and tantalum. (See p. 27.) This could drive up prices and/or adversely affect other segments of the economy demanding the same mineral.

Thus, it appears that implementation of a national energy program may intensify an already recognized undue U.S. vulnerability for some strategic minerals to contingencies that might either seriously disrupt supplies or cause sharp increases in price.

Strategic minerals are also critical to a national energy program

Strategic minerals for which implementation of a national energy program may intensify an already recognized undue U.S.

SCHEDULE OF MAXIMUM U.S. ENERGY-RELATED DEMAND

AS A PERCENT OF PROJECTED WORLD MINE CAPACITY

(1976 - 2000) (note a)

Mineral	For any 5-year period to 2000	For entire 25-year scenario
Aluminum ores	4	3
Antimony	11*	8
Asbestos	2	2
Barite	5	4
Chromium	12*	10*
Cobalt	b/	b/
Columbium	18*	13*
Copper	2	2
Feldspar	4	3
Fluorspar	4	4
Gold	5	4
Gypsum	19*	11*
Iron ore	3	2
Lead	6	4
Manganese	9	8
Mercury	3	2
Molybdenum	1	2
Nickel	5	5
Platinum Group	3	3
Silver	10*	7
Sulfur	2	2
Tantalum	81*	63*
Titanium	4	3
Tungsten	3	2
Vanadium	5	5
Zinc	3	3

a/By definition, demand by the alternative synfuel, nuclear, and solar and other renewable technologies was added to Bureau of Mines' total projected demand. Since demand by these alternative technologies varied in each of the four energy scenarios, the highest demand was used for analytical purposes.

b/Not available.

import vulnerability are also energy-critical in that they are essential for energy-related uses. These minerals are concentrated primarily within the steel industry and are capable of tolerating high stress and temperature and/or severe corrosive and erosive environments.

A 1974 National Academy of Science report entitled "Materials Technology in the Near-Term Energy Program," identified nine minerals, including aluminum ores, chromium, cobalt, manganese, nickel, and the platinum group metals, as being critical to a national energy program. These minerals were evaluated against such criteria as essentiality to the energy program and the potential adequacy of substitutes. Similarly, the 1976 U.S. Geological Survey study identified both chromium and manganese as essential to the future development and production of energy and pointed out that for some potential energy uses, columbium might also be essential.

Our projections also indicated that strategic minerals may be essential to the development of each group of energy technologies--coal, oil, gas, solar and other renewables, nuclear, and synfuels--with solar and other renewables being the major consumer. (See pp. 16 to 19.) Since solar and other renewable technologies are still speculative to a large degree, potential opportunities for substitution exist. For example, a September 1978 study by the Department of Energy's Pacific Northwest Laboratory of 13 photovoltaic cell designs in 15 system configurations found 7 systems to be astonishingly free of serious probable future mineral constraints.

The opportunity for substitution may be more limited for other energy technologies. For example, researchers at the Lawrence Berkeley Laboratory have concluded that chromium cannot be eliminated from the steel alloys needed to build advanced synthetic fuel plants where temperature and intense chemical attack are a threat to most metals. Research emphasis has shifted to studying chemical attack and compiling data on how conditions can be altered to increase the life of alloys containing less chromium. The researchers also noted that steel parts containing cobalt can function under conditions even more severe than is possible with chromium alone and that energy plants made with these components would last longer and run more efficiently. Similarly, Department of Energy officials informed us that the strategic minerals required by the nuclear technolgies might be considered particularly critical since specifications are so stringent that substitution is virtually precluded.

ALTERNATIVES ARE AVAILABLE TO MITIGATE THE ADVERSE IMPACT OF MOST SUPPLY DISRUPTIONS OR SHARP PRICE INCREASES

Although our analysis found that the relative availability of certain strategic and energy-critical minerals is uncertain, the concensus among most risk assessments we reviewed is that the probability of prolonged periods of physical supply stringency or sharp price increases in any given nonfuel mineral market appears remote and the economic impact of most supply disruptions or price increases appears minimal. (See p. 30.) However, a national energy program may be subject to short-term contingencies in certain mineral markets such as actions by foreign governments or other entities intended to disrupt supplies or raise prices, civil or military conflicts in producing areas, generalized demand surges, and natural disasters. While a national energy program is not subject to the same stringent time frames as are defense-related needs during periods of national emergency, any short- or long-term supply disruption or price increase could become a stumbling block to the smooth implementation of an energy supply system.

It must be noted that the probability of short-term contingencies does not necessarily imply that Federal intervention is warranted. Most of these contingencies fall within the bounds of normal business risks and do not require Federal attention. Further, within each energy program time frame opportunities appear available to mitigate most adverse impacts through incidential, market-related incentives such as

--shifting emphasis among competing energy technologies,

--substituting technological designs that are less mineral intensive or utilize different minerals in both energy and nonenergy applications,

--substituting other minerals in applications where cost and preferred use are the key criteria,

--reducing consumption through conservation,

--expanding domestic and foreign supplies,

--increasing recycling, and

--drawing down industry stocks.

However, the availability of many of these alternatives is uncertain due primarily to the lead time associated with their implementation.

<u>The probability of prolonged periods of physical supply stringency or sharp price increases appears remote</u>

While it is virtually impossible to predict the economic and political motivations of foreign mineral producing countries, most risk assessments we reviewed have found that political, military, and economic ties with the United States and other industrialized consuming countries appear to sub-

RISK ASSESSMENTS REVIEWED BY GAO

DEPARTMENT OF THE INTERIOR:

--Demand and Supply of Nonfuel Minerals and Materials for the United States Energy Industry, 1975-90 - A Preliminary Report. U.S. Geological Survey, Professional Paper 1006-A, B. 1976.

--Developing a Critical Minerals Index: A Pilot Study. Office of Minerals Policy and Research Analysis, July 1979.

DEPARTMENT OF COMMERCE:

--Policy Implications of Producer Country Supply Restrictions: Overview and Summary. Charles River Associates, Report No. 20, December 1976.

ENVIRONMENTAL PROTECTION AGENCY:

--Lead, Copper and Zinc Price Forecasts to 1987. Volumes I and II, Charles River Associates, June 1980.

GENERAL SERVICES ADMINISTRATION:

--Cobalt: An Industry Analysis. Charles River Associates, 1971.

--Tungsten: An Industry Analysis. Charles River Associates, 1971.

NATIONAL SCIENCE FOUNDATION:

--Materials Availability in a Changing World. National Science Foundation, October 1, 1975.

DEPARTMENT OF ENERGY:

--Future U.S. Energy Supply: Constraints by Nonfuel Mineral Resources. H. E. Goeller, Oak Ridge National Laboratory, December 1980.

--Raw Material Requirements for Energy Development Programs. Bechtel Corporation, January, 1978.

--Achieving a Production Goal of 1 Million B/D of Coal Liquids by 1990. TRW Energy Systems Planning Division, March 14, 1980.

--Silicon Materials Outlook Study for 1980-85 Calendar Years. Jet Propulsion Laboratory, California Institute of Technology, November 1, 1979.

--A Methodology for Identifying Material Constraints on Implementation of Solar Technologies. Battelle Pacific Northwest Laboratory, March 1978.

--A Methodology for Assessing Systems Materials Requirements. National Aeronautics and Space Administration, January 1980.

--Materials Availability for Fusion Power Plants. Battelle Pacific Northwest Laboratory, September 1976.

--A Federal Look at the Needs for Energy-Related Materials Research and Development. Committee on Materials (COMAT), Federal Council for Science and Technology, Vol. 2, 1976.

--U.S. Energy Supply Prospects to 2010. Committee on Nuclear and Alternative Energy Systems (CONAES), National Research Council, 1979.

--Study of Materials Implications of Fossil Energy. Oak Ridge National Laboratory, 1980.

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stantially reduce the probability of long-term supply disruptions or sharp price increases. Factors contributing to this low probability include (1) many mineral rich developing nations are dependent on revenues from mineral exports and are thus more concerned with total revenues and maintaining employment levels in the short-term than with maximizing long-term profits, (2) the divergent economic, political, historical, and cultural backgrounds of the mineral exporting nations, (3) the opportunity for entry and expansion by other producers in most mineral markets, inflicting possible significant and permanent damage to dominant producers' income and employment, and (4) most major producing countries already monopolize their mineral markets, having nearly full advantage of their current position with little economic incentive for further restrictions or price increases.

According to these risk assessments, past experience has shown that once a nonfuel mineral cartel is formed, its chance of successfully controlling the market price is low. Most attempts to control nonfuel mineral markets have not been successful because of (1) deterioration of the monopoly position as consumers substitute other minerals or reduce consumption, (2) differences as to price structure and rivalry among producing countries for market shares when demand begins to decline, (3) new suppliers entering the market, and (4) the strength of major importing manufacturing countries such as the United States to withstand the inflationary effect by passing on costs in finished goods.

Lead time is a criterion for determining the vulnerability of a national energy program

While the probability of prolonged periods of physical supply stringency or sharp price increases appears remote, they could occur, and coupled with short-term contingencies, could constrain implementation of a national energy program. Within each energy scenario, alternatives are available to mitigate any adverse impact. However, the lead time associated with their implementation appeared to be a primary criterion in determining their availability and corresponding U.S. vulnerability.

Short-term mitigating measures for many minerals may be limited primarily to industry stock drawdowns and reduced consumption through conservation. For many strategic and critical minerals, however, private industry typically maintains substantial stocks to offset potential contingencies. For example, the Bureau of Mines reports that between 1976 and 1980, private industry maintained from 3 months to 20 months of contingency stocks for the nine energy-critical and strategic minerals identified in our analytical efforts.

Voluntary conservation in the form of reduced consumption for nonessential uses could also help mitigate any supply disruption or sharp price increase in the short-term and provide additional time to implement other alternative mitigating measures. This could occur for many of the energy-critical and strategic minerals including platinum for jewelry and chromium for flatware, sinks, trim, and wheel covers.

Direct mineral substitution in both energy and nonenergy-related uses could enhance conservation efforts and make minerals available for applications for which there is currently no substitute. Many applications for stainless steel including flatware, sinks, trim, and wheel covers could use aluminum, plastics, and other materials with only perhaps some economic and/or aesthetic sacrifice, but at a savings of between 17 and 19 percent of total chromium consumed. In fact, a 1976 National Academy of Sciences study found that this Nation could save up to one third of the chromium used annually with little or no discomfort.

Nickel can be substituted for cobalt in many applications including some energy-related uses, although with a possible loss in performance. Nickel as well as molybdenum can also be used as a substitute for manganese in alloy steels. Other examples of potential substitution include titanium and molecular sieves for platinum in catalytic applications (comprising nearly 50 percent of current domestic consumption); titanium and tantalum for columbium in metal and alloy applications (up to 90 percent of current domestic consumption); aluminum and ceramics for tantalum in electric components, mainly capacitators (up to 66 percent of current domestic consumption); and manganese, aluminum, chromium, molybdenum, and copper for nickel in stainless and alloy steels (up to 95 percent of current domestic consumption). However, substitutability of other minerals for manganese and chromium in alloy steels would require adjustments in specification ranges where cost and preferred use, as opposed to performance, are the key criteria.

Accelerated recycling is another potential mitigating measure with a relatively short lead time. While estimated recycled chromium contained in purchased stainless steel scrap amounted to 9 percent of total U.S. chromium demand in 1980, Bureau of Mines studies have shown that another 14 percent in scrap metal was lost to U.S. industries because the metal was not collected, was downgraded for use in lower quality materials, or was exported. Similarly, in 1980, about 16 percent of platinum group metal sales to industry was refined from scrap, yet according to Bureau officials, over 25 percent of annual domestic consumption could be met through accelerated recycling and reprocessing of spent converter catalysts.

Other alternatives require longer lead times. For example, the entry and expansion of domestic and foreign production capacity during periods of physical supply stringency or sharp price increases could help mitigate any future adverse impact. In the event of a supply disruption from South Africa, substantial alternative supplies of the platinum group metals appear feasible in the midterm. Total reserves at the Stillwater, Montana, complex have been estimated at about 225 million troy ounces or about one-fourth of the world's known reserves and domestic production could start as early as 1983. Further, any supply disruption or sharp price increase by South Africa, the world's leading platinum group metals producing nation, could be met, at least in part, by increased production and price competition by the Soviet Union and Canada.

Foreign countries also appear capable of expanding supplies in other mineral markets if dominant producers disrupt supplies or raise prices. For example, alternative suppliers of cobalt include Canada, Australia, New Caledonia (a French territory near Australia), Finland, Morocco, and the Philippines which together produced about 25 percent of total world mine production in 1980 and have additional capacity expansion planned. Deep seabed nodules in the Pacific Ocean could also be another source of cobalt, manganese, nickel, and other minerals available to both domestic and foreign companies by the end of this decade if certain problems associated with legal ownership and mining rights as well as mining and metallurgical limitations are resolved.

Within each energy program there appeared to be long-term opportunities for reducing energy-related demand for strategic and critical minerals by shifting emphasis among the competing technologies. For example, our projections indicated that solar and other renewables will be major consumers of nonfuel minerals. (See pp. 16 to 19.) In the absence of technological breakthroughs, a shift from solar to nuclear or synfuels could substantially decrease the amount of energy-critical and strategic minerals required.

Substituting technological designs that are less mineral intensive or utilize different minerals also appears viable. The Bechtel Group of Companies, a major energy-related engineering and construction firm, states that considerable design flexibility in the choice of metal alloys used in energy supply and transportation facilities exists. Although a specific engineering design calls for a specific alloy, a small design change can often allow another alloy to be used. Bechtel concludes that if there is reason to do so, many substitutions could be made and the proportion of various minerals used could be quite different. For example, we substituted another technological design having the same life expectancy for the solar heating and cooling of buildings in the TASE 6 and TASE 14 scenarios. The design change reduced the amount of chromium required for solar and other renewable technologies by over 50 percent.

Substituting technological designs for other than energy-related applications could also provide additional future supplies for energy uses. Development of new and improved engine fuels or an oxide catalyst as a substitute for the catalytic converter to control automotive emissions or switching to a stratified charge diesel engine could decrease domestic demand for chromium and platinum by up to 6 percent and 35 percent, respectively.

These and other measures indicate a mulititude of alternatives are available to mitigate the adverse impact of supply disruptions or sharp price increases in most mineral markets, but not all alternatives are available for a specific strategic and critical mineral. For example, the United States currently has no known reserves of chromium, columbium, manganese, or tantalum. Thus, domestic mine production is not feasible without improvements in extraction and mining technology and/or increased market prices. In fact, our analysis indicated that each mineral may have to be analyzed and evaluated on its own merits before comparative analysis can be performed and that generalizations concerning the availability of nonfuel minerals are difficult, if not impossible, to make.