Demand and Supply of Nonfuel Minerals and Materials for the United States Energy Industry, 1975-90—A Preliminary Report

Demand for Nonfuel Minerals and Materials by the United States Energy Industry, 1975–90

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By GUS H. GOUDARZI, LAWRENCE F. ROONEY, and GLENN L. SHAFFER

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PREFACE

The U.S. Government has announced a goal of energy independence within the next few decades. If such a goal is to be reached, major attention must be given to all possible sources of energy. Attention must also be given to the nonfuel raw materials needed to produce this energy—for example, the materials needed to build a drilling platform or a nuclear powerplant. The basic constituents of almost all these materials are derived from minerals.

The U.S. Geological Survey has begun a Minerals for Energy Production (MEP) program to determine if increased energy production to attain energy independence would be constrained by an inadequate supply of minerals necessary to produce that energy. MEP has six major objectives:

1. To identify and project the quantity of basic nonfuel raw material needed by the energy industries 1975—90 to attain energy independence in the United States.
2. To review the domestic reserves and resources of those commodities identified and their geological availability abroad.
3. To evaluate U.S. demand compared to adequacy of domestic resources, alternative sources of supply, materials that might substitute, and other pertinent factors.
4. To determine the most-stressed materials and to recommend research that would lead to new domestic identified resources.
5. To establish a computerized data base for nonfuel minerals needed for energy production.
6. To undertake field investigations of those nonfuel mineral commodities likely to be most stressed by increased energy production.

This report is only a preliminary step in the MEP program to keep abreast of U.S. energy preparedness, whose vectors are rapidly changing in both direction and magnitude. Objectives 5 and 6 of the MEP program, not covered in this report, deserve further mention here.

Establishing a computerized data base is an integral part of the MEP program and will be required as a continuing effort. Through a systematic search of all literature on each particular commodity, data are gathered for every deposit or mineral district and compiled for storage in the Geological Survey's Computerized Resource Information Bank (CRIB) for future reference by researchers.

In addition to augmentation of the CRIB data base and updates of the existing CRIB files on particular commodities under study, a MEP computerized data base has been established. This data base, when complete, will contain all available essential economic information such as annual and cumulative production, tenor of ores, reserves, resources, and production capacities for every known significant deposit of most commodities. The MEP files are structured to be accessible through the Geological Survey's Geologic Retrieval and Synopsis Program (GRASP).

As long as accurate files are kept up to date, fundamental information with many economic applications can be retrieved virtually instantaneously in numerical and (or) graphic forms for each commodity in the data base. These files, which supplement the more general geological files stored in CRIB, will endure beyond the life of MEP to serve future mineral resource projects conducted by the Survey or the Nation.

Perhaps the most vital part of the MEP program is the detailed field investigations of those resources whose demand by the energy industries may be large or whose supply may be short. At least to a rough approximation, this report identifies those commodities and suggests avenues of research. It is of vital interest to the Nation to pursue those avenues and whatever other avenues of research may help attain and maintain the Nation's energy independence.

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the chapters]

METRIC-ENGLISH EQUIVALENTS

Metric unit		English equivalent
Length		
millimetre (mm)	= 0.03937	inch (in)
metre (m)	= 3.28	feet (ft)
kilometre (km)	= .62	mile (mi)
Area		
square metre (m^2)	= 10.76	square feet (ft^2)
square kilometre (km^2)	= .386	square mile (mi^2)
hectare (ha)	= 2.47	acres
Volume		
cubic centimetre (cm^3)	= 0.061	cubic inch (in^3)
litre (l)	= 61.03	cubic inches
cubic metre (m^3)	= 35.31	cubic feet (ft^3)
cubic metre	= .00081	acre-foot (acre-ft)
cubic hectometre (hm^3)	= 810.7	acre-feet
litre	= 2.113	pints (pt)
litre	= 1.06	quarts (qt)
litre	= .26	gallon (gal)
cubic metre	= .00026	million gallons (Mgal or 10^6 gal)
cubic metre	= 6.290	barrels (bbl) (1 bbl=42 gal)
Weight		
gram (g)	= 0.035	ounce, avoirdupois (oz avdp)
gram	= .0022	pound, avoirdupois (lb avdp)
tonne (t)	= 1.1	tons, short (2,000 lb)
tonne	= .98	ton, long (2,240 lb)
Specific combinations		
kilogram per square centimetre (kg/cm^2)	= 0.96	atmosphere (atm)
kilogram per square centimetre	= .98	bar (0.9869 atm)
cubic metre per second (m^3/s)	= 35.3	cubic feet per second (ft^3/s)

Metric unit		English equivalent
Specific combinations—Continued		
litre per second (l/s)	= .0353	cubic foot per second
cubic metre per second per square kilometre [$(m^3/s)/km^2$]	= 91.47	cubic feet per second per square mile [$(ft^3/s)/mi^2$]
metre per day (m/d)	= 3.28	feet per day (hydraulic conductivity) (ft/d)
metre per kilometre (m/km)	= 5.28	feet per mile (ft/mi)
kilometre per hour (km/h)	= .9113	foot per second (ft/s)
metre per second (m/s)	= 3.28	feet per second
metre squared per day (m^2/d)	= 10.764	feet squared per day (ft^2/d) (transmissivity)
cubic metre per second (m^3/s)	= 22.826	million gallons per day (Mgal/d)
cubic metre per minute (m^3/min)	= 264.2	gallons per minute (gal/min)
litre per second (l/s)	= 15.85	gallons per minute
litre per second per metre [(l/s)/m]	= 4.83	gallons per minute per foot [(gal/min)/ft]
kilometre per hour (km/h)	= .62	mile per hour (mi/h)
metre per second (m/s)	= 2.237	miles per hour
gram per cubic centimetre (g/cm^3)	= 62.43	pounds per cubic foot (lb/ft^3)
gram per square centimetre (g/cm^2)	= 2.048	pounds per square foot (lb/ft^2)
gram per square centimetre	= .0142	pound per square inch (lb/in^2)
Temperature		
degree Celsius (°C)	= 1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	= [(1.8×°C)+32]	degrees Fahrenheit

Demand for Nonfuel Minerals and Materials by the United States Energy Industry, 1975-90

By JOHN P. ALBERS, WALTER J. BAWIEC, *and* LAWRENCE F. ROONEY

DEMAND AND SUPPLY OF NONFUEL MINERALS AND MATERIALS FOR THE UNITED STATES ENERGY INDUSTRY, 1975–90– A PRELIMINARY REPORT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1006–A

Minimum amounts of mineral commodities needed by the energy industry are tabulated according to the major types of energy production

CONTENTS

TABLES

DEMAND FOR NONFUEL MINERALS AND MATERIALS BY THE UNITED STATES ENERGY INDUSTRY, 1975-90

By JOHN P. ALBERS, WALTER J. BAWIEC, and LAWRENCE F. ROONEY

ABSTRACT

Large amounts of certain nonfuel mineral raw materials are needed to attain U.S. energy goals 1975–90 as projected by the Federal Energy Administration's Project Independence Blueprint "business-as-usual" scenario. Estimates of nonfuel mineral raw-material requirements for modular units of fossil fuel, geothermal, hydroelectric, nuclear, and solar energy production in this report permit computation of total material requirements for other scenarios.

Minimum estimates of nonfuel mineral raw-material requirements for all energy types 1975–90 indicate that concrete and iron are needed in the largest tonnages, but that substantial quantities of other materials such as aluminum, barite, bentonite, manganese, and nickel must also be available if the United States is to attain energy independence by 1990.

INTRODUCTION

As attention has focused on a goal of energy independence for the United States, the availability of certain nonfuel raw materials needed to produce energy has become of increasing concern. This report, a part of the U.S. Geological Survey's Minerals for Energy Production (MEP) program, seeks to estimate the amount of basic nonfuel materials needed to achieve the objectives outlined in the Project Independence Report (PIR) of the U.S. Federal Energy Administration (1974a). As used here, "basic material" means an element such as aluminum or iron, or a substance such as concrete that is derived from minerals. Other required materials such as wood, rubber, paint, plastics, and fiberglass are not included in the estimates.

In order to limit the study to manageable proportions, only materials for equipment or facilities directly used in the production and transportation of fuel or energy are considered. Equipment includes items such as drilling rigs, mine trucks, tractors, shovels, power generating plants, pipelines, and refineries, but does not include the tools and plants necessary to manufacture the equipment or facilities, except that the amount of tungsten that would be used in cutting tools is estimated.

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Contributing companies, institutes, and trade associations

Air Products & Chemicals Co.
Allis-Chalmers
American Iron and Steel Institute
American Petroleum Institute
Bethlehem Steel Corp.
Bucyrus-Erie Co.
Butler Manufacturing Co.
Caterpillar Tractor Co.
Crane Co.
Dravo Corp.
Dresser Industries, Inc.
Electric Power Research Institute
Edison Electrical Institute
Foster Wheeler Corp.
General Electric Co.
General Motors Corp.
Greenerd Press & Machine Co., Inc.
Hercules Inc.
Ingersoll-Rand
International Association for Drilling Contractors
International Harvester
Joy Manufacturing Co.
Keystone Electric Co., Inc.
Lawrence Berkeley Radiation Laboratory
Leblond
Longyear Co.

Mississippi Marine Towboat Co.
Motor Vehicle Manufacturers Association of the U.S., Inc.
O'Brian Machinery Co.
Ortner Freight Car Co.
Pennsylvania Crusher Corp.
Reed Tool Co.
Rockwell International
Rogers Engineering Co., Inc.
Sprague & Henwood, Inc.
The Refractories Institute
Westinghouse Electric Corp.
Wiley Manufacturing
Winsmith
Zapata Corp.

PROJECTED ENERGY SUPPLY AND DEMAND

No one can predict with confidence the supply and demand of energy in its various forms in the year 1990. Many sources of energy, such as oil and uranium, are hidden in the Earth, and their quantities can only be estimated. Other sources, such as the Sun and oil shale, depend on technical achievements that themselves lie in the future, and complex and variable political and economic pressures can modify both supply and demand. Lead time for most energy production is considerable, 10 years or more, and some of the early projections are out of date for this reason alone. Nonetheless, projections must be made if we are to plan for the future, and many such projections of energy supply and demand have been published. Representative projections are listed in tables 1–3.

TABLE 1.—*Some projections of energy production in the United States, 1985–2000*

Reference	1985	1988	1990	2000
Petroleum (billions of barrels per year)				
U.S. Federal Energy Admin., 1974f, p. 3—				
Business as usual [1]	5.5	6.0	-----	----------
Accelerated development	7.3	8.1	-----	----------
Dupree and Corsentino, 1975, p. 63	5.3	--	-----	5.0
Dupree and West, 1972, p. 10 [2]	4.1	--	-----	3.7
U.S. Federal Energy Admin., 1975, reply to an international agency questionnaire on energy resource and development prospects, unpub report, p. 6 [3].	4.5–5.1	--	5.3	----------
Engineering and mining Journal, 1974, p. 76 [4].	4.3	--	-----	----------
McLean and Davis, 1973, p. 31	5.1	--	-----	3.7 –6.6
Morrison, 1974, p. 51	----------	--	-----	9.0
National Petroleum Council, 1971, p. 14.	4.0	--	-----	----------
Shale oil (millions of barrels per year)				
U.S. Federal Energy Admin., 1974g, p. 8—				
Business as usual	91	--	164	----------
Accelerated development	365	--	584	----------
Dupree and Corsentino, 1975, p. 46	110	--	-----	730
Morrison, 1974, p. 53	----------	--	-----	1,500
National Petroleum Council, 1972, p. 117.	146	--	-----	----------
Natural gas (trillions of standard cubic feet per year)				
U.S. Federal Energy Admin., 1974d, p. VI–9 [5]—				
Business as usual	17.4	18.0	-----	----------
Accelerated demand	19.1	19.5	-----	----------
Dupree and Corsentino, 1975, p. 65.	18.2	--	-----	16.5
Dupree and West, 1972, p. 10. [2]	21.7	--	-----	22.1
Engineering and Mining Journal, 1974, p. 78.	18	--	-----	----------
McLean and Davis, 1973, p. 31	27	--	-----	15 –25
Morrison, 1974, p. 50	----------	--	-----	50
National Petroleum Council, 1971, p. 14.	14.5	--	-----	----------
U.S. Dept. of Interior, 1972, p. 26	31	--	-----	----------

TABLE 1.—*Some projections of energy production in the United States, 1985–2000*—Continued

Reference	1985	1988	1990	2000
Pipeline gas from coal (trillions of standard cubic feet per year)				
U.S. Federal Energy Admin., 1974i, p. 106. [2]	0.06	--	-----	3.0
Dupree and Corsentino, 1975, p. 65	.5	--	-----	4.7
Dupree and West, 1972, p. 31 [6]	2	--	-----	5.5
National Petroleum Council, 1973, p. 6. [2]	2	--	-----	----------
Coal (millions of metric tonnes per year)				
U.S. Federal Energy Admin., 1974b, p. 129—				
Business as usual	998	--	1,179	----------
Accelerated development	1,871	--	2,542	----------
U.S. Federal Energy Admin., 1975, reply to an international agency questionnaire on energy resources and development prospects, unpub. report, p. 1. [7]	892 –1,990	--	2,521	----------
Morrison, 1974, p. 48 and 49	----------	--	-----	1,204
National Petroleum Council, 1971, p. 14.	846	--	-----	----------
Solar energy (10^{15} Btu's per year)				
U.S. Federal Energy Admin., 1974h, p. I–7—				
Business as usual	0.8	--	2.6	10.8
Accelerated development	1.4	--	4.9	38.8
Morrison, 1974, p. 41	small	--	small	small
National Academy of Sciences, 1974, p. 14. [8]	.3	--	-----	----------

[1] Assumes $11 per barrel of oil in constant mid-1973 dollars.
[2] Converted from British thermal units (Btu's).
[3] Includes natural gas converted into oil equivalent.
[4] Its source: the National Petroleum Council.
[5] Nonassociated gas in lower 48 States with a minimum acceptable price of $1 in constant 1973 dollars for the last thousand feet.
[6] Includes about 22 percent derived from oil in 1985 and about 7 percent in 2000 and is described as "demand."
[7] Converted from metric tonnes of oil equivalent production potential.
[8] Brookhaven base case.

TABLE 2.—*Some projections of energy consumption or demand in the United States, 1980–2000*

Reference	1980	1985	1990	2000
Petroleum (billions of barrels per year)				
U.S. Federal Energy Admin., 1974a, p. 30, 34, and 46—				
Business as usual [1]	----	6.6	----	----------
Accelerated development [2]	----	6.5	----	----------
Clark, 1973, p. 27	----	11.3	13.1	----------
Clark, 1973, p. 28 (alternative projection).	----	8.8	9.3	8.4
Darmstadter, 1971, p. 204 [3]	----	-----	----	9.3
Dupree and Corsentino, 1975, p. 32	7.4	8.3	----	9.3
Dupree and West, 1972, p. 7 [3]	----	8.7	----	12.3
Morrison, 1974, p. 51	----	-----	----	7 – 16
Morrison and others, 1968, p. 128	----	-----	8.9	9.6
National Academy of Sciences, 1974, p. 14. [3]	----	7.8	----	----------
National Petroleum Council, 1971, p. 14.	----	9.4	----	----------
Adapted from National Academy of Sciences, 1975b, p. A/3–5. [3]:				
Robert R. Nathan Associates, Inc., 1968.	5.2	-----	----	----------
U.S. Department of Interior, 1968	6.1	-----	----	----------
U.S. Bureau of Mines, 1968	6.1	-----	----	9.8
Texas Eastern Transmission Corp., 1968.	6.8	8.1	----	----------
Chase Manhattan Bank, 1968	6.8	-----	----	----------
Morrison, W. E., 1970	6.3	-----	----	----------
EBASCO Services, Inc., 1970	6.6	7.5	----	----------
National Petroleum Council, 1971	8.0	9.3	----	----------
U.S. Department of Interior, 1971	7.9	-----	----	----------
Schurr, S. H., Homan, P. T., 1971.	6.7	-----	----	----------
Steele, H. B., 1971	7.8	9.2	----	----------
Gambs, G. C., 1971	9.0	-----	----	----------
Heydinger, E. R., 1971	7.9	-----	----	----------
Shell Oil, February 1972	8.6	10.8	----	----------
Shell Oil, March 1973	9.0	10.4	11.7	----------
Chase Manhattan Bank, 1972	----	10.9	----	----------
National Petroleum Council, 1972—				
Percent energy supplied domestically:				
Low growth				
96.5	----	6.6	----	----------
89.5	----	7.1	----	----------

TABLE 2.—*Some projections of energy consumption or demand in the United States, 1980–2000*—Continued

Reference	1980	1985	1990	2000
Petroleum (billions of barrels per year)—Continued				
Adapted from National Academy of Science, 1975b—Continued				
National Petroleum Council—Continued				
Percent energy supplied domestically—Continued				
80.5	----	8.5	----	----------
73.5	----	9.9	----	----------
Intermediate growth				
96.5	----	8.5	----	----------
89.5	----	9.0	----	----------
80.5	----	10.4	----	----------
73.5	----	11.9	----	----------
High growth				
96.5	----	9.5	----	----------
89.5	----	10.4	----	----------
80.5	----	11.6	----	----------
73.5	----	12.2	----	----------
U.S. Department of Interior, 1973	7.2	8.6	----	12.1
Morrison, W. E., 1973—				
Case A	7.0	8.5	10.2	16.5
Case B	6.9	8.1	9.3	12.1
Case C	6.4	7.5	8.6	11.2
Case D	7.4	8.8	10.0	13.0
Natural gas (trillions of cubic feet per year)				
Darmstadter, 1971, p. 204 [3]	----	-----	----	45.5
Dupree and Corsentino, 1975, p. 32 [3]	19.9	19.5	----	19.0
Dupree and West, 1972, p. 10	----	29.4	----	38.1
Engineering and Mining Journal, 1974, p. 78.[4]	----	35.8	----	----------
Morrison, 1974, p. 50	----	-----	----	35–56
National Petroleum Council, 1971, p. 14.	----	21.5	----	----------
U.S. Department of Interior, 1972, p. 12.	----	38.2	----	49.0
Adapted from National Academy of Sciences, 1975b, p. A/8–9 (10^{15} Btu's per year[5]):				
Robert R. Nathan Associates, Inc., 1968.	28.0	-----	----	43.6
U.S. Department of Interior, 1968	25.5	-----	----	----------
U.S. Bureau of Mines, 1968	25.5	-----	----	----------
Texas Eastern Transmission Corp., 1968.	31.9	38.7	----	----------
American Gas Association, 1968	27.7	35.6	----	----------
Chase Manhattan Bank, 1968	24.3	-----	----	----------
American Gas Association, 1969	32.3	40.3	49.7	----------
Stanford Research Institute, 1970	29.9	-----	----	----------
Morrison, W. E., 1970	27.2	-----	35.0	41.7
EBASCO Services, Inc., 1970	30.4	35.0	----	----------
Resources for the Future, Inc., 1971	27.3	-----	35.0	47.0
U.S. Bureau of Mines, 1970	----	-----	----	35.9–57.5
National Petroleum Council, 1971	22.4	22.2	----	----------
Schurr, S. H. and Homan, P. T., 1971.	27.5	-----	----	----------
Steele, H. B., 1971	24.7	24.2	----	----------
Shell Oil, March 1973	24.7	24.8	23.0	----------
National Petroleum Council, 1972—				
Percent energy supplied domestically:				
96.5	26.9	32.8	----	----------
89.5	25.2	28.1	----	----------
80.5	21.1	21.9	----	----------
73.5	17.8	15.5	----	----------
U.S. Department of Interior, 1973	27.0	28.4	----	34.0
Chase Manhattan Bank, 1972	----	27.1	----	----------
Massachusetts Institute of Technology, 1973—				
"Deregulation"	29.9	-----	----	----------
"Cost of service deregulation"	24.2	-----	----	----------
"Regulatory status quo"	27.0	-----	----	----------
Federal Power Commission, 1973—				
Case A	25.4	27.8	32.4	43.0
Case B	24.3	25.7	28.9	33.9
Case C	22.5	23.8	26.7	31.4
Case D	26.2	27.6	31.0	36.5
Coal (millions of metric tonnes per year)[6]				
Clark, 1973, p. 27 [7]	----	576	653	----------
Clark, 1973, p. 28 (alternative projection).	----	653	730	768
Darmstadter, 1971, p. 204 [3]	----	-----	----	950
Dupree and Corsentino, 1975, p. 61	668	837	----	1,415
Dupree and West, 1972, p. 23	----	810	----	1,188
Engineering and Mining Journal, 1974, p. 75—				
Case I	----	1,424	----	----------
Case II/III	----	1,029	----	----------
Case IV	----	911	----	----------
Morrison, 1974, p. 48–49	----	-----	----	951–2,705
Morrison and others, 1968, p. 128	----	-----	622	776
U.S. Department of Interior, 1972, p. 12.	----	771	----	907
Adapted from National Academy of Sciences, 1975b [3]:				
Robert R. Nathan Associates, Inc., 1968.	668	-----	----	987
U.S. Bureau of Mines, 1968	700	-----	----	813

TABLE 2.—*Some projections of energy consumption or demand in the United States, 1980–2000*—Continued

Reference	1980	1985	1990	2000
Coal (millions of metric tonnes per year)[6]—Continued				
Adapted from National Academy of Science, 1975b—Continued				
Texas Eastern Transmission Corp., 1968.	722	838	----	----------
Stanford Research Institute, 1970	562	-----	----	----------
Morrison, W. E., 1970	649	-----	----	----------
EBASCO Services, Inc., 1970	664	747	----	----------
Schurr, S. H., and Homan, P. T., 1971.	649	-----	----	----------
National Petroleum Council, 1971	722	842	----	----------
Schurr, S. H., and Homan, P. T., 1971.	602	-----	----	----------
Steele, H. B., 1971	562	617	----	----------
Shell Oil, February 1972	649	689	----	----------
Shell Oil, March 1973	613	689	845	----------
National Petroleum Council, 1972—				
Percentage energy supplied domestically:				
96.5	660	1,038	----	----------
80.5	555	722	----	----------
73.5	522	628	----	----------
U.S. Department of Interior, 1973	584	780	----	----------
Chase Manhattan Bank, 1972	----	813	----	----------
Federal Power Commission, 1973—				
Case A	602	678	578	845
Case B	606	693	795	878
Case C	559	642	736	813
Case D	649	747	856	943

[1] Sum of production and imports at $11 per barrel in mid-1973 dollars.
[2] No imports.
[3] Converted from Btu's.
[4] Its source: The National Petroleum Council.
[5] Approximately equivalent to trillions of standard cubic feet per year.
[6] Projections have been categorized as consumption or demand in the references cited; however, with regard to coal, the terms appear to have been used almost interchangeably.
[7] Converted from barrels of oil.

TABLE 3.—*Some projections of generating capacities of electric powerplants in the United States, 1983–2000*

[In 1,000 megawatts of electrical generating capacity (1,000 MWe)]

Reference	1983	1985	1990	1984–93	2000
Hydroelectric					
U.S. Federal Energy Admin., 1974j, p. 36.	66	--------	---	79	--
Dupree and Corsentino, 1975, p. 36.	--	94	---	--	153
Hittman Associates, Inc., 1972, p. IV–15.	--	--------	69	--	89
U.S. Atomic Energy Comm., 1974a, p. 14.	--	97	115	--	150
U.S. Federal Power Comm., 1971, p. 1–18–29—					
Conventional	--	--------	82	--	--------
Pumped storage	--	--------	70	--	--------
Fossil fuels					
U.S. Federal Energy Admin., 1974a, p. 127—					
Business as usual:					
Coal	--	327	---	--	--------
Oil	--	81	---	--	--------
Gas	--	48	---	--	--------
Combustion turbine	--	162	---	--	--------
Total		618			
Demand Management:					
Coal	--	379	---	--	--------
Oil	--	64	---	--	--------
Gas	--	48	---	--	--------
Combustion turbine	--	171	---	--	--------
Total		662			
Dupree and Corsentino, 1975, p. 36.	--	603	---	--	824
Hittman Associates, Inc., 1972, p. IV–15.	--	--------	569	--	745
U.S. Atomic Energy Comm., 1974a, p. 14.	--	472	570	--	780
U.S. Federal Power Comm., 1971, p. I–18–29.	--	--------	633	--	--------
Nuclear					
U.S. Federal Energy Admin., 1974e, p. 3.1–1 and 3.1–2—					
Business as usual	--	275	500	--	--------
Accelerated development	--	400	730	--	--------
Dupree and Corsentino, 1975, p. 36.	--	200	---	--	900

TABLE 3.—*Some projections of generating capacities of electric powerplants in the United States, 1983–2000*—Continued

Reference	1983	1985	1990	1984–93	2000
Nuclear—Continued					
Engineering and Mining Journal, 1974, p. 80—					
High	--	332	602	--	1500
Most likely	--	280	508	--	1200
Low	--	256	412	--	825
Hittman Associates, Inc., 1972, p. IV–15.	--	--------	343	--	671
Mitre Corporation, 1975, p. 21.	--	95	---	--	--------
U.S. Atomic Energy Comm., 1974a, p. 14.	--	231	475	--	1090
U.S. Atomic Energy Comm., 1974b, p. 6—					
Case A	--	231	410	--	850
Case B	--	260	500	--	1200
Case C	--	275	575	--	1400
Case D	--	250	475	--	1090
U.S. Department of Interior, 1972, p. 15.	--	--------	447	--	903
U.S. Federal Energy Admin., 1975, Reply to an international agency questionnaire on energy resources and development prospects, unpub. report, p. 12.[1]	--	169–242	---	--	--------
U.S. Federal Power Comm., 1971, p. I–18–29.	--	--------	475	--	--------
Geothermal					
U.S. Federal Energy Admin., 1974c, p. V–4.	--	31	101	--	--------
Dupree and Corsentino, 1975, p. 36.	--	3	---	--	10
Electric Power Institute, 1975, oral commun.	--	5	---	--	100
Adapted from U.S. Federal Admin., 1974c, table 9, p. A2–2:					
U.S. Bureau of Mines, 1972.	--	4	---	--	40
U.S. Department of Interior, 1972.	--	19	---	--	75
National Petroleum Council, 1972:					
Case I	--	19	---	--	--------
Case IV	--	3.5	---	--	--------
Geothermal Energy, W. Hickel, 1972.	--	132	---	--	395
Rex and Howell, 1973	--	--------	400	--	--------
Calif. Div. of Oil & Gas, 1972 (in Stanford Research Institute, 1973).	--	--------	---	--	7.5 (in Calif.)
Stanford Research Institute, 1973.	--	11.8	---	--	4.4 (in Calif.)
Futures Group "Normal program," 1974.	--	9–11	---	--	55–200
Futures Group "Crash program," 1974.	--	27–40	---	--	270–800
Solar					
U.S. Federal Energy Admin., 1974h, p. III–A–4—					
Business as usual	--	--------	---	--	40
Accelerated development	--	--------	---	--	80
Dupree and West, 1972, p. 18.	--	--------	---	--	insignificant

[1] Converted from metric tonnes of oil equivalent.

When the Minerals for Energy Production (MEP) program was begun, the most comprehensive study of U.S. energy needs had been summarized in the Project Independence Report (PIR), complemented by a series of task force reports for Project Independence Blueprint (PIB) on various aspects of the problem (U.S. Federal Energy Admin., 1974 a–l). The PIR and PIB reports give low and high scenarios—Business as Usual (BAU) and Accelerated Development—for the energy sources that they consider. In this report, the BAU scenarios are followed; in other words, the estimates of the demand for basic materials needed to produce energy are based on the lower projections of energy production. In a few instances, PIB task force projections are supplemented by published projections from other qualified sources.

The use of these figures is not intended to identify them as the most probable of the published projections. Wherever possible the estimates of basic materials required for the production of energy are made in terms of modular units so that the reader can apply the data to other projections if he wishes.

ESTIMATED BASIC MATERIAL REQUIREMENTS

In this report the estimates of basic material requirements for energy production are tabulated under five major types of energy sources: fossil fuel, geothermal, hydroelectric, nuclear, and solar. Transportation is considered under fossil fuel because, in terms of massive requirements of materials, it applies mainly to coal. The requirements of electric-power transmission and distribution from the various energy sources are treated separately at the end of the report.

Wherever possible the estimates of basic material requirements are made in terms of modular units—such as 1,000 MWe (thousand megawatts of electrical generating capacity) nuclear plant or a 4.5 million-tonnes-per-year coal mine—so that computations can be made more easily for various production mixes or scenarios, like the projections shown in tables 1–3. Thus, for example, the reader need only multiply the number of 1,000 MWe plants in a particular projection (table 3) by the number of tonnes of each material required to build that plant to obtain a rough approximation of the amount of basic materials needed to achieve that projected production. This approach is impractical for the oil and gas and hydroelectric industries; nor was it used for uranium mining because of the extreme difference in the sizes of mines, which range from one- or two-man "gopher hole" operations to large mines that produce millions of tons of ore.

In order to provide some concept of the total amount of materials that may be required by expanded energy production in the United States, estimates of basic materials required by the BAU scenario are summarized for each energy source. The time periods used differ, depending on usage in the PIB reports. Wherever possible, 1975–90 is used. Requirements for oil and gas production, however, are compiled for the years 1977–88, and those for geothermal energy, coal transportation, fossil-fueled turbine and gas generators, and electric-power transmission and distribution are compiled through 1985. These material requirements are summed in table 31 and projected to 1990 in table 1 of Goudarzi, Rooney, and Shaffer (1976), chapter B of this report.

Throughout, tonnage is reported generally in metric units designated as tonnes. Where short tons (0.907 tonnes) are used, they are so designated. Figures are rounded only in the summary tables.

An estimate of the basic materials presently invested annually in U.S. energy production is not attempted in this report. No governmental agency collects data that can be disaggregated to show how much of any one mineral commodity goes to energy industries. Moreover, existing industries vary greatly in size. Collection of data on a modular basis for future energy development, however, is both practical and informative though inexact.

Insofar as possible, the basic information for estimating future material requirements was obtained from PIB task force reports. However, information in the various PIB reports is presented in different ways—for example, in units of different kinds of machines and in weight units of metals or minerals that are contained in a machine or plant. It was necessary in many cases to consult representative manufacturers of various items of machinery and equipment to determine in detail the identity and quantities of basic materials needed. The data supplied by them has been aggregated in the tables and in some cases also supplemented from other sources. For example, because information on the amount of manganese in steel was rarely supplied by industry contributors unless it was in manganese-alloy steels, the average manganese content of carbon steels had to be estimated. Similarly, the amount of tungsten used in tungsten-carbide cutting tools for the manufacture of equipment was known only for a few items of machinery and was prorated to other machinery chiefly according to the weight of the machine.

Many of the minor metals in machinery, such as cadmium, boron, and vanadium, had to be estimated in a similar way from detailed information supplied by one or two manufacturers of a few representative machines. Table 4 gives the percentages of minor materials in mining equipment estimated on the basis of total weight.

All the tables that follow are, therefore, rough approximations, and this report should be considered no more than a general overview of the material requirements. It aspires to encourage others to evaluate more accurately the materials, and therefore the amount of minerals, that will be needed to expand energy production. Accurate and detailed data must exist somewhere for every component required for conventional energy production. When these data become accessible, the information provided here can be corrected or supplemented. Data on energy systems not yet generally adopted must be speculative to a large degree. As time passes, however, plans for those systems will become clearer, and close attention will have to be paid to their requirements for minerals.

TABLE 4.—*Assumed percentages of minor constituent materials in mining equipment, based on total weight*

Minor material	Percentage
Antimony	0.1
Asbestos	.011
Boron	.002
Chromium	.16
Cobalt	.003
Lead	.55
Manganese	[1].8
Molybdenum	.1
Nickel	.08
Niobium	.003
Silver	.001
Vanadium	.003
Zinc	[2].005

[1] Unless otherwise specified.
[2] If the item of equipment has an engine.

ENERGY FROM FOSSIL FUELS

COAL MINING

The annual capacity of coal production during the next 15 years is projected to expand from 621 million tonnes in 1975 to 1,179 million tonnes in 1990 (U.S. Federal Energy Admin., 1974b, p. 131–133). Sixty percent of the projected production in 1990 is expected to be from surface mines and 40 percent from underground mines (U.S. Federal Energy Admin., 1974b, p. 133).

For an estimate of the basic materials that would be required by this expansion, one 4.5 million-tonnes-per-year surface mine (table 5) and one 2.7 million-tonnes-per-year underground mine (table 6) were used as modular units (U.S. Federal Energy Admin., 1974b, p. 159–175). Table 7 gives the basic materials for each modular unit.

To reach the projected production level, 74 additional 4.5 million-tonnes-per-year surface mines and 82 additional 2.7 million-tonnes-per-year underground mines would be needed. Total material requirements are estimated in table 7. The mines are assumed to come on line and stay on line without any replacement. Only equipment that totals significant amounts of materials and for which industry

TABLE 5.—*Estimated basic equipment from one 4.5 million-tonnes-per-year surface coal mine*

[Adapted from U.S. Federal Energy Admin., 1974b, p. 168]

Item	Quantity
Overburden drill (blast hole)	2
Blast hole nickel alloy bits (6¼ in)	30,000
Power shovel (100 yd³)	1
Cable handler	1
Walking drag line (100 yd³)	1
Power shovel, coal (15 yd³)	2
Large bulldozers	6
Heavy roadgrader	1
Truck (coal haulers, 75 ton)	7
Truck (maintenance, lubrication, water, and so forth).	12
Front end loaders (10 to 15 yd³)	2
Crane truck	2
Pickup truck	12
Shop, mechanical with tools and equipment.	1
Drill rig (4,000-ft depth capacity)	1
Unit train loading facility	1
Crusher	1
High voltage cable	16,000 ft
Buildings	36,000 ft²
Explosives	Undetermined

TABLE 6.—*Estimated equipment requirements for one 2.7 million-tonnes-per-year underground coal mine*

[Adapted from U.S. Federal Energy Admin., 1974b, p. 159–160]

Item	Quantity
Continuous miner	16
Loading machine	17
Shuttle car	33
Roof bolter	17
Ratio feeder	17
Auxiliary fan	17
Jeep (mantrip, mechanic, personnel)	31
Rock duster	30
Supply car	70
36-inch rope type conveyor system	36,000 ft
High voltage cable	16,000 ft
Rail (60 lb)	102,000 ft
Fresh water pipe (1½-in diameter)	51,000 ft
Scoop tractor	17
Front end loader (5 yd³)	1
Forklift	1
Bulldozer	1
Pickup truck	4
Drilling rig (4,000 ft)	1
Roof bolts	10,000
Drill steel (3-in. diameter)	1,500 ft
Core barrel	2
Crusher	1
Unit train loading facility	1
Pumps 200 ft³/min	17
Pumps 1,000 ft³/min	17
Buildings	36,000 ft²
Explosives	Undetermined

supplied data was considered. Where industry did not provide information on small amounts of the more exotic materials in equipment, the materials were assumed to be present in the proportions shown in table 4, which are based on avarages of information received from manufacturers of similar equipment.

TABLE 7.—*Estimated basic material requirements for modular unit coal mines and total requirements, 1975–90 (in metric tonnes)*

Commodity	Surface mine, 4.5 million tonnes-per-year	Underground mine, 2.7 million tonnes-per-year	Total for 74 surface mines and 82 underground mines 1975–90
Aluminum	6.4	4.08	[1] 244,618
Antimony	7.3	1.86	693
Asbestos	1.0	.18	88
Boron	.36	.033	30
Cadmium	.7	.064	57
Chromium	18.4	53.2	5,724
Cobalt	.28	.054	25
Concrete	1,265	1,265	194,340
Copper	232.9	90.8	24,681
Iron	9,687	5,209	1,143,976
Lead	4.1	9.5	1,082
Manganese	75.0	44.6	9,207
Molybdenum	7.0	1.86	671
Nickel	28.1	12.9	3,137
Niobium	.28	.054	25
Silver	.09	.017	8
Tin	.034	.28	26
Vanadium	.28	.054	25
Zinc	.68	1.1	140

[1] Includes 243,813 tonnes of aluminum used in 8,345,700 tonnes of explosives in coal mining 1975–90 (U.S. Federal Energy Admin., 1974b, p. 35).

COAL TRANSPORTATION

The four major modes of transportation of coal in 1985 are assumed to be railway, waterway, slurry pipeline, and truck. The largest impact on basic materials requirements will be made by increased waterway and railway transportation.

The waterway projections in table 8 include both the replacement of barges and towboats and the incremental materials investment in barges and towboats according to the Federal Energy Administration (FEA) low scenario for incremental coal flow to census regions. Just to maintain the present coal-flow capacity to 1985, 1,661 barges and 243 towboats must be replaced.

TABLE 8.—*Estimated basic material requirements for transportation of coal via rail* [1] *and water,* [2] *1975–85 (in metric tonnes)*

[Based on Federal Energy Administration low-scenario incremental coal flow to census regions]

Commodity	2,579 barges [3]	378 towboats [4]	unit trains [5]	Total
Aluminum	------	34	2,711	2,745
Chromium	------	3	2,042	2,045
Copper	------	103	29,188	29,291
Iron	696,477	161,629	3,062,892	3,920,999
Lead	------	------	2,008	2,008
Manganese	5,617	1,303	[6] 20,793	27,714
Nickel	------	2	805	807
Silver	------	------	40	40
Tin	------	------	134	134

[1] Adapted from U.S. Federal Energy Admin., (1974k, p. IV–7, 9).
[2] Adapted from U.S. Federal Energy Admin. (1974k, p. V–28).
[3] Includes 1,661 replacement barges.
[4] Includes 243 replacement towboats.
[5] 58,000 hopper cars and 2,950 locomotives.
[6] Assumes 0.6 percent manganese in steel.

The railway projections in table 8 are based on the FEA low scenario for incremental coal flows to census regions using six-axle, 3,000 hp locomotives and H–100 open-hopper rail cars. This scenario calls for an incremental flow of coal by 1985 of 305 million tonnes (U.S. Federal Energy Admin., 1974k, p. IV–1).

Estimates indicate that a given length of track with a prorated number of locomotives and hopper cars requires approximately the same amount and kind of materials as the same length of slurry pipeline (U.S. Federal Energy Admin., 1974k, p. VII–13 to 29). Therefore, any tradeoff between railways and pipelines will not have a significant effect on the basic material requirements. Also, the basic materials required for additional truck capacity will not be significant because, according to PIB, "... there is a very large amount of excess coal truck capacity available to be used if shipments of coal via truck increase (for whatever reason) over the next 10 to 15 years" (U.S. Federal Energy Admin., 1974k, p. VII–40).

SYNTHETIC FUELS FROM COAL

The synthetic fuels that can be derived from coal are: (1) high-Btu pipeline gas for private use; (2) low-Btu utility gas for power production facilities; and (3) liquid fuels, such as high-grade synthetic crude oil. Technologies available to produce each of these synthetic fuels are numerous. Only a few were selected in estimating basic material requirements to represent a cross section of the total industry. These selections are not meant to suggest which methods would be more successful or more efficient.

Table 9 gives estimated basic material requirements for modular unit coal gasification and liquefaction plants of five different types, and estimated total requirements for 30 plants of various types to increase production of synthetic fuels between 1975 and 1990.

These estimates are adapted from the Data Supplement of the PIB "Synthetic Fuels from Coal" (U.S. Federal Energy Admin., 1974i, p. 9–13, 19).

The estimates incorporate a 5 percent learning curve but no economies of scale. The learning curve is included to project a rough estimate of the savings in materials as a result of experience gained. The economies-of-scale factors are not included because only one size of each plant is considered. A more complete explanation of the synthetic fuel model produced by Battelle Institute can be found in the Data Supplement of PIB "Synthetic Fuels From Coal."

OIL AND GAS EXPLORATION AND PRODUCTION

The total amount of steel required by the oil industry 1977–88 (table 10) was determined by the graphical interpretation of data presented on exhibit VI–2 of the PIB task force report on oil (U.S. Federal Energy Admin., 1974f, p. VI–7). The amount of steel in tubular goods was similarly determined by a graphical interpretation of exhibit VI–2, and the difference between total steel and tubular goods steel is assumed to be the amount that goes into rigs and platforms. It was necessary to distinguish between tubular goods steel and rig-and-platform steel in order to compute the amount of manganese (assumed to average 1.3 percent for tubular goods and 0.8 percent for platforms and drill rigs).

The total amount of steel and other materials to be required by the gas industry (table 10) was determined by simply using the ratio of hole footage projected to be drilled for gas to the footage to be drilled for oil, a ratio of approximately 47 to 53. These footage figures were determined from the PIB task force report (U.S. Federal Energy Admin., 1974d, p. III–8) and from a computer printout supplied to us by the Project Independence task force.

TABLE 9.—*Estimated basic material requirements for single coal gasification and liquefaction plants of different types, and total requirements for 30 plants, 1975–90*

[Adapted from U.S. Federal Energy Admin., 1974i, Data Supplement, p. 9–13, 19]

Type of plant	Capacity (million standard cubic feet per day)	Commodity (metric tonnes)			
		Aluminum	Copper	Iron	Manganese
High-Btu pipeline gas, synthane	250	3,811	318	34,989	282
High-Btu pipeline gas, Lurgi process	250	4,537	363	41,049	331
Low-Btu fuel gas, fixed bed, atmospheric pressure	1,568	-----	45	14,943	120
Liquid fuel, gas/oil	[1] 224	-----	----	101,061	815
Liquid fuel, Fischer-Tropsch process	[2] 325	519	----	124,285	1,003
Total for 30 synthetic fuel plants of various types		65,199	5,368	860,398	6,939

[1] And 38,580 barrels per day.
[2] And 19,550 barrels per day.

TABLE 10.—*Assumed equipment and material requirements for oil and gas exploration and production, 1977–88*

	Oil	Gas
Total tons of steel	47,747,000 short tons	42,342,000 short tons
Oil country tubular goods (steel).	17,420,000 short tons	15,448,000 short tons
Rig and platform steel	30,327,000 short tons	26,894,000 short tons
Total cumulative footage to be drilled.	1,403,100,000 ft	1,237,800,000 ft
Rigs and platforms		
Total cumulative number.	45,765	40,584
Nickel per rig or platform.	250 lb	250 lb
Chromium per rig or platform.	500 lb	500 lb
Engines per rig or platform (1,000 hp).	3	3
Copper per 1,000 hp engine.	1,786 lb	1,786 lb
Bits		
Number of bits used	1,403,100	1,237,800
Bit life (average)	1,000 ft	1,000 ft
Bit size (average)	9.25 in	9.25 in
Bit weight (average)	130 lb	130 lb
Nickel per bit (3.5 percent).	4.6 lb	4.6 lb
Tungsten carbide per bit.	16.2 lb	16.2 lb
Tungsten in tungsten carbide (94 percent).	15.2 lb	15.2 lb
Drilling muds		
Barite per foot	19.5 lb	19.5 lb
Bentonite per foot	8.5 lb	8.5 lb
Concrete per 1,000 feet (average).	16.6 short tons	16.6 short tons

The number of drilling bits required (table 10) assumes an average bit life of 1,000 feet. The average amount of barite and bentonite used per foot was calculated from data published by the National Petroleum Council (1974, p. 186–187). Such calculation assumes that the average depth of wells drilled in 1988 will be approximately the same as that of wells drilled in 1973. (In fact, the average depth will probably be greater.)

The estimated basic material requirements for oil and gas exploration and development between 1977 and 1988 are given in table 11. Calculations are based on the data in table 10.

Concrete was calculated by averaging the tonnes of cement per 1,000 feet of hole to be drilled in the various regions covered by the PIB report (U.S. Federal Energy Admin., 1974d, p. V–39), and converting the cement to tonnes of concrete.

TABLE 11.—*Estimated basic material requirements for oil and gas exploration and development, 1977–88 (in metric tonnes)*

Commodity	Oil	Gas	Total
Barite	12,414,111	10,951,606	23,365,717
Bentonite	5,411,279	4,773,777	10,185,056
Chromium [1]	10,382	9,200	19,582
Concrete	21,135,836	18,645,811	39,781,647
Copper	111,256	98,662	209,918
Iron	42,971,743	38,106,829	81,078,572
Manganese [2]	425,663	377,454	803,117
Nickel [3]	8,120	7,190	15,310
Tungsten [4]	9,676	8,537	18,213

[1] Assumes 500 lb chromium per rig.
[2] Assumes average of 1.3 percent manganese for tubular goods and 0.8 percent for platforms and drill rigs.
[3] Matrix of bit contains 3.5 percent nickel in 130-lb bits. Assumes 250 lb of nickel in camshaft of drill rig.
[4] Assumes an average bit is between 8¾- and 9⅝-in diameter, contains 15.2 lbs of tungsten, and weighs 130 lb.

OIL SHALE

In estimating a production in 1990 of 450,000 barrels per day (at $7 per barrel) of oil from oil shale (U.S. Federal Energy Admin., 1974g, p. 8), the use of four basic types of oil shale facilities is assumed: a 100,000 barrels-per-day underground mine, a 100,000 barrels-per-day surface mine, a 50,000 barrels-per-day underground mine, and a 50,000 barrels-per-day in-situ "mine." In the surface and underground mine units, the shale would be mined by room and pillar methods, crushed, and fed into retorts, where the hydrocarbons would be extracted by heat. The in-situ units considered herein would require either the injection of steam or hot water directly into the oil shale or underground conventional or nuclear explosions to release the hydrocarbons, which would then be drawn off by modified oil wells. The unit models for these facilities are listed in table 12.

On the basis of these unit plants, Battelle Institute researchers constructed a computer model of the cumulative basic material requirements of the oil-shale industry through the year 1990. This model

TABLE 12.—*Estimated basic material requirements for unit models of oil-shale mines, and for oil-shale mining, 1975–90* [1]

Type of mine	Underground	Underground	Surface	In situ	Total 1975–90
Capacity (barrels/day)	50,000	100,000	1,000	50,000	450,000 in 1990
Commodity (metric tonnes):					
Aluminum	91	165	165	27	644
Chromium	1,740	3,185	3,234	9,972	14,146
Copper	454	817	817	318	5,114
Iron [2]	61,401	112,424	114,154	351,973	499,306
Manganese	515	944	958	2,955	4,191
Nickel	773	1,416	1,437	4,432	6,287

[1] U.S. Federal Energy Admin. (1974g, p. 134).
[2] Includes 15 percent alloy or stainless steel.

takes into consideration the types of plants constructed, State where located, economies of scale, construction and production schedules, and a "learning curve" that conserves materials as operating experience is acquired. Consequently, the totals for oil-shale mining 1975–90 given in table 12 do not represent a simple addition of materials used in the four-unit model.

FOSSIL-FUELED POWERPLANTS

Fossil-fueled powerplants will account for more than 50 percent of the total electricity generated in the United States at least until 1980 and, in absolute capacity, will remain a major power source beyond the turn of the century (Electrical World, 1974, p. 55). The basic material requirements will be correspondingly large.

Table 13 is based on projections for additional capacities of fossil-fuel-generated electrical energy from the Project Independence Report (U.S. Federal Energy Admin., 1974a, p. 70), which calls for an increased generating capacity by 1985 of 366,000 MWe by coal and 189,000 MWe by combustion turbines and other fossil-fueled units [1]. Data on basic materials for a 900 MWe fossil-fueled, steam-turbine-generator set and a 59 MWe gas-turbine-generator set were supplied by industry. The ratio of transformer to generator capacity was assumed to be 1.1:1. The 900 MWe unit includes a 990 megavolt amperes (MVA) transformer, and the 59 MWe gas turbine unit includes a 65 MVA transformer. As the only data available, these units were used to calculate amounts of materials. To meet the new demands for fossil-fueled energy for 1985, about 406 coal-fired plants of 900 MWe capacity and 166 combined cycle powerplants will be required. These projections are based on a worst-case scenario of large, standalone, conventional fossil-fuel plants with add-on 59 MWe turbine generator sets.

[1] It is noteworthy that these projections are much larger than those in Electrical World (1974, p. 55).

REFINERIES

During the next 15 years—or at least through 1985—oil refineries built in the United States will probably be designed to refine mostly crude oil from Alaska and Saudia Arabia. Some of the refineries already in use will need repair, modernization, and modification to process the crudes from these sources or to meet environmental restrictions, especially in the sulfur content of fuel oils and the lead content of gasoline (U.S. Federal Energy Admin., 1974l, p. III–5).

Each refinery will be designed for particular crudes and markets. No one set of specifications will apply to all. The generalized, "typical" refinery—though it provides the best estimate for all refineries—is the least likely to be built.

In the PIB task force report on facilities two cases are presented, one for a gasoline refinery, and one for a fuel refinery. Case 1 is the Alaska crude oil/gasoline type refinery (200,000 barrels per calendar day), which we have selected as a typical refinery for purposes of estimating the needs of basic materials. Table 14 lists the requirements for one such plant as adapted from Project Independence (U.S.

TABLE 13.—*Estimated basic material requirements for fossil-fueled powerplants, 1975–85 (in metric tonnes)*

	A	B	C	D	E	Total
Number of units	1	406	1	1	166	572
Type of unit	Steam-turbine [1]	Steam-turbine, type A	Gas turbine [2]	Combined cycle,[3] 1 type A, 4 type C	Combined cycle type D	Column B and E
Capacity (MWe)	900	[4] 366,000	59	1,136	[4] 189,000	[4] 555,000
Commodity:						
Abestos	0.34	138	0.022	0.4	66	204
Chromium	21	8,526	3.2	33.8	5,611	14,137
Cobalt	-----	---------	1.9	7.6	1,262	1,262
Concrete	92,265	37,459,590	204.2	93,082	15,451,612	52,911,202
Copper	424	172,144	14.8	483	80,178	252,322
Iron	22,184	9,006,704	218.4	23,057	3,827,462	12,834,166
Magnesia	1.5	609	.096	1.9	315	924
Manganese	179	72,674	1.8	186	30,876	103,550
Mica (scrap)	1.1	447	.07	1.4	232	679
Molybdenum	.9	365	.24	1.9	315	680
Nickel	6.8	2,761	3.7	21.6	3,586	6,347
Silver	-----	---------	.0014	0.0056	.9	.9
Tungsten	-----	---------	.29	1.16	193	193
Vanadium	.26	106	.036	.4	66	172

[1] Including 990 MVA transformer.
[2] Including pad and 65 MVA transformer.
[3] Including pad and 1250 MVA transformer.
[4] U.S. Federal Energy Admin (1974a, p. 70).

TABLE 14.—*Estimated basic material requirements for gasoline refineries, 1977–90 (in metric tonnes)*

Commodity	1 refinery, 200,000 barrels per day [1]	25 refineries, each 200,000 barrels per day [2]
Aluminum	4.5	113
Asbestos [3]	1,677	41,925
Chromium	506	12,650
Concrete	6,974	174,350
Copper	1,116	27,900
Iron	82,846	2,071,150
Manganese	674	16,850
Nickel	329	8,225

[1] Adapted from U.S. Federal Energy Admin. (1974l, p. III–30).
[2] Estimated from projections in U.S. Federal Energy Admin. (1974l, p. VIII–21).
[3] Short fiber for insulation.

Federal Energy Admin., 1974l, p. III–30), and for 25 such plants as estimated from Project Independence data (U.S. Federal Energy Admin., 1974l, p. VIII–21).

DEEP-WATER PORTS

Deep-water ports reduce the transportation costs of imported crude oil by making unloading facilities available to very large crude carriers, and they also reduce the risk of oilspills in coastal waters. Deep-water ports can be developed at existing harbors by dredging channels of sufficient depth to accept large tankers, or by providing unloading facilities in deep waters offshore (U.S. Federal Energy Admin., 1974l, p. V–1).

The deep-water port facilities include berths for tankers, any necessary booster pumping facilities, pipelines from berth to tank farm, and the necessary intermediate tankage at the terminal. They do not include the distribution pipelines and pumping facilities from marine terminal to refineries. In table 15 it is assumed that five deep-water ports will be constructed: three offshore—on the east coast, the gulf coast, and the west coast—and two inshore harbors—on the gulf coast and the west coast.

TERMINAL FOR LIQUID NATURAL GAS

"The typical liquid-natural-gas (LNG) terminal contains facilities to berth an LNG tanker, receive and store LNG, raise the pressure of the LNG to the gas pipeline pressure, vaporize the LNG, compress the boil-off gases, and deliver a daily average of 500 million cubic feet to a gas pipeline at generally not less than 40°F and 1,200 psig [pounds per square inch gauge]" (U.S. Federal Energy Admin., 1974l, p. VI–1). Table 16 gives the estimated basic material requirements for one typical LNG terminal.

Only one LNG terminal, probably to be located at Savannah, Ga., is planned for the United States over the next 10 years or so. It will cover about 170 acres and will not include any offshore area in the Savannah River.

TABLE 16.—*Estimated basic material requirements for one typical liquid natural-gas terminal for a tanker with a cargo capacity of 750,000 barrels*

[Adapted from U.S. Federal Energy Admin., 1974l, p. VI–28]

Commodity	Metric tonnes
Aluminum	145
Chromium	19.6
Concrete	365,208
Copper	72.6
Iron	12,759
Manganese	104
Nickel	8.7

NEW PIPELINES

The PIB task force report on transport of energy materials (U.S. Federal Energy Admin., 1974k, part VI) makes a breakdown of the steel required for crude oil, oil-product, and natural gas pipelines and tanker facilities. For new crude oil the principal new movements are from Prudhoe Bay to the Pacific coast, from Seattle to Chicago, and from Los Angeles to Houston. The task force estimates that the steel requirements will be 5.3 million tonnes (U.S. Federal Energy Admin., 1974k, p. VI–8). Transportation of the Alaskan crude will constitute about 60 percent of the material requirements, and transportation of California crude will constitute most of the remainder.

Steel requirements for new oil-product pipelines are estimated at 1.9 million tonnes of steel, and indications are that, as with natural gas and crude oil, the petroleum products will become progressively

TABLE 15.—*Estimated basic material requirements for five deep-water port facilities (in metric tonnes)*

[Adapted from U.S. Federal Energy Admin., 1974l, p. V–25 to V–40]

Commodities	East coast	Gulf coast		West coast		Total for five plants
	Offshore	Inshore	Offshore	Inshore	Offshore	
Chromium	1,960	1,960	1,960	1,960	1,960	9,800
Concrete	118,694	23,739	317,508	23,739	40,059	523,739
Copper	163	9	318	9	118	617
Iron	93,511	73,821	118,738	73,821	59,418	419,309
Manganese	777	682	980	682	479	3,600
Nickel	871	871	871	871	871	4,356

more expensive as they are transported from the west to the east coast.

Two alternative scenarios for transporting natural gas from the Prudhoe Bay and the southern Alaska areas to the conterminous United States are offered by the PIB transportation task force. One envisions a pipeline from the north slope across Canada to Emerson, Manitoba, and to Portland, Oreg., from which terminals the gas would be delivered to demand regions (U.S. Federal Agency Admin., 1974k, p. VI–12). The other alternative would be the construction of a gas pipeline from Prudhoe Bay to Valdez, where an LNG tanker terminal would be located for transport of the gas in the form of LNG to conterminous U.S. entry ports. The tonnages of steel required for the Canadian pipeline route plus U.S. continental segments and for the Prudhoe Bay-Valdez pipeline plus LNG tanker are estimated to be nearly equal, about 10.5 million tonnes of steel each (U.S. Federal Energy Admin., 1974k, p. VI–14 and VI–15).

The total steel required for pipeline transport of crude oil, oil-product, and natural gas is about 17.7 million tonnes, as shown in table 17.

TOTAL REQUIREMENTS

The total basic material requirements for energy production from fossil fuel for the period 1975–85 are summarized in table 18.

GEOTHERMAL ENERGY

By the year 1985, it has been estimated that geothermal powerplants will reach a generating capacity of 4,500 MWe (Vasil Roberts, 1975, written commun.). Of this total capacity, 50 percent is expected to be produced by flash-steam plants through the development of dry-steam resources, and 50 percent by binary-cycle plants. Two major types of binary-cycle plants, differing basically in type of heat exchanger, are under development. The most popular heat exchanger used with brackish or sea water is made of an alloy of 90 percent copper and 10 percent nickel. Titanium heat exchangers are more resistant to corrosion but more expensive.

The basic materials required for a flash-steam plant and for each type of binary-cycle plant are given in table 19. The modular flash-steam plants are all considered to be one-unit stand alones with a capacity of 100 MWe.

The total basic material requirements for geothermal powerplants are also listed in table 19. The number of flash-steam plants, binary-cycle plants,

TABLE 17.—*Estimated basic material requirements*[1] *for pipeline transportation of oil and gas from Alaska to the United States, and from Western United States to Eastern United States*

[Adapted from U.S. Federal Energy Admin., 1974k, p. VI-6 to VI-11]

Commodity	Metric tonnes
Iron	17,443,150
Manganese[2]	247,700
Niobium[3]	885
Vanadium[4]	3,540

[1] Requirements for pumps and valves not included.
[2] Assumes 1.7 percent manganese in steel.
[3] Assumes 0.005 percent average niobium content in steel.
[4] Assumes 0.02 percent average vanadium content in steel.

TABLE 18.—*Total estimated basic material requirements for energy production from fossil fuels, 1975–85*

Commodity	Metric tonnes[1]
Aluminum	313,000
Antimony	690
Asbestos	42,200
Barite	23,400,000
Bentonite	10,200,000
Boron	30
Cadmium	57
Chromium	78,100
Cobalt	1,290
Concrete	94,000,000
Copper	555,000
Iron	120,000,000
Lead	3,090
Manganese	1,220,000
Magnesia	920
Mica	680
Molybdenum	1,350
Nickel	44,500
Niobium	910
Silver	49
Tin	160
Tungsten	18,400
Vanadium	3,740
Zinc	140

[1] Numbers rounded.

TABLE 19.—*Estimated basic material requirements for unit geothermal plants, and total requirements for 4,500 MWe of geothermal energy in 1985 (in metric tonnes)*

	A Flash-steam plant, 100 MWe capacity[1]	B Binary-cycle plant, 50 MWe capacity, with copper-nickel heat exchangers[2]	C Binary-cycle plant, 50 MWe capacity, with titanium heat exchangers	D Total for 4500 MWe[3] (22 type A) (23 type B) (23 type C)
Aluminum	-----	2,095	2,095	96,000
Asbestos	787	393	393	35,400
Chromium	60	----	----	1,320
Concrete	15,063	7,532	7,532	678,000
Copper	86	365	9	10,500
Iron	[4]2,779	3,637	3,637	228,400
Magnesia	4,623	2,312	2,312	208,000
Manganese[5]	6	36	36	1,790
Nickel	27	41	2	1,580
Titanium	-----	----	200	4,600

[1] Assumes well requirement of 10 wells per 100 MWe, spaced at one well per 10 acres. Each well 4,000 feet deep, plus total of 4,000 feet of surface piping.
[2] 90 percent copper, 10 percent nickel.
[3] Numbers rounded.
[4] Includes 247 tonnes of iron in chromium-nickel stainless steel, 1,245 tonnes of plant carbon steel, and 1,286 tonnes of pipe and casing.
[5] Assumes 0.20 percent manganese in plant carbon steel and 0.28 percent manganese in underground piping and casing.

copper-nickel or titanium heat exchangers is not meant to project a probable mix of geothermal power plants in 1985, but simply to present a possible scenario utilizing all the types of plants that may be available.

HYDROELECTRIC ENERGY

According to the PIB task force report on facilities (U.S. Federal Energy Admin., 1974l, p. VIII–39), the total new planned capacity for conventional and pumped storage hydroelectric power in the contiguous United States 1975–90 is about 53,686 MWe.[2] This figure was determined by subtracting the 1974 capacity from the estimated 1990 BAU capacity.

The estimated basic material requirements for conventional and pumped storage hydroelectric power to 1990 (table 20) were adapted from the

TABLE 20.—*Estimated basic material requirements for additional hydroelectric generating capacity of about 53,500 MWe, 1975–90*

[Adapted mainly from U.S. Federal Energy Admin., 1974l, p. VIII–39 through 66]

Commodity	Metric tonnes[1]
Aluminum	807
Chromium	1,390
Concrete	114,000,000
Copper	17,200
Iron	1,990,000
Manganese	16,000
Mica	4,470
Nickel	617

[1] Numbers rounded.

PIB report on facilities (U.S. Federal Energy Admin., 1974l, p. VIII–51 to VIII–66). The materials requirements for the various regions and years were summed for a grand total. Chromium and nickel were added as constituents of stainless steel in percentages of 18 and 8, respectively.

Because of the variability in both the size and composition (concrete or earth-filled dam) of future hydroelectric power facilities, we were not able to construct a modular unit that would be representative of any one size or type.

NUCLEAR ENERGY

Greatly increased nuclear power production and coal production are expected to fill the gap resulting from decreased reliance on oil and gas during the next few decades. As of June 30, 1975, 55 nuclear plants were operable in the United States, 76 were being built, and 112 more were planned (Mining Record, 1975, p. 1). The total capacity of the operable plants was about 37,000 MWe, and the total capacity of all 243 plants—operable, under construction, or planned—was about 243,000 MWe. The Project Independence BAU projection of nuclear generating capacity in 1990 is 500,000 MWe. Although the industry is experiencing considerable delays, largely for environmental reasons, a rapid growth of the industry during the next few decades seems likely.

Demands for materials by the nuclear industry can be categorized under mining and milling, enrichment, and power generation.

URANIUM MINING AND MILLING

Uranium is the fuel used in largest quantities by the nuclear industry, although thorium is also used. Both elements occur generally in low-grade ores that may be mined by open-pit or underground methods. The ores required considerable beneficiation. Most of the uranium being produced in the United States today is from sedimentary rocks in the West. The uranium compound used to calculate reserves and production in U_3O_8.

Activity of the uranium mining industry in the United States will probably increase significantly until approximately 1988. This increase will be a direct result of nuclear energy growth and the expanded demand for U_3O_8 to fuel the additional nuclear reactors. The cumulative demand for U_3O_8 on which our basic material requirements are based is 710,000 tonnes by 1990 (U.S. Federal Energy Admin., 1974e, p. 3.12–9).

Because of the extreme variation in uranium mine sizes, the modular mine approach was not attempted. The basic materials required to fulfill the U_3O_8 demand were estimated from the uranium mining equipment requirements listed in table 21. These equipment projections are very similar to the projections of the PIB task force on nuclear energy (U.S. Federal Energy Admin., 1974e, p. VII–27 to VII–32) except for small items with an insignificant material content. In some cases, industry data did not include small amounts of the more exotic materials in various items of equipment. These were estimated according to the percentages in table 4.

The total basic materials impact of the uranium mining industry to 1990 is indicated in table 22. These figures are directly proportional to the numbers of items for each piece of equipment, which makes them only as good as the equipment estimates.

[2] The PIB task force on water requirements (U.S. Federal Energy Admin., 1974j, p. 36) estimates a figure for conventional new capacity of about 23,700 MWe by 1993.

TABLE 21.— *Estimated equipment requirements for mining of uranium ore, 1975–90*

[Adapted from U.S. Federal Energy Admin., 1974e, p. VII–27 to VII–32]

Item	Quantity
Roof bolts	10,710,000
Drill steel	8,450,000 ft
Bits	2,600,000
Pumps (200 gal/min)	9,730
Pumps (1,000 gal/min)	2,920
Hoists (100 hp)	458
Hoists (1,000 hp)	182
Slusher	3,250
Slusher cable	287,000,000 ft
3-ton rail cars	5,700
Rail (60 lb)	1,800,000
Loaders	1,560
Cars (5-ton diesel)	7,800
Jackhammers	39,000
Water pipe	9,900,000 ft
Ventilation line	9,900,000 ft
Compressor (250 ft^3/min)	3,640
Compressor (1,000 ft^3/min)	1,560
Road grader	1,140
Maintenance truck	1,820
75-ton truck	2,730
20-ton truck	5,460
Fork lift	380
30-ton trucks	9,100
Pickup trucks	5,500
Small drill rig	3,250
Heavy bulldozer	3,740
Scrapers (30 yd)	1,240
Backhoes	2,730
Power shovel (15 yd^3)	260
Generator (500 Kw)	500
Generator (1,500 Kw)	240
Mechanical shop	470
Drill rig (blast hole)	2,000
Truck for small drill rig	3,250
Quonset type huts	1,630
Primary crusher	85
Secondary crusher	170
Grinders (ball or rod mill)	85
Steel autoclaves (10×10 ft cyl)	90
Titanium clad (lead lined) autoclaves	170
Gear reducers	1,430
Drill mobiles	400
Continuous miners	480
Wireline hoist and ⅜-in cable	3,250
Trammer	1,140
Powerline (heavy duty)	9,900,000 ft
Concrete (for buildings)	1,630
Explosives:	
Dynamite	163,339 tonnes
Nitrate	37,205 tonnes

URANIUM-ENRICHMENT FACILITIES

Uranium-enrichment facilities must be developed at a rate equivalent to the development of U.S. nuclear-generation capacity because they will supply fuel for light-water reactors (LWR's) until about 1988.

The grade of uranium ore is now about 0.22 percent U_3O_8 but is expected to fall to 0.075 percent by the late 1980's. Of uranium's two principal isotopes, U–235 and U–238, it is the U–235, because of its fissionable characteristics, that is used to fuel light-water reactors. U–235 is only 0.7 percent of U_3O_8 by weight. To concentrate the U–235 to the level at which it can be used as a fuel (2 to 4 percent), it is first converted to uranium hexafluoride (UF_6), which is then concentrated to the necessary 2 to 4 percent U–235.

TABLE 22.—*Estimated basic material requirements for mining of uranium ore, 1975–90*

Commodity	Metric tonnes
Aluminum	7,718
Antimony	374
Asbestos	77
Boron	11
Cadmium	22
Chromium	6,754
Cobalt	14
Concrete	187,851
Copper	16,136
Iron	1,389,248
Lead	4,641
Manganese	14,492
Molybdenum	426
Nickel	6,904
Niobium	14
Silver	8
Tin	189
Titanium	122
Vanadium	14
Zinc [1]	2,414

[1] Assumes 1.8 oz of zinc per square foot of galvanized pipe surface (U.S. Steel Corp., 1970, p. 25).

Of the two types of uranium-enrichment plants expected to come into production, only gaseous-diffusion plants are considered in this report because of the lack of available information on gas-centrifuge plants. The estimate of basic material requirements for uranium-enrichment facilities (table 23) is based on a unit gaseous diffusion plant with a capacity of 8,750 tonnes per year. Although the materials estimate is for an add-on plant, the requirements should be similar for a stand-alone plant of the same capacity. Following the BAU scenario, the rate at which additional plants will come on-line is estimated to be one every 18 months starting in 1983. The total basic material requirements to 1990 are therefore estimated for five gaseous-diffusion plants (table 23).

TABLE 23.—*Estimated basic material requirements for gaseous diffusion plants, to 1990*

Commodity	1 plant 8,750 tonnes per year [1]	5 plants [2] each 8,750 tonnes per year
Aluminum	5,726	28,630
Concrete	564,887	2,824,435
Copper	4,900	24,500
Iron	145,710	728,550
Manganese [3]	661	3,305
Nickel	4,791	23,955

[1] Adapted from Oak Ridge National Laboratory (written commun., April 23, 1975).
[2] PIB projects that, beginning in 1983, one new plant will be brought into production every 18 months (U.S. Federal Energy Admin., 1974e, p. 3.13–2).
[3] Assume 0.2 percent manganese in carbon structural steel and 0.6 percent manganese in other steel.

NUCLEAR POWERPLANTS

Most of the nuclear powerplants projected to 1990 will be LWR's, in a ratio of 70 percent pressurized-water reactors and 30 percent boiling-water reactors (U.S. Federal Energy Admin., 1974e, p. III–6). Only about 9 percent of the nuclear plants in 1990 are expected to be high-temperature-gas reactors, which are not included in this study; their exclusion should not introduce much error into the projection of basic material requirements. Although PIB states that only 50 percent of the additional nuclear reactor plants will be stand-alones, in this report all plants are assumed to be stand-alones and not additions to pre-existing facilities because we were unable to obtain data on cycling in partial plants. The basic material requirements for LWR's are given in table 24.

The first commercial fast-breeder reactor powerplant in the United States is expected to come on-line by 1988. The basic material requirements for this type of reactor are given in table 25. Within the time-frame covered by this report, the total basic material requirements for the fast-breeder type of reactor should not be significant.

TOTAL REQUIREMENTS TO 1990

The total estimated basic material requirements of the nuclear industry to 1990 are summarized in table 26. This table includes the mining equipment, 5 uranium-enrichment facilities, 500 light-water reactors, and 1 liquid metal fast-breeder reactor.

Fusion reactors are not expected to become sources of commercial power until 2000, beyond the time-frame of this report. They are therefore not included in this study.

TABLE 25.—*Estimated basic material requirements for one liquid metal, fast-breeder reactor plant with a capacity of 1,000 MWe.*

[Adapted from U.S. Atomic Energy Comm., 1974c, p. 10–8]

Commodity	Metric tonnes [1]
Aluminum	18
Asbestos [2]	138
Chromium	410
Concrete	184,775
Copper	730
Iron	35,000
Lead	50
Magnesia	780
Manganese	410
Molybdenum	160
Nickel	480
Silver	1
Tin	2
Zinc	2

[1] Rounded to nearest tonne.
[2] Short fiber for insulation.

SOLAR ENERGY

Solar energy is the world's largest potential source of energy and the only renewable source that is discussed in this report. Until now only a small percentage of the country's total research budget has

TABLE 24.—*Estimated basic material requirements for unit light-water reactor (LWR) plants and for reactor plants with a total capacity of 500,000 MWe in 1990 (in metric tonnes)*

Commodity	Modular units of 1,000 MWe capacity: Boiling-water reactor (BWR) plant [3]	Modular units of 1,000 MWe capacity: Pressurized-water reactor (PWR) plant [4]	Replaceable core components for plants of 1,000 MWe capacity [1,2]: 1 PWR for 15 years [5]	Replaceable core components for plants of 1,000 MWe capacity [1,2]: 500 LWR's for 15 years	Total for 150 BWR's and 350 PWR's, including replaceable core components for 15 years
Aluminum	54	18	0.00375	0.8	14,401
Asbestos [6]	------	138	---------	---------	48,300
Cadmium	------	------	.225	50.6	51
Chromium	110	415	6.75	1,518.8	163,269
Concrete	190,175	166,349	---------	---------	86,748,400
Copper	907	726	.00075	.17	390,150
Indium	------	------	.6375	143.4	144
Iron	25,767	34,195	24.375	5,484.4	15,838,784
Lead	------	47	---------	---------	16,450
Magnesia	------	783	---------	---------	274,050
Manganese	209	[7] 467	.675	151.9	194,952
Molybdenum	128	164	.02625	5.9	76,606
Nickel	49	484	3.75	843.8	177,594
Niobium	------	------	.0375	8.4	8
Silver	------	1	3.375	759.4	1,040
Tin	------	2	1.875	421.9	1,122
Titanium	------	------	.0075	1.7	2
Zinc	------	2	---------	---------	700
Zirconium	------	------	122.25	27,506	27,506

[1] Nuclear power cycle has following parameters: plant factor, 85 percent; fuel enrichment, 3.2 percent; fuel burnup, 33,000 MWd/tonne uranium; and tails assay, 0.200 percent.
[2] Adapted from Bryan (1975, written commun.).
[3] Class BWR-6 plant with Mark III containment.
[4] Adapted from Bryan and Dudley (1974, p. 5).
[5] It is assumed that boiling water and pressurized water reactors require essentially the same amount and kind of core materials.
[6] Short fiber for insulation.
[7] Assumes 1.3 percent manganese in steel.

TABLE 26.—*Total estimated basic material requirements for nuclear energy, 1975–90* [1]

Commodity	Metric tonnes [2]
Aluminum	51,000
Antimony	375
Asbestos [3]	48,500
Boron	11
Cadmium	73
Chromium	170,000
Cobalt	14
Concrete	89,900,000
Copper	432,000
Indium	145
Iron	18,000,000
Lead	21,100
Magnesia	275,000
Manganese	213,000
Molybdenum	77,200
Nickel	209,000
Niobium	23
Silver	1,050
Tin	1,310
Titanium	125
Vanadium	14
Zinc	2,420
Zirconium	27,500

[1] Includes 150 boiling-water and 350 pressurized-water reactors, 5 uranium-enrichment facilities, 1 liquid-metal fast-breeder reactor, replaceable core components, and materials required to explore, develop, and produce uranium ore sufficient to meet their needs.
[2] Numbers rounded.
[3] Short fiber for insulation.

been spent on solar energy. Yet proponents tend to be enthusiastic, and general interest appears to be growing so rapidly that great advances in technology may happen quickly. The assessment here presupposes a research and development program that will solve successfully the economic and technologic problems of solar energy.

Six technologies for solar energy are considered in this report. The potential impact of each between 1980 and 2000 is indicated in table 27. Basic material requirements for each type to 1990, and total requirements for all six types, are estimated in table 28. A brief summary of each type follows.

TABLE 27.—*Projected production of solar energy by various technologies, 1980–2000* [1]

[Adapted from U.S. Federal Energy Admin., 1974h, p. I–7]

	10^{15} Btu's per year				
	1980	1985	1990	1995	2000
Heating and cooling	0.01	0.3	0.6	1.3	2.3
Solar thermal	.0	.002	.02	.1	.6
Wind conversion	.008	.4	1.6	2.7	4.0
Bioconversion	.06	.1	.2	.4	.7
Ocean thermal	.0	.03	.1	.4	1.7
Photovoltaic conversion	Negligible	.003	.07	.3	1.5
Total U.S. demand	93	120	144	165	180

[1] Assumptions include (1) the successful completion of the recommended research and development program plan for solar energy technologies; and, (2) conventional fuel prices equivalent to $11 per barrel of oil.

SOLAR HEATING AND COOLING OF BUILDINGS

Solar heating and cooling of buildings is expected to be the most significant of all solar energy technologies. Solar heating and cooling technology could be used not only to heat and cool buildings, but also to provide hot water for agricultural applications such as drying crops or heating greenhouses.

The thermal energy used is derived from the Sun's rays incident upon some type of solar collector, most likely a flat-plate collector installed in the sides or roofs of buildings. This flat-plate collector, which is covered by some transparent material, absorbs the heat from the Sun's rays and transfers this heat to a working fluid percolating through the collector. The heated fluid, usually water or air, then either

TABLE 28.—*Estimated basic material requirements for six main types of solar energy to 1990 (in metric tonnes)*

[Adapted from U.S. Federal Energy Admin., 1974h, p. II–46, III–A–17, IV–C–5, V–17 to 24, VI–17 to 18, VII–A–15]

	Solar heating and cooling 0.6 × 10^{15} Btu's per year	10 thermal-conversion units [1] each 100 MWe	Wind-energy conversion systems, total 53,515 MWe	Total for 4 bioconversion technologies (See table 29)	41 ocean-thermal conversion units, each 100 MWe, and 13 transformers, each 347 MVA; total 4,100 MWe	Photovoltaic power systems total 8,058 MWe	Total for 6 main types of solar energy [2]
Aluminum	5,211,485	889	------	34	29,764	------	5,242,000
Antimony	------	------	------	6	------	------	6
Asbestos	------	------	------	1	------	------	1
Chromium	------	38	------	14	------	------	52
Concrete	------	9,414,794	------	6,630,089	3,799,039	------	19,800,000
Copper	------	------	308,533	42	8,579	------	317,000
Glass	7,107,148	113,431	------	------	------	------	7,220,000
Iron	9,909,296	191,525	11,870,535	1,241,714	75,755	1,091,210	24,400,000
Lead	------	------	------	61	------	------	61
Manganese	79,914	1,544	[3] 107,805	10,012	488	8,800	209,000
Molybdenum	------	5	------	6	------	------	11
Nickel	------	12	------	8	------	------	20
Silicon	------	------	------	------	------	[4] 3,500	3,500
Zinc	------	------	------	8	------	------	8

[1] Includes materials for grid system, 150 MWth—megawatts (thermal)—central receiver boiler (cavity type), and feedwater heaters for 100 MWe steam turbine. Does not include turbine, generator, dry cooling tower, storage pressure vessels, or steel pipe.
[2] Numbers rounded.
[3] Assumes 0.9 percent manganese in steel.
[4] Table 1 on page VII–A–3 of the PIB task force report on solar energy states that 2,700 metric tonnes of cadmium may be used as an alternative for silicon in 1990, but cadmium is not listed as a required commodity on the specifications sheet (U.S. Federal Energy Admin., 1974h, p. VII–A–15).

utilizes the heat immediately or is taken to some type of storage area, where it can be kept for short periods of time until needed.

According to the PIB task force report on solar energy (U.S. Federal Energy Admin., 1974h, p. I–17), "The demand on resources for this application will be small compared to other U.S. demands for construction resources, and is not considered to be limiting."

SOLAR THERMAL CONVERSION

Solar thermal conversion systems collect the heat contained in the incident rays of the Sun at high temperatures for the generation of electricity. This solar heat is collected either through a field of heliostats, which are mirrors that focus the Sun's rays on a central boiler, or through a field of parabolic troughs that concentrate the Sun's thermal energy into some type of working fluid, which then goes to a central receiving point. Beyond that point, the solar thermal conversion plant is approximately the same as a conventional fossil-fueled powerplant. According to the U.S. Federal Energy Administration (1974h, p. III–2), "There are no fundamental technical limitations that would prevent substantial application of solar thermal conversion systems."

WIND-ENERGY CONVERSION SYSTEMS

Wind-energy conversion systems (WECS) will consist of one or more rotor devices linked to an electrical generator through some type of grid system. These conversion systems will range in capacity from 5 to 50 kilowatts for farm and rural applications and from 1 to 3 megawatts for interconnection with public utility grids.

Pertinent data must be studied and analyzed further, but some characteristics of wind-energy conversion systems are obvious. The utility grids would be located in areas where wind energy is available, such as along coasts, the Great Plains, and the Great Lakes. Also, the conversion of solar energy as wind directly into electrical energy is more efficient than conversions that require intermediate conversion to thermal energy.

BIOCONVERSION TO FUELS

"Bioconversion to Fuels (BCF) as defined in this solar energy program includes the production of plant biomass (i.e., organic matter) and the conversion of this biomass to a variety of clean fuel products and other useful clean energy forms" (U.S. Federal Energy Admin., 1974h, p. V–1). Four sources of biomass are considered here: urban solid waste, agricultural residues, terrestrial biomass farms, and marine biomass farms (table 29). Through biochemical and physical-chemical processes such as combustion and pyrolysis, a significant amount of methane or alcohol could be produced from these biomass sources. Prior to 1985 urban solid waste and agricultural residues are expected to be the most significant BCF technologies, with the terrestrial and marine biomass farms expected to become the major BCF energy feedstock materials thereafter.

The estimated basic material requirements for all BCF facilities 1975–1990 are summed in table 29. These totals are also listed in table 28 in realtion to requirements for the other types of solar energy.

OCEAN THERMAL-ENERGY CONVERSION

Ocean thermal-energy conversion systems as now planned will consist of a series of semisubmersible hulls incorporating power-pack modules capable of converting ocean thermal energy into electrical

TABLE 29.—*Estimated basic material requirements for four bioconversion technologies, 1975–90 (in metric tonnes)*

[Adapted from U.S. Federal Energy Admin., 1974h, p. V–17, 20, 23, 24]

Source of biomass	150 urban solid waste plants [1]	60 plants using agricultural residues feedstock [2]	Terrestrial biomass farms [3]	Marine biomass farms [4]	Total
Capacity in 1990 (10^{15} Btu's per year)	0.18	0.06	0.44	0.2	
Aluminum	------	------	34	------	34
Antimony	------	------	6	------	6
Asbestos	------	------	1	------	1
Chromium	------	------	14	------	14
Concrete	423,666	180,954	------	6,025,468	6,630,089
Copper	------	------	42	------	42
Iron	397,884	1,397	116,664	725,769	1,241,714
Lead	------	------	61	------	61
Manganese	3,209	12	941	5,850	10,012
Molybdenum	------	------	6	------	6
Nickel	------	------	8	------	8
Zinc	3	1	------	4	8

[1] 1,000 short tons of waste per day per plant.
[2] 1,000 tons of residue per day per plant.
[3] Estimated land requirement equals 1.6 million acres in 1990.
[4] Estimated total marine space in 1990 is 800,000 acres.

energy. The energy will be obtained by an exchange of heat between a working fluid (such as ammonia or propane) operating in a closed cycle, and the ocean water—similar to a refrigeration cycle.

The impact of ocean thermal-energy conversion systems will not become apparent until the 1990's, when rapid growth is expected. Initially, the ocean-thermal powerplants will be located relatively near shore and transmit their electricity to onshore areas. Later, chemical storage might be utilized by ocean-thermal powerplants farther out to sea, where tankers would pick up the product (hydrogen) on established runs.

The total estimated basic material requirements for ocean thermal conversion 1975–90 are shown in table 28.

PHOTOVOLTAIC ELECTRIC-POWER SYSTEMS

Photovoltaic electric-power systems convert the light that strikes solar cells directly into electrical current. No intermediate step to convert the solar energy to thermal energy is necessary; therefore, these systems can operate at a relatively high efficiency.

Photovoltaic cells can supply electricity from either a dispersed display, such as on houses and other buildings, or a centralized display, which would be necessary to produce electricity for public utilities. Because of the adaptability of photovoltaic electric-power systems, they could be used in conjunction with most other types of solar-energy technologies.

ELECTRIC-POWER TRANSMISSION AND DISTRIBUTION

Regardless of how electrical power is generated, it must be transmitted, in many cases for distances of several hundred miles, and distributed in local areas to the users. These transmission and distribution systems require substantial amounts of aluminum, copper, and steel in cable, transformers, and towers.

According to the PIB task force report on facilities the trend in transmission has been to shift from the 69 kV through the 138 kV class of lines to the 230, 345, 500, and 765 kV classes of lines. "The development of Ultra High Voltage (UHV) (1,000 KV and higher) transmission lines is in progress at several test locations. . . . Considerable development work is being done on Extra-High Voltage (EHV) underground cables, with 345 KV now approaching a standard design and an initial 500 KV cable in service" (U.S. Federal Energy Admin., 1974l, p. VII–211).

TABLE 30.—*Estimated basic material requirements for electrical transmission and distribution powerlines and transformers, based on an additional capacity of 759,000 MWe, by 1985*

[Data on projected capacity from U.S. Federal Energy Admin., 1974a, p. 70; data on materials per 1,000 MWe from U.S. Federal Energy Admin., 1974l, p. VII–227, 228]

Commodity	Metric tonnes [1]
Aluminum	8,430,000
Copper	2,130,000
Iron	13,800,000
Manganese	111,000

[1] Numbers rounded.

Electrical-power distribution has at the same time been shifting from 5 kV to 15 kV classes of circuits. Underground distribution facilities are also increasing in many areas at a rapid rate. Insulation systems for underground cables present a difficult technological problem.

Table 30 gives the estimated total basic material requirements for electric-power transmission and distribution of 759,000 MWe new capacity 1975–85

TABLE 31.—*Total estimated basic material requirements for anticipated significant energy sources, approximately 1975–90* [1]

Commodity	Metric tonnes [2]	Short tons [2]
Aluminum	14,100,000	15,500,000
Antimony	1,070	1,180
Asbestos	126,000	139,000
Barite	23,400,000	25,700,000
Bentonite	10,200,000	11,200,000
Boron	41	45
Cadmium	130	209
Chromium	251,000	276,100
Cobalt	1,300	1,430
Concrete	319,000,000	351,000,000
Copper	3,460,000	3,810,000
Fluorite (aluminum and steel production) [3]	1,580,000	1,740,000
Indium	145	160
Iron	179,000,000	197,000,000
Lead	24,300	26,700
Magnesia	484,000	532,000
Magnesia (steel production) [4]	573,000	627,000
Manganese	1,770,000	1,950,000
Mica	5,140	5,660
Molybdenum	78,600	86,400
Nickel	256,000	282,000
Niobium	935	1,030
Silicon	3,500	3,850
Silicon (steel and aluminum production) [5]	662,000	728,000
Silver	1,100	1,210
Tin	1,470	1,620
Titanium	4,720	5,190
Tungsten [6]	33,000	36,300
Vanadium	3,750	4,130
Zinc	2,560	2,820
Zirconium	27,500	30,250

[1] See text for explanation of energy sources and periods involved and table 1 in Goudarzi, Rooney, and Shaffer (1976), chapter B of this report, for requirements extrapolated for full time period.
[2] Numbers rounded.
[3] Average 9 lb of CaF_2 per metric tonne of steel and 132 lb per metric tonne of aluminum.
[4] Average 7 lb per metric tonne of steel.
[5] Average 5.5 lb per metric tonne of steel and 33 lb per metric tonne of aluminum.
[6] Used mostly in the manufacture of machinery.

in the Project Independence Report (U.S. Federal Energy Admin., 1974a, p. 70). The projections are based on generating units of 1,000 MWe capacity and are subject to the PIB assumptions (U.S. Federal Energy Admin., 1974l, p. VII-221 to VII-226).

SUMMARY

All of the estimated basic material requirements for anticipated significant energy sources considered herein are summarized in table 31. Although most of the material requirements listed are for 1975-90, some of the data are for a shorter period of time as noted in the tables throughout the text. Thus, in terms of the BAU scenario from PIB, these are minimum figures for 1975-90. In table 1 of Goudarzi, Rooney, and Shaffer (1976), chapter B of this report, the totals for shorter time periods have been extrapolated to 15 years (1975-90) in every case as a straight line function.

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Supply of Nonfuel Minerals and Materials for the United States Energy Industry, 1975-90

By GUS H. GOUDARZI, LAWRENCE F. ROONEY, *and* GLENN L. SHAFFER

DEMAND AND SUPPLY OF NONFUEL MINERALS AND MATERIALS FOR THE UNITED STATES ENERGY INDUSTRY, 1975–90—
A PRELIMINARY REPORT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1006–B

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SUPPLY OF NONFUEL MINERALS AND MATERIALS FOR THE UNITED STATES ENERGY INDUSTRY, 1975-90

By Gus H. Goudarzi, Lawrence F. Rooney, and Glenn L. Shaffer

ABSTRACT

Availability of large quantities of mineral raw materials and the capability of industry to produce them are essential in the development and production of energy, which is fundamental to virtually every aspect of industrial society. The proposed energy independence of the United States cannot be predicated on an assumed infrastructure of mineral independence. In recent years the United States has become a net importer of many raw materials, and the national stockpile has provided a significant portion of U.S. supply of a few commodities.

The United States has no reserves of chromite, cobalt, manganese, and niobium and is totally dependent on imports for these commodities; imports also provide a significant part of the supply of aluminum (bauxite), fluorite, nickel, and tungsten. Reserves of only a few commodities—barite, bentonite, copper, iron ore, lead, molybdenum, and zinc—are adequate to meet the national demand 1975–90. Significant increases in production above that of 1973 for commodities such as aluminum, barite, bentonite, fluorite, iron ore, and tungsten are needed to satisfy the demand by the energy industries.

U.S. energy production is impossible without adequate supplies of minerals to produce energy-related hardware, so research is essential to increase U.S. resources and reserves for many commodities discussed in this report.

INTRODUCTION

Current plans to expand the development and production of energy in the United States depend upon the availability of large quantities of mineral raw materials (Albers and others, 1976, chapter A of this report) and the capability of industry to produce them. In general, the U.S. mineral industry is believed capable of meeting demand posed by increased energy production. In recent decades, however, the United States has become a net importer rather than a net exporter of minerals, and its proposed energy independence cannot be predicated blindly on an assumed infrastructure of mineral independence.

Domestic reserves and resources of some mineral commodities are unknown or poorly known, and those of others are inadequate to satisfy the projected or even the present demand. This report focuses attention on those critical or basic commodities whose supplies might be severely stressed by an acceleration in energy development and production.

FUNDAMENTAL IMPORTANCE OF ENERGY PRODUCTION

Of all the components of our solar system, energy is primary. In the strictest sense of the word, it is fundamental. Given unlimited cheap energy, any element could be refined from the oceans or rocks; even if the rains should cease to fall, the oceans could be desalted and the land irrigated. In a more immediate sense, our entire civilization is kinetic rather than static because of the energy it consumes. The Nation runs on energy. It follows then that, if the Nation chooses to maintain or increase its energy consumption, allocation of mineral raw materials to the energy-producing sector of the economy will have top priority. Other less fundamental uses, though equally critical in daily living, will share what is left. It is important, therefore, that the impact of increased energy production on the availability of mineral commodities be assessed.

Such assessment depends on the accuracy of two kinds of information: the demand for mineral commodities by the energy industries and the ability of U.S. producers to satisfy that demand.

DEMAND ESTIMATES

Demand for materials is difficult to determine for a number of reasons. First of all, it depends on the total demand for energy, about which there is no agreement (see tables 1–3 in chapter A, by Albers and others, 1976). Second, no systematic reporting of the amounts of materials needed by the energy industries has ever been undertaken. Chapter A of this study is in many instances incomplete, but it is at least a first attempt. Third, the energy industries have not reported mineral commodities that they need *indirectly*. We have gone a step in this direction by estimating the fluorite, magnesia, and silicon needed to manufacture the steel required by the energy industries and adding them to our tabulations of total requirements. Fourth, the production of raw materials and equipment for energy takes energy and thus reduces the net energy available (and therefore increases the need for basic raw materials), a condition that will be accentuated through the years by the use of leaner ores. We have made no allowance for this in our study, but we have included a discussion of this significant aspect of the problem under the heading, "Energy Budget."

In chapter A (Albers and others, 1976), projections are made of the demand for nonfuel mineral materials by each type of energy industry, for various time spans between 1975 and 1990, on the basis of a "business-as-usual" (BAU) scenario of energy production outlined by the U.S. Federal Energy Administration in its Project Independence reports of 1974. Table 1 summarizes these data for 29 commodities, projecting them all to a 1975–90 time frame.

The total demands listed in table 1 must be considered as minimum requirements. Even so, in absolute terms, the amounts of aluminum, barite, bentonite, concrete, copper, iron, and manganese needed are large; and, relative to their domestic availability, so are the amounts of chromium, fluorite, indium, and tungsten. Furthermore, the list is by no means complete. Undoubtedly, additional mineral commodities are used by the energy industries but were not reported. (For example, the petroleum-refining industry used 124,000 troy ounces of platinum in 1973, 22 percent of the total U.S. demand. At the same rate of consumption, the cumulative demand by the petroleum industry to 1990 would amount to almost 2 million ounces.) Also, the mineral commodities required to build new equipment and processing or manufacturing plants to increase the output of commodities such as steel are not taken into account. Thus, the effect of increased energy production on the demand for minerals needed by supporting industries is not quantified, even though the demand may be increased more rapidly for some of these minerals than for the minerals reported by the energy industries.

SUPPLY DATA

Bearing in mind the identified minimum requirements for nonfuel raw materials that a "business-as-usual" approach to energy independence would generate (table 1), and recognizing that other materials directly or indirectly related to energy development have not been identified, we have compiled available supply and demand data on 29 mineral commodities known to be needed for energy production to 1990 (table 2) and on 13 commodities for which demands by the energy industries are undetermined (table 3). The tabulations show reserves, identified resources, and primary production of minerals in the United States and in the world, and import, export, and consumption data for the United States. The baseline data presented are for 1973, the latest year for which final figures were available. Percentages of net imports (imports minus exports) relative to consumption are shown to underscore U.S. dependence on or independence from foreign sources. The major sources of imported mineral commodities are listed in table 4.

Assumed annual growth rates, adapted mostly from U.S. Bureau of Mines projections, were used to arrive at a 1975 postulated annual consumption, which in turn was used to calculate the total cumulative demand figures 1975–90 shown on tables 2 and 3. These cumulative total demand figures are assumed to include some demand for energy. The magnitude of that demand is not disaggregated in the Bureau projections but is assumed to be considerably less than the Project Independence Blueprint (PIB) projections.

RESOURCE APPRAISALS

Because energy independence is the Nation's goal, the ability of the United States to satisfy the demand for mineral commodities by the energy industries depends to a great degree on domestic reserves and resources. Definitions for such terms as *reserves*, *identified resources*, and *undiscovered resources*, jointly adopted by the U.S. Bureau of Mines and the U.S. Geological Survey (1976, p. 3) are based on two key criteria: the extent of geologic knowledge about the resource and the economic feasibility of its recovery. The term *reserves* generally refers to identified deposits that can be recovered economically at present prices, and the term *resources* includes, in addition, deposits that cannot be recovered economically at present prices. *Identified resources*

TABLE 1.—*Minimum estimates of nonfuel mineral requirements for energy production in the United States, 1975–90, by types of energy industries*

[All figures are in metric tonnes (1 tonne=2204 lb). Adapted from Albers and others, 1976]

Commodity	Fossil fuel energy: Coal mines and transport	Fossil fuel energy: Synthetic fuel from coal	Fossil fuel energy: Oil, gas, oil shale development and exploration	Fossil fuel energy: Fossil-fuel powerplants	Fossil fuel energy: Oil and gas refineries, port facilities, LNG pipelines	Geothermal powerplants	Hydroelectric plants	Nuclear energy: Uranium mining and processing	Nuclear energy: Nuclear fission powerplants	Heating and thermal conversion	Solar energy: Wind energy	Solar energy: Bioconversion	Solar energy: Ocean thermal conversion	Solar energy: Photovoltaic power	Electric transmission and distribution	Total [2] demand by energy industries 1975–90
Aluminum	248,736	65,199	644	----	266	144,600	805	36,348	14,419	5,212,374	----	34	29,764	----	12,645,000	18,400,000
Antimony	693	----	----	----	----	----	----	374	----	----	----	6	----	----	----	1,070
Asbestos	88	----	----	277	44,860	53,100	----	77	48,438	----	----	1	----	----	----	147,000
Barite	----	----	29,207,146	----	----	----	----	----	----	----	----	----	----	----	----	29,200,000
Bentonite	----	----	12,731,320	----	----	----	----	----	----	----	----	----	----	----	----	12,700,000
Boron	30	----	----	----	----	----	----	11	----	----	----	----	----	----	----	41
Cadmium	57	----	----	----	----	----	----	22	51	----	----	----	----	----	----	130
Chromium	8,792	----	38,624	19,226	23,356	1,980	1,380	6,754	163,679	38	----	14	----	----	----	264,000
Cobalt	25	----	----	1,716	----	----	----	14	----	----	----	----	----	----	----	1,760
Concrete	197,340	----	49,727,058	71,959,235	1,075,502	1,017,000	114,000,000	3,012,286	86,933,175	9,414,794	----	6,630,088	3,799,039	----	----	348,000,000
Copper	68,618	5,368	267,512	343,158	30,543	15,750	17,200	40,636	390,880	----	308,533	42	8,579	----	3,195,000	4,690,000
Fluorite [1]	43,793	7,447	420,049	71,850	83,157	10,068	8,232	10,898	66,483	353,754	48,913	5,114	2,094	4,492	841,994	1,980,000
Indium	----	----	----	----	----	----	----	----	144	----	----	----	----	----	----	145
Iron	7,025,475	860,398	101,847,521	17,454,466	20,091,349	342,000	1,988,000	2,117,798	15,873,784	10,100,821	11,870,535	1,241,714	75,755	1,091,210	20,700,000	213,000,000
Lead	4,094	----	----	----	----	----	----	4,641	16,500	----	----	61	----	----	----	25,300
Magnesia [1]	22,475	2,755	326,674	57,140	64,667	313,184	6,365	6,782	365,866	32,339	38,044	3,976	242	3,494	66,135	1,310,000
Manganese	50,778	6,939	1,008,087	140,828	269,464	2,685	16,000	17,797	195,362	81,458	107,805	10,012	488	8,800	167,000	2,080,000
Mica	----	----	----	936	----	----	4,470	----	----	----	----	----	----	----	----	5,410
Molybdenum	671	----	----	925	----	----	----	426	76,766	5	----	6	----	----	----	78,800
Nickel	4,348	----	25,425	8,632	13,165	2,370	615	30,859	178,074	12	----	8	----	----	----	264,000
Niobium	25	----	----	----	885	----	----	14	9	----	----	----	----	----	----	933
Silicon [1]	21,384	3,140	256,682	43,909	50,813	3,027	5,013	5,874	40,317	103,453	29,892	3,125	636	6,245	241,205	815,000
Silver	68	----	----	----	----	----	----	8	1,041	----	----	----	----	----	----	1,120
Tin	227	----	----	----	----	----	----	189	1,124	----	----	----	----	----	----	1,540
Titanium	----	----	----	----	----	6,900	----	122	2	----	----	----	----	----	----	7,020
Tungsten	1,972	----	32,553	262	----	----	----	5,263	----	----	----	15	----	----	----	40,100
Vanadium	25	----	----	233	3,540	----	----	14	----	----	----	----	----	----	----	3,810
Zinc	140	----	----	----	----	----	----	2,414	702	----	----	8	----	----	----	3,260
Zirconium	----	----	----	----	----	----	----	----	27,506	----	----	----	----	----	----	27,500

[1] For each tonne of steel, 4 kg (9 lb) of fiuoride, 3.2 kg (7 lb) of magnesia, and 2.5 kg (5.5 lb) of silicon required in steel manufacture have been included in the totals. For each tonne of aluminum, 60 kg (132 lb) of fiuorite and 15 kg (33 lb) of silicon have also been included.

[2] Figures have been rounded.

TABLE 2.—*U.S. supply and demand for 29 mineral commodities needed by the energy industries, 1975–90*

[All figures are in metric tonnes (1 tonne=2,204 lb), unless otherwise noted; all figures are rounded; troy oz.-troy ounces (32,151 troy ounces=1 tonne); NA—data not available; E—estimate; *—includes supplement from U.S. stockpile and industry inventory; N.p.—no U.S. production. Sources: U.S. Bur. of Mines, 1970, 1975a, b; Brobst and Pratt, 1973; U.S. Geol. Survey, commodity specialists (oral and written communications).]

Commodity	Reserves[1]		Identified resources[2]		Primary production 1973		U.S. trade 1973		U.S. consumption 1973	Net imports for consumption 1973 (percent)	Average annual growth rate 1975–90 (percent)	Total cumulative demand 1975–90	Total demand by energy industries 1975–90	Average annual demand by energy industries 1975–90	Average annual demand by energy industries 1975–90 as percentage of 1973 U.S. production
	United States	World	United States	World	United States	World	Imports	Exports							
Aluminum—															
Metal	--------	--------	--------	--------	4,108,000	15,160,000	557,000	509,000	6,175,000	7	6.0	171,180,000	18,400,000	1,227,000	30
Bauxite	41×10^6	$15,750 \times 10^6$	250 to 300×10^6	20 to 30×10^9	1,910,000	69,400,000	14,350,000	12,200	16,914,000	85	6.0	468,890,000	--------	--------	---
Alumina	--------	--------	--------	--------	--------	--------	3,062,000	951,000	--------	---	--	--------	--------	--------	---
Antimony	91,000	4,173,000	118,000	5,100,000[E]	1,160	69,325	18,650	465	40,300*	45	3.5	862,000	1,070	71	6
Asbestos	3,628,000	87,100,000	72,500,000	170,500,000	136,000	4,073,000	718,000	60,000	802,860	82	2.0	14,730,000	147,000	9,800	7
Barite	59×10^6	181×10^6	91×10^6	289×10^6	1,000,000	4,320,000	650,000	62,000	1,444,000	41	2.3	27,320,000	29,200,000	1,950,000	>100
Bentonite	910×10^6	NA	$1,820 \times 10^6$	NA	2,800,000	NA	--------	--------	2,800,000	0	2.5[E]	54,600,000	12,700,000	847,000	30
Boron	28×10^6[E]	76×10^6[E]	NA	NA	187,800	310,200	1,800	86,000	103,400	0	5.0	2,580,000	41	3	<1
Cadmium	326,500	1,270,000	1,795,000	16,750,000	2,575	17,050	2,560	140	5,650*	43	2.5	109,000	130	9	<1
Cement (for concrete).	--------	--------	--------	--------	77,510,000	707,900,000	6,027,000	243,000	82,065,000	7	5.0	2,050,000,000	81,200,000	5,410,000	7
Chromium (Metal).	--------	--------	--------	--------	0	--------	--------	63,500[E]	540,000[E]	---	2.5	10.430,000	264,000	17,600	N.p.
Chromite (Ore).	0	$1,690 \times 10^6$	8.2×10^6	$2,675 \times 10^6$	0	6,765,000[E]	[3]1,114,000[E]	--------	1,730,000*[E]	100	2.5	33,400,000	--------	--------	N.p.
Cobalt	0	2,450,000	762,000	4,500,000	0	25,640	8,710	1,130	8,500*	89	2.6	166,000	1,760	120	N.p.
Copper	82×10^6	390×10^6	193×10^6	586×10^6	1,560,000	7,127,800	[4]533,000	265,000	[4]2,210,000	12	4.4	51,880,000	4,690,000	313,000	20
Fluorite (fluorspar).	5.4×10^6	95×10^6	34.2×10^6	188.5×10^6	225,890	4,446,100	1,100,000	5,000	1,226,000	89	4.1	27,900,000	1,980,000	132,000	58
Indium troy oz.	10×10^6	49×10^6	58×10^6[E]	109×10^6	130,000[E]	1,740,000	811,000	NA	1,110,000	73	1.6	19,560,000	4,629,744	309,000	>100
Iron ore	$9,000 \times 10^6$	$252,000 \times 10^6$	$97,000 \times 10^6$	$780,000 \times 10^6$	89,107,000	864,148,000	43,995,000	2,743,000	149,300,000	28	2.0	2,739,900,000	[5]344,000,000	[6]23,000,000	26
Lead	53.5×10^6	145×10^6	81×10^6	Large	547,100	3,490,000	256,750	114,300	1,398,000*	10	2.6	27,270,000	25,300	1,690	<1
Magnesia MgO).	Large	Large	Large	Large	778,000[E]	[7]8,000,000[E]	153,000[E]	54,000[E]	874,500[E]	11	1.7	15.570,000[E]	[8]1,310,000	87,300	11
Magnesium (Metal).	--------	--------	--------	--------	111,000	236,780	2,700	36,000	105,500	0	3.0	2,140,000	--------	--------	---
Manganese—															
Metal	--------	--------	--------	--------	28,000	9,740,000	--------	--------	1,410,000	---	2.0	25,880,000	2,080,000	139,000	>100
Ferromanganese.	--------	--------	--------	--------	620,000	--------	354,000	8,000	1,013,000*	34	2.0	18,590,000	2,447,000	163,000	26
Ore	0	$5,443 \times 10^6$	976×10^6	$12,890 \times 10^6$	[9]220	22,035,000	1,370,000	51,700	[10]1,941,400*	68	2.0	35,600,000	--------	--------	N.p.
Mica—															
Scrap	Large	Large	Large	Large	160,500	248,600	2,700	44,540	122,500	0	4.0	2,760,000	5,410	360	<1
Sheet	0	Large	0	Large	14	13,400	2,310	3,060	2.920*	100	4.0	66,000	0	0	---
Molybdenum	3,630,000	4,990,000	15,880,000	28,584,000	52,570	82,200	210	34,400	33,100	0	5.0	827,000	78,880	5,250	10
Nickel	131,400	44,452,000	15,250,000	70,000,000	16,580	658,630	173,340	20,000	211,000*	73	3.4	4,470,000	264,000	17,600	>100
Niobium	0	10,342,000	109,840	10,342,000	0	10,585	1,830	35	2,745*	65	5.0	68,600	915	61	N.p.
Silicon	Large	Large	Large	Large	524,250	1,776,800	64,400	14,500	595,000	8	2.6	11,600,000	815,000	54,300	10
Silver troy oz.	$1,500 \times 10^6$	$6,000 \times 10^6$	$2,300 \times 10^6$	NA	37,800,000	305,900,000	130,700,000	11,200,000	[11]196,000,000	61	2.5	3,785,000,000	35,900,000	2,390,000	6
Tin	40,000	10.300,000	140,800	20,570,000	100[E]	236,200	51,150	3,460	66,900*	71	1.1	1,109,000	1,540	100	>100
Titanuim[12]															
Metal.	2.3×10^6	133×10^6	162×10^6	$1,070 \times 10^6$	259,450	1,533,140	[13]320,000	2,100	585,130*	54	4.2	13,450,000	7,020	470	<1
Ilmenite	91×10^6	410×10^6	508×10^6	[14]$3,300 \times 10^6$	737,800	3,525,850	278,500	907	988,830	28	4.0	22,270,000	--------	--------	---
Rutile	453,000	7,890,000	3,080,000	38,000,000	[15]8,170	[15,16]341,100	[15]189,600	--------	251,290*	75	4.0	5,660,000	--------	--------	---
Tungsten	118,000	1,630,000	300,000	2,000,000	3,440	38,700	4,890	40	6,980*	69	7.0	215,000	40,100	2,670	78
Vanadium	104,300	9,710,000	Large	10,440,000	4,410	25,600	2,570	850	7,750*	22	5.0	194,000	3,810	254	6
Zinc	45×10^6	250×10^6	120×10^6	$1,300 \times 10^6$	434,550	5,785,180	738,300	13,600	1,495,600*	48	3.1	30,700,000	3,260	220	<1
Zirconium	5,443,000	NA	6,350,000	18,000,000	55,000[E]	285,000	44,700[E]	14,300	67,500	45	4.0	1,520,000	27,500	1,830	3

[1] Reserves—That portion of the identified resource from which a usable mineral can be economically and legally extracted at the time of determination.

[2] Identified resource—Specific bodies of mineral-bearing materials whose location, quality, and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category.

[3] Includes all categories of chromium.

[4] Does not include scrap.

[5] Calculated from 213,000,000 metric tonnes of metal to shipping grade ore (62 percent Fe).

[6] Calculated from 14,000,000 metric tonnes of metal to shipping grade ore (62 percent Fe).

[7] MgO calculated from Mg.

[8] Includes 722,000 tonnes refractory magnesia needed by the steel industry.

[9] U.S. manganiferous iron ore (5-10% Mn) production 184,000 tonnes.

[10] 68 percent import, 32 percent stockpile.

[11] Primary demand 162×10^6 troy ounces.

[12] Titanium metal contained in rutile and ilmenite.

[13] Includes all categories of titanium.

[14] Calculated from TiO_2.

[15] Rutile concentrate.

[16] Excludes communist countries.

TABLE 3.—*U.S. supply and demand data for selected mineral commodities, 1975–90, for which demands by the energy industries are undetermined*

[All figures are in metric tonnes (1 tonne=2204 lb.), unless otherwise noted; all figures are rounded; troy oz.—troy ounces (32,151 troy ounces=1 tonne); *—includes supplement from national stockpile and industry inventory; +—excess imports to inventory; Δ—excludes Communist countries; E—estimate; N/A—data not available; X—excludes U.S. production. Sources; U.S. Bur. of Mines, 1970, 1975a,b; Brobst and Pratt, 1973; U.S. Geol. Survey, commodity specialists (oral and written communications).]

Commodity	Reserves [1]		Identified resources [2]		Production		U.S. trade		U.S. consumption	Net import for consumption 1973 (percent)	Average annual growth rate 1975–90 (percent)	Total cumulative demand 1975–90
	United States	World	United States	World	United States 1973	World 1973	Import 1973	Export 1973	1973			
Beryllium	32,000	NA	142,000	NA	NA	160 E-X	59	50	316 *	3	2.0	5,800
Bismuth	11,800	113,400	14,100	116,000	NA	4,000 E-X	1,214	69	1,319 *	87	1.4	22,800
Cesium	Small	NA	NA	NA	0	27	5.9	NA	6.2*	95	8.0	210
Graphite	0	Large	9,070,000	Large	4,000 E	390,000 E	70,000	7,200	72,000 E *	87	3.0	1,460,000
Hafnium	43,500 E	NA	118,000 E	330,000 E	37	77	<1	None	30	0	2.0	550
Helium [3]	[4] 155,000	NA	NA	NA	[4] 3,205	[4] 3,337	0	[5] 150	[5] 497	0	6.0	[5] 13,800
Lithium	760,000 E	1,220,000 E	3,200,000 E	8,450,000 E	3,900 E	5,900 E	154	725 E	3,400 E	0	5.0	85,000
Mercury [6]	450,000	5,300,000	950,000	7,185,000	2,170	276,200	46,075	340	[7] 54,280 *	85	1.0	900,000
Platinum group metals (troy oz.)	3,000,000	624,000,000	181,000,000	948,000,000	20,000	5,174,000	2,503,000	628,000	1,831,000 +	100	2.0	33,600,000
Rare earths [8]	4,536,000	6,980,000	NA	18,000,000	18,330	27,100	1,760	5,425 E	14,790	0	3.5	316,000
Selenium	35,000	168,000 Δ	Large	Large	285	1,360 E	250	120	560 *	23	4.0	12,600
Strontium	1,000,000	Large	1,400,000	Large	None	38,280	14,800	NA	14,800 *	100	3.0	301,000
Tantalum	0	50,000 Δ	1,560	59,000	None	1,040	520	125	685 *	57	3.0	13,900

[1] Reserves—That portion of the identified resource from which a usable mineral can be economically and legally extracted at the time of determination.

[2] Identified resource—Specific bodies of mineral-bearing materials whose location, quality, and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category.

[3] Million cubic feet of contained helium measured at 14.7 pounds per square inch absolute (lb/in²a) at 70°F.

[4] Includes both high-purity and crude helium (helium in mixtures consisting of approximately 70 percent helium and 30 percent nitrogen).

[5] High-purity helium.

[6] 76-pound flasks of metal.

[7] Includes secondary.

[8] Data are for rare-earth oxides (REO).

TABLE 4.—*Major sources of imports of mineral commodities by the United States in 1973*

[Source: U.S. Bureau of Mines Commodity Data Summaries, 1975]

Aluminum (bauxite)	Jamaica, Australia, Surinam
Antimony	Republic of South Africa, Bolivia
Asbestos	Canada
Barite	Ireland, Peru, Mexico
Bismuth	Peru, Mexico, Japan
Cadmium	Canada, Australia, Japan
Cesium	West Germany, Canada
Chromium	Republic of South Africa, U.S.S.R. Philippines
Cobalt	Zaire, Belgium
Copper	Canada, Peru, Chile, Republic of South Africa
Graphite	Mexico, Malagasy Republic
Indium	Canada, U.S.S.R., Peru
Iron ore	Canada, Venezuela, Brazil, Australia
Lead	Peru, Canada, Australia
Manganese	Brazil, Gabon, Australia
Mercury	Canada, Algeria, Spain
Mica (sheet)	Brazil, India
Nickel	Canada, Norway, New Caledonia
Niobium	Brazil, Thailand
Platinum group metals	U.S.S.R., United Kingdom, Republic of South Africa
Rutile (titanium)	Australia, India
Selenium	Canada
Silver	Mexico, Canada. Peru
Strontium	Mexico, United Kingdom, Spain
Tantalum	Thailand, Australia, Canada, Zaire
Tin	Malaysia, Thailand, Bolivia
Titanium	Japan, U.S.S.R., United Kingdom
Tungsten	Canada, Bolivia, Peru
Vanadium	Republic of South Africa, Chile
Zinc	Canada, Australia
Zirconium	Australia

are specific bodies of mineral-bearing material whose location, quality, and quantity are known from geologic evidence supported by engineering measurements. *Undiscovered resources* are unspecified bodies of mineral-bearing materials surmised to exist on broad geologic knowledge and theory.

The quantity of usable reserves within most deposits changes with economic conditions and advanced technology, so estimates must be revised often. Resources that were considered marginal in the past may now be recoverable reserves because of these changes. Estimates of proved reserves commonly are considered to be accurate within about 20 percent. The errors in estimates of resources are much greater. More accurate estimates that would differentiate between identified and undiscovered resources are needed to define the supply problems and provide a basis for policy decisions.

Resource estimates presented in this report, although based on best available data, are provisional and incomplete. Continued effort is essential to identify resources of those mineral commodities that may be in short supply in the next few decades because of expanding demands and intense competition for sources among industrialized nations.

Some of the commodities reviewed here are not in short supply but play so important a role in the economy and in energy production that they must be assessed. Domestic resources of some materials, such as copper, lead, and zinc, are probably adequate to meet national needs to the end of this century, but factors such as production costs make a part of them uneconomic to develop and bring into production in competition with imports. In our appraisal of domestic resources, economic factors and new technology have been considered but have not greatly affected the resource estimates. It is assumed that if the raw material from outside sources were unavailable, technological capability coupled with national demand would make possible the utilization of some of the presently uneconomic domestic resources.

In contrast, the domestic potential resources of some materials, such as bauxite (aluminum), manganese, and fluorite, are probably not sufficient to meet industry demand now or in the future, and the Nation will continue to depend on imports of these materials. However, use of high-alumina clays and alunite for the production of aluminum may be possible in the not-too-distant future, harvesting of manganese nodules from sea floors may become a reality, and substitutes, such as synthetic flux for fluorite, may be developed for other critical materials in short supply.

ENERGY BUDGET

A significant aspect of the non-fuel requirements for increased energy production is the energy budget or energy cycle. The term "energy budget" implies that the energy used to produce energy must be subtracted from the gross amount of energy available to obtain the energy profit. It takes energy to make energy; in fact, the energy industries are one of the largest energy-consuming sectors of the economy.

This thermodynamic relationship is fundamental and becomes of greater and greater social interest as efficiencies in energy production and conversions approach their theoretical maxima under present technologies. Much research is being done on energy budgets, but the subject is so complex that the few results to date can be considered only tentative.

To illustrate the nature of the problem, consider the energy cost of producing electricity from a ton of coal. An obvious and large cost is the thermal loss within the powerplant itself. Other energy costs, though much smaller (Chapman and others, 1974, p. 231), are equally obvious: the British thermal units (Btu's) spent in mining, crushing, beneficiating, and transporting the coal. Other costs are less obvious: the Btu's that go into the manufacture of the mining, crushing, beneficiating, transportation, and powerplant equipment. And other costs, which might be called overhead, are even less obvious: the Btu's that go into the construction and maintenance of railroad depots and ancillary installations that should be charged off to coal transport; the Btu's needed to manufacture fertilizers, tractors, and the fuel for tractors (as well as the Btu's in the fuel itself) to produce the food for all the personnel employed in the many stages of power production; the Btu's needed to build transportation equipment and to transport workers to their jobs; the Btu's needed to provide the workers' clothing and homes, and to maintain their health. Every energy-using facet of society that contributes to the production of energy must be charged to it. Fortunately, many of these are probably so small that historically they could be ignored as long as the net energy profits were large. But the subject is now of such vital importance that it must be researched. It is possible, in fact, that the total energy costs of a particular power source may exceed its energy profits and operate on the hidden subsidy of another power source.

Hidden subsidies apply to all new energy industries, most clearly in the form of research, pilot projects, and capital construction. At the present time, however, the hidden subsidies and intangible costs are most important with respect to the nuclear industry. Most of the Btu's that go into the construction of a nuclear powerplant and support of personnel are from fossil fuels. And, as Chapman, Leach, and Slesser (1974, p. 242) have noted, the handling and storage of nuclear wastes will cost energy for many years after a nuclear plant has been dismantled. Thus, the overhead in Btu's of nuclear plants demands close scrutiny.

Another aspect of the energy budget that deserves close scrutiny is the increasing energy costs of fuels and materials—whether it be in mining leaner ores, attempting to flush more oil out of any given reservoir, or extracting oil from shale. The exponential nature of this increase is vividly portrayed in the accompanying graph (fig. 1) constructed by Page and Creasey (1975, p. 12). Here we are not dealing with the unknown or with unpredictable social or technological forces or even the murky realm of undiscovered mineral deposits. We are dealing with immutable physical laws that prescribe the ultimate limits of mineral-resource development.

According to preliminary data (table 5), the cost in Btu's 1975–90 of producing 20 of the commodities discussed in this report is large, equivalent to more than 18 billion barrels of oil. The amount needed to produce the same raw materials for energy production is much less, about 2.5 billion barrels, but this figure is unequivocally minimum. In the 15 year period, the projected amount of energy needed to produce these few commodities is between 10 and 15 percent of the total projected net energy consumption in the United States (gross energy minus conversion losses to electrical energy).

Some commodities, pound for pound, are obviously far more costly in energy than others—aluminum and magnesium, for example. Other commodities, such as iron and concrete, are costly because of the large amount consumed annually. Moreover, the cost in Btu's of all commodities will rise as the grade of ore decreases and as the depth of deposit and distance to market increase, trends that can be balanced only temporarily by increased efficiencies.

COMMODITY SUMMARIES

ALUMINUM

Aluminum is a ductile, lightweight metal that has efficient electrical and thermal conductivity, is resistant to oxidation, and has high reflectivity. It is used in nearly all segments of the U.S. economy, such as the construction, electrical, packaging, consumer-durables, and equipment industries. Aluminum is essential to the production, conversion, and transportation of energy. It is used in machinery, construction, electric generators, and heavy-duty powerlines, to name just a few applications.

The production of aluminum is itself an energy-intensive process, and the capital costs of an aluminum-producing facility—including mining, Bayer conversion, reduction, and milling—are high. Some substitutions for aluminum are possible: stainless steel, magnesium, and zinc can be substituted for aluminum in transportation uses; copper in electrical uses; and titanium, lead, plastic, and fiberglass in some applications.

Aluminum is made from alumina (Al_2O_3), and this oxide is itself a manufactured product. Bauxite is the raw material from which most alumina is made, but other types of rocks such as alunite and nepheline syenite also are used (notably in the U.S.S.R.) for making alumina.

Both bauxite and alumina are used for essential products other than metal. About 88 percent of the bauxite and alumina consumed in the United States is used for production of aluminum, 6 percent in chemicals, 4 percent in refractories, and 2 percent in abrasives.

Bauxite is used as an ore of aluminum because it is rich in aluminum in a form that is extractable at low cost, and it occurs in large deposits. It is formed by the weathering of such aluminum-bearing rocks as nepheline syenite and basaltic lava. During weathering, the bauxite becomes enriched in aluminum as surface waters dissolve and remove the other

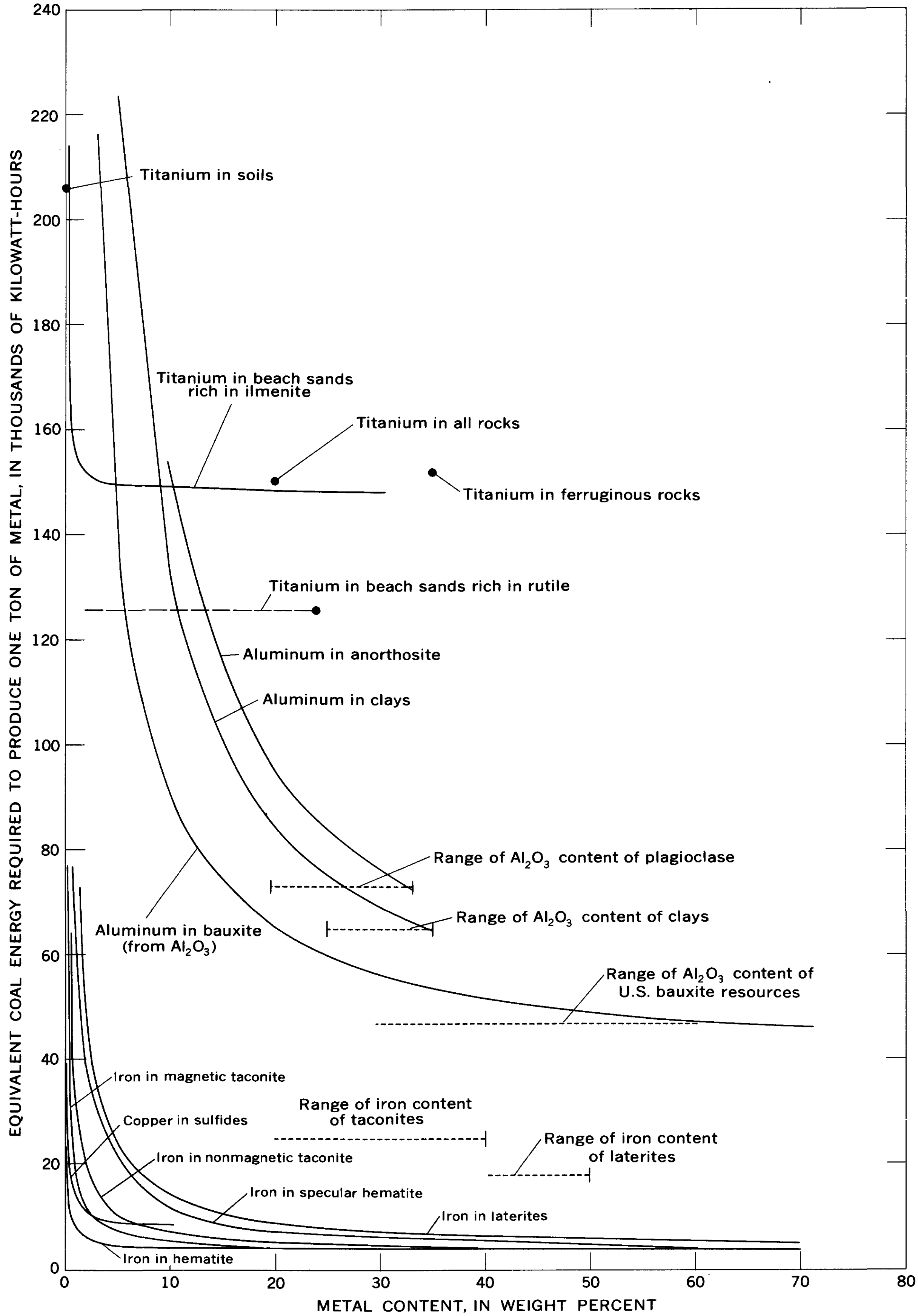
EQUIVALENT COAL ENERGY REQUIRED TO PRODUCE ONE TON OF METAL, IN THOUSANDS OF KILOWATT-HOURS
METAL CONTENT, IN WEIGHT PERCENT
240
220
200
180
160
140
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
Titanium in soils
Titanium in beach sands rich in ilmenite
Titanium in all rocks
Titanium in ferruginous rocks
Titanium in beach sands rich in rutile
Aluminum in anorthosite
Aluminum in clays
Range of Al_2O_3 content of plagioclase
Range of Al_2O_3 content of clays
Aluminum in bauxite (from Al_2O_3)
Range of Al_2O_3 content of U.S. bauxite resources
Iron in magnetic taconite
Copper in sulfides
Range of iron content of taconites
Range of iron content of laterites
Iron in nonmagnetic taconite
Iron in specular hematite
Iron in laterites
Iron in hematite

TABLE 5.—*Energy requirements for production of selected mineral commodities needed by energy industries and other users in the United States, 1975–90*

[Sources: Battelle Columbus Laboratories; 1975a, 1975b; U.S. Bur. of Mines, 1975c]

Commodity (primary product)	Energy requirements in 10^6 Btu's/tonne	Total demand by energy industries 1975–90 (metric tonnes)	Minimum energy requirements for production of materials to meet demand by the energy industries 1975–90 (10^6 Btu's)	Total demand by all users 1975–90 (metric tonnes) [1]	Minimum energy requirements for production of materials to meet demand by all users 1975–90 (10^6 Btu's)
Aluminum (ingot)	268.9	18,400,000	4,947,760,000	171,180,000	46,030,300,000
Asbestos (fiber)	7.6	147,000	1,117,200	14,730,000	111,950,000
Barite (ground)	0.9	[2] 29,200,000	26,280,000	27,320,000	24,590,000
Bentonite	2.2	12,700,000	27,940,000	54,600,000	120,120,000
Boron (boric oxide)	9.5	132	1,250	8,320,000	79,040,000
Cement (portland)	8.4	81,200,000	682,080,000	2,050,000,000	17,220,000,000
Chromium:					
High-carbon ferrochromium	67.2	264,000	[3] 23,878,800	10,430,000	[3] 943,390,000
Low-carbon ferrochromium	142.2				
Copper (refined)	123.5	4,690,000	579,215,000	51,880,000	6,407,180,000
Fluorspar (concentrates)	5.6	2,200,000	12,320,000	31,000,000	173,600,000
Iron:					
Gray iron castings	37.5	213,000,000	7,987,500,000	684,975,000	25,686,560,000
Steel slabs	26.5	----------	----------	----------	----------
Carbon steel castings	46.3	----------	----------	----------	----------
Lead (refined)	29.8	25,300	753,950	27,270,000	812,650,000
Magnesia (basic brick refractory MgO)	29.8	573,000	17,075,400	[4] 13,079,000	389,750,000
Magnesium (metal)	394.6	----------	----------	2,140,000	844,440,000
Manganese (ferromanganese)	54.6	2,447,000	133,606,200	25,880,000	1,413,050,000
Mica (ground from mining ore)	18.1	5,410	97,900	2,826,000	51,150,000
Molybdenum (molybdic oxide)	159.8	78,800	12,592,250	827,000	132,150,000
Nickel (ferronickel)	436.5	264,000	115,236,000	4,470,000	1,951,160,000
Silicon (ferrosilicon 50 percent Si)	84.9	815,000	69,193,500	11,600,000	984,840,000
Titanium:					
Sponge	449.7	7,020	3,156,900	13,450,000	[5] 1,370,530,000
Dioxide	94.8	----------	----------		
Zinc (elemental)	71.7	3,260	233,750	30,700,000	2,201,190,000
Total 10^6 Btu's	----	----------	14,640,040,000	----------	106,947,640,000
Bbl oil equivalent [6]	----	----------	2,524,140,000	----------	18,439,250,000

[1] Based on growth rates specified in table 2.
[2] The amount of barite projected for use by the energy industries exceeds the amount projected for all uses for two reasons: (1) the projected growth rate for energy use exceeds the projected growth rate for all uses; and, (2) unlike other commodities, most barite is used by the energy industries.
[3] Based on assumption that 31 percent of all chromium demanded 1975–90 is in the form of low-carbon ferrochromium, and 69 percent is in the form of high-carbon ferrochromium. (U.S. Bur. of Mines, 1975c, p. 280).
[4] Assumes that 84 percent of all magnesia consumed 1975–90 is of refractory grade.
[5] Based on assumption that 98 percent of all titanium demanded 1975–90 is in the form of titanium dioxide, and 2 percent is in the form of titanium sponge. (U.S. Bur. of Mines, 1975c, p. 1231).
[6] One barrel (bbl) of oil = 5.8×10^6 Btu's.

elements in the parent rock. Wet tropical climates, continuous rainfall, constant warm temperatures, and relatively good drainage during a long period of geological time are conducive to such natural enrichment.

Reserves of metal-grade bauxite in the United States are estimated at about 40 million tonnes, restricted to Arkansas. Bauxite for other uses occurs primarily in Alabama and Georgia as well as in Arkansas. The potential bauxite resources of the United States, estimated at about 250–300 million tonnes, include lateritic deposits in Hawaii, Oregon, and Washington; deeply buried and thin deposits in Arkansas; and other small scattered deposits in Southeastern United States. Domestic identified resources of bauxite are inadequate to fulfill the long-term demand.

The world reserves of bauxite are large, about 16 billion tonnes, and the world resources have been estimated at 20 to 30 billion tonnes. The largest reserves of bauxite are in Brazil, Surinam, Guyana. French Guiana, Jamaica, and Haiti in the western hemisphere; in Australia; and in Guinea and Ghana in West Africa. Large unexplored areas in South America, Asia, Africa, and Australia are favorable for discovery of major new deposits. Recently, significant discoveries were reported in India, Malaysia, Indonesia, and the British Solomon Islands. Practically inexhaustible resources of other aluminous rocks exist in virtually every major country of the world, but the metal cannot now be recovered economically from these rocks.

In 1973 the United States produced about 2 million tonnes of bauxite and imported about 14 million

◄ FIGURE 1.—Energy requirements for recovery of iron, titanium, and aluminum at different grades from various sources (from Page and Creasey, 1975, p. 12).

tonnes. More than 2 million tonnes of alumina and nearly 50,000 tonnes of aluminum were also imported for domestic consumption. Imports of bauxite and alumina, mainly from Jamaica, Surinam, Guyana, and Australia, supplied about 87 percent of the U.S. requirements for manufacture of aluminum metal and of certain refractories, abrasives, and chemicals. Bauxite mined in Arkansas, Georgia, and Alabama supplied the remaining 13 percent. Metal-grade bauxite was produced domestically only in the Arkansas district. Barring unforeseen developments, the growing requirements of the aluminum industry in the United States will be met by imports of increasing amounts of aluminum metal and alumina rather than of bauxite ore.

Incomplete data show that at least 18 million tonnes of aluminum metal is needed by the energy sector 1975–90, or an average of about 1.2 million tonnes annually. This is equivalent to about 30 percent of the domestic aluminum production in 1973.

High-alumina clays have long been considered to be the most favorable potential nonbauxite source of aluminum in the United States (National Materials Advisory Board, 1970, p. 13). The total resource of clays containing as much as 25 percent alumina is very large, but the deposits that are potential major economic sources of aluminum are limited and may be in the order of nearly 10 billion tonnes. However, the value of these clays for other products such as paper filler and coater, refractories, catalysts, and ceramics exceeds the value that can be assigned to a nonbauxite raw material for aluminum production.

Alunite (37 percent alumina), used as an ore of aluminum in the U.S.S.R., reportedly has been found in large quantities in Utah. Recovery of alumina from alunite has been successfully demonstrated in pilot plants. A pilot plant operated in the early 1950's by the U.S. Bureau of Mines proved that alumina could also be recovered from anorthosite (23 to 28 percent alumina). Large deposits of anorthosite, near Laramie, Wyo., have been purchased by an aluminum company.

Large quantities of dawsonite and nahcolite are present in strata associated with the rich oil-shale deposits in the Piceance Creek basin, northwestern Colorado. Alumina for production of aluminum metal and sodium aluminate for use in water-pollution control are potential products of this dawsonite. Other less promising potential resources include aluminous shale and slate, aluminum phosphate rock, nepheline syenite, saprolite, coal ash, and copper-leach solutions.

Geologic research is needed on the nonbauxite sources of aluminum in the United States. Adequate detailed geologic information on these potential resources is not available.

ANTIMONY

Antimony is a brittle metal that imparts strength, hardness, and corrosive resistance to alloys. It is essential as a constituent of antimonial lead for storage batteries, and of bearing-metal and other alloys. It is also used in fire-retardant chemicals, glass pigments, rubber, and plastics, and by the electronic industry.

Other substances may be substituted for antimony in most uses, but substitutes may be in short supply or may be more expensive to use. Substitution is restricted by the necessity of making changes in production techniques and factory equipment. Titanium, chromium, zirconium, tin, calcium, and lead are used as substitutes in various applications.

Stibnite (Sb_2S_3) is the predominant ore of antimony; tetrahedrite ($Cu_8Sb_2S_7$) is also important. Base-metal deposits containing antimony also yield substantial amounts of the metal.

Antimony deposits are small, discontinuous bodies. Simple deposits, in which the ore is principally stibnite, occur in the United States, Mexico, Bolivia, Peru, People's Republic of China, Republic of South Africa, Yugoslavia, and Algeria. Complex deposits, in which stibnite is associated with other minerals, generally are mined primarily for lead, gold, silver, and tungsten. Most of the antimony produced in the United States is from these complex deposits as a byproduct.

The United States has reserves of nearly 91,000 tonnes and identified resources of nearly 118,000 tonnes, mainly in Idaho, Nevada, Alaska, and Montana. Potential sources of antimony are lead, silver, and copper-zinc deposits like those from which most of the domestic antimony is now recovered. At least 50 percent of known antimony resources of the United States is contained in complex lead-silver-copper and gold deposits, 25 percent in scattered simple deposits in Idaho and Alaska, and about 25 percent in complex deposits in the Yellow Pine district of Idaho, in which a high-price antimony outvalues other metals.

Major world resources of antimony are in the Republic of South Africa, People's Republic of China, Bolivia, U.S.S.R., Thailand, Turkey, Yugoslavia, and Mexico. These countries also account for more than 90 percent of the total world production.

In 1973, the United States produced 1,160 tonnes of antimony, 665 tonnes of which were recovered from domestic lead ores. U.S. consumption was more than 40,000 tonnes, a figure equal to about 60 percent of the world's primary output. Sales from government stockpile accounted for nearly 10 percent, and secondary recovery provided a significant portion of U.S. supply. Imported ores and concentrates accounted for more than 90 percent of the total U.S. smelter output. About 50 percent of the imported antimony ores came from the Republic of South Africa, Mexico, and Bolivia. Most of the metal was imported from China, Yugoslavia, Japan, and Mexico.

Incomplete data received from industry show that about 1,100 tonnes of antimony will be required by the energy industries 1975–90 principally in the coal-transportation systems and uranium-mining and processing operations. This demand, equivalent to about 70 tonnes of antimony per year, is 6 percent of U.S. primary production in 1973, but is less than 0.3 percent of the total U.S. consumption in 1973. It does not appear that demand by the energy sector will pose a supply problem. However, because 45 percent of U.S. demand is met by imports, serious consideration should be given to improving the domestic sources of supply and thus the production of the metal.

Antimony is present in lead ores in the Tri-State district of Missouri, Oklahoma, and Kansas, and in the upper Mississippi Valley. Antimony is also a constitutent of some base-metal deposits in the Eastern United States. In fringe areas of some mineralized zones, as in Nevada, potential resources possibly exist. Areas of known base-metal, tungsten, silver, and gold mineralization may also be potential sources of antimony.

ASBESTOS

Asbestos is the common name applied to fibrous minerals. Chrysotile, the fibrous form of serpentine, accounts for more than 90 percent of world asbestos production. Amosite and crocidolite, fibrous varieties of the amphiboles, account for most of the rest. Asbestos is graded primarily on the length of its fiber.

Because asbestos fibers are inert and incombustible, they have many commercial uses. By far the greatest use is in asbestos cement. Most of the remainder is used in floor tile, asbestos paper, and friction products such as brake linings. Because asbestos fibers can be woven into cloth, about 2 percent of the asbestos consumed in the United States is used in textiles. Chrysotile low in iron is valued as an electric cable insulator. Other materials, such as fiberglass and magnesia, can substitute for asbestos for some uses. In projected energy production asbestos will be needed mainly by the nuclear, geothermal, and refining industries.

Most chrysotile occurs as veins only a few centimetres thick in serpentines, ultramafic intrusions, or associated rocks. Asbestos fibers are generally oriented perpendicular to the length of the vein (cross fibers), but some are more or less parallel to the vein (slip fiber). Most of the recovered fiber is less than 3/8-inch long.

The U.S. reserves of asbestos, estimated at 3.6 million tonnes, are not large. Deposits of chrysotile asbestos are being, or have recently been, worked in Arizona, California, and Vermont. Anthophyllite, a fibrous amphibole, has been produced in North Carolina. U.S. resources of all asbestos minerals are estimated at only 72.5 million tonnes. World reserves are estimated at 87 million tonnes and world resources at 170 million tonnes.

Most world production of asbestos is in the U.S.S.R. and Canada with large production also in the Republic of South Africa, People's Republic of China, and Italy. Many other countries have some production.

About 800,000 tonnes of asbestos were used in the United States in 1973, about 82 percent of which was imported, mostly from Canada. Most of the crocidolite and amosite were imported from the Republic of South Africa.

The estimated total demand reported by the energy industries for 1975–90—147,000 tonnes—averages about 10,000 tonnes per year, or 1 percent of the 1973 consumption and 7 percent of the 1973 domestic production. Thus, from the standpoint of both world production and reserves, supplies of asbestos would not appear to be critical as long as imports can be considered secure.

Research that may lead to the discovery of commercial deposits of asbestos in the United States should be accelerated. The theory of plate tectonics provides new perspectives as to the distribution, structure, and emplacement of serpentinites, the host rocks for most chrysotile asbestos. Detailed investigation of areas known to be geologically favorable, such as the western foothills of the Sierra Nevada and Klamath Mountains and the northern part of the Appalachian belt, is recommended.

BARITE

Barite ($BaSO_4$) is a mineral widely distributed mostly as veins in igneous rocks and as veins, nodules, and laminated beds in sedimentary rocks. Its major uses depend on its high specific gravity and inertness.

By far the largest use of barite is as a weighting component in well-drilling fluid. Other uses are for the manufacture of industrial chemicals, ceramics, and glass, and as a pigment, filler, and extender. In the energy industries, it is used mainly in oil and gas exploration and development to contain downhole pressures.

No economical substitute has been found for barite in its principal use. Iron ore is comparable in specific gravity and cost but is more abrasive and stains clothing.

Some small, rich barite deposits are veins and cavity fillings, probably of hydrothermal origin. The larger barite deposits, however, are residual or bedded. Most residual deposits, such as those in Missouri, result from the accumulation of barite residuum over carbonate bedrock. Bedded deposits, such as those in Nevada, are thin layers of dark barite interlayered with dark chert and siliceous shale or siltstone and appear to be of sedimentary origin. Barite also is a common gangue mineral in some metal deposits.

The U.S. reserves of barite, estimated at 59 million tonnes, and identified resources, estimated at 91 million tonnes, are mainly in Nevada, Missouri, and Arkansas—the sites of present-day production. Smaller resources occur in many other States, notably Alaska, California, Illinois, Kentucky, and Wisconsin. In 1973, of 1.4 million tonnes of barite used in the United States, the net imports were about 41 percent, mostly from Ireland, Peru, and Mexico.

World reserves of barite, estimated at 181 million tonnes, and world identified resources, estimated at 289 million tonnes, are fairly evenly distributed in more than a dozen countries. The largest reserves are in the United States, Yugoslavia, and the People's Republic of China.

The estimated demand for about 29 million tonnes of barite by the oil and gas industry 1975–90 averages about 2 million tonnes per year, or about 135 percent of the 1973 annual consumption and 195 percent of the 1973 annual domestic production. A demand of 29 million tonnes is nearly half of the U.S. reserves and a large fraction of world reserves. This stress may be somewhat less severe than it appears, however, because of the very fact that more than 80 percent of the barite produced is used in oil and gas exploration. If exploration should fall off rapidly after 1990, the life of presently known reserves would be greatly extended. On the other hand, deeper drilling after 1990 might require even more barite per year than is projected to 1990. New uses, such as shielding for fusion reactors, may place additional stress on the domestic supply of barite.

Efforts must be made to identify new barite resources. Some possible research programs are: reexamination of old mining districts where deposits of barite mixed with other gangue minerals may have been overlooked; study of rocks deposited in ancient swamp environments where bedded deposits might occur; and more thorough exploration of Alaska, the Appalachian region, salt domes, the sea floor, carbonatites, and layered volcanic rocks. Accelerated research on potential barite resources is recommended.

BENTONITE

Bentonite is the general term given to clays, principally sodium or calcium montmorillonites, with swelling or bonding properties that permit their use as a sealer or binder. Bentonitic clays are sedimentary deposits of altered volcanic ash or tuff generally only a few metres in maximum thickness. The largest known U.S. deposits of sodium (or swelling) bentonite are in the West, especially Wyoming.

Almost all bentonite for projected energy production is swelling bentonite used as drilling mud by the oil and gas industry. About 2.8 million tonnes of bentonite was used for all purposes in the United States in 1973, almost all of which was produced domestically. Twenty-one percent of this total, or about 580,000 tonnes, was swelling bentonite used as drilling mud. The estimated demand for almost 13 million tonnes of swelling bentonite by the energy industries during the 15 years between 1975 and 1990 averages about 850,000 tonnes per year, or about 147 percent of the 1973 U.S. consumption by the oil and gas industry and about 30 percent of the 1973 total U.S. consumption (table 2).

Considerably higher estimates have been made. Industrial Minerals (1975) estimates that 62 million tonnes of Wyoming bentonite will be used in the United States 1975–90, 17.7 million tonnes of it in oil- and gas-well drilling. The oil and gas industry would then use an average of 1.2 million tonnes per year, 207 percent of its 1973 annual domestic consumption. A spokesman for the bentonite industry (Industrial Minerals, 1975, p. 22) projects a 1985 consumption by the oil and gas industry of 1.6 million tonnes per year, almost three times the industry's 1973 consumption. Moreover, about 50 percent of the total U.S. consumption of bentonite is by the steel and metal casting industries, which in turn supply the steel and equipment for the energy industries.

Although U.S. bentonite reserves are estimated at about 900 million tonnes and resources are large, the reserves of swelling bentonite suitable for drilling mud are much smaller, and quantitative estimates are not available. Both transportation and drying add much to production costs. If oil and gas drilling increases as projected, considerable pressure will be placed on the bentonite industry to meet the demand. Research on the composition and distribution of swelling bentonite in the United States, in conjunction with a mapping program, must be emphasized.

BORON

Boron is a light nonmetallic element that occurs in nature only as a compound. Its major uses are in glass, vitreous enamels, soaps and cleansers, and fertilizer. It has many minor uses, such as in metallurgical fluxes, dehydrating agents, fire retardants, and thermal insulators. For many of its uses, boron has no satisfactory substitutes. Soda ash and detergents can substitute in cleansers.

In the energy sector, boron was reported as a component in machinery used by the coal and uranium industries. It is also used for nuclear control elements and radiation shields and a coating material in solar batteries.

Boron is a common constituent of volcanic gasses, which are believed to have been the source of boron materials precipitated in playas, lakes, or fans from springs or vents associated with volcanoes. Because the most abundant boron minerals are highly soluble, they are largely limited to Tertiary or younger rocks and to arid parts of the world. Most boron is produced from Tertiary or Quaternary lake deposits or lake brines. The most common minerals in boron deposits are borax and kernite (hydrated sodium borates) and colemanite (hydrated calcium borate). Tourmaline (a complex silicate containing boron and fluorine) is a common mineral in igneous rocks but is not a potential source of domestic boron in the foreseeable future.

The United States, the world's largest producer of boron minerals, produced 188,000 tonnes of boron in 1973, entirely from southern California. Turkey is the world's second largest producer. U.S. reserves, mainly in southern California, are estimated at 28 million tonnes, and U.S. resources are thought to be large. Most of the world reserves, estimated at 76 million tonnes, and resources are in the United States, Turkey, and the U.S.S.R.

The demand for 41 tonnes of boron by the energy industries 1975–90 averages 3 tonnes per year, less than 0.002 percent of the 1973 U.S. production. Accelerated production of energy should not in itself strain U.S. production capacity; other expanded demands for boron may be far more severe. Boron, like potash, is one of those commodities that are highly concentrated in a few geological environments. It is amenable to rapid and cheap production, therefore to rapid expansion of uses, and ultimately to rapid exhaustion. The reserves and identified resources are large, however, and are sufficient to last centuries at the present rate of use.

CADMIUM

Cadmium is a malleable, ductile, toxic element that occurs as an impurity in zinc-bearing minerals. Cadmium is used mainly in electroplating of fabricated steel products to obtain superior corrosion resistance and in nickel-cadmium batteries. It is also used in the manufacture of pigments, plastics, and television picture tubes, and in alloys. Some observers suggest that cadmium is an essential element in the utilization of solar energy.

Nickel-cadmium batteries presently account for about 20 percent of the cadmium market, and pigments for about 25 percent. Growth in these two areas more than makes up for the decline in cadmium's primary usage, electroplating, which has hitherto consumed nearly 60 percent of the domestic supply.

In some applications zinc can substitute for cadmium. Some industry observers claim that the performance of zinc in electroplating is at least equal to, and in some instances better than, that of cadmium.

The chief source of commercial cadmium is sphalerite, the cadmium content of which ranges from 0.1 to 1 percent. Most of the deposits containing cadmium are the massive-sulfide and stratabound zinc deposits. Because cadmium is recovered as a byproduct of zinc extraction and purification, its production is a function of zinc production.

Domestic reserves of about 300,000 tonnes and resources of about 1.8 million tonnes of cadmium are sufficient to meet U.S. demands to the end of the century and beyond. However, because of the shortages of zinc smelting and refining capacity, the country depends on imports of cadmium to meet its demand and will continue to do so as long as zinc mining, smelting, and refining capacity are not increased.

Recoverable identified resources of the United States are in the Mississippi Valley, Appalachian, Rocky Mountain, and Pacific coast regions.

World reserves of cadmium are estimated at about 1.3 million tonnes, and world resources at nearly 17 million tonnes. These identified resources are principally contained in zinc ores in Canada, Mexico, Australia, People's Republic of China, Peru, Morocco, southwest Africa, Poland, Yugoslavia, and the U.S.S.R.

In the United States, primary production provides about 46 percent of the domestic consumption. The rest is imported as metal, flue dust, or zinc concentrates from Mexico, Peru, Canada, and Japan. In recent years the combined industry stocks and U.S. stockpile release have provided nearly 10 percent of U.S. supply of the metal.

The new zinc smelter in Clarksville, Tenn., which is expected to come on line in 1977, will also produce cadmium. However, the amount produced will depend on the cadmium content of the ores used. Some industry spokesmen point out that much of the new zinc production capacity will be from mines whose ores contain relatively little cadmium.

Industry reports show that a total of about 130 tonnes of cadmium is required by the energy sector 1975–90, or an average annual demand of about 9 tonnes. This demand by the energy sector, less than 1 percent of the total U.S. primary production, does not pose a supply problem. However, the Nation is dependent on imported metal, ores, and concentrates to meet its requirements. Increased zinc production and smelting and refining capacities will decrease U.S. dependency on imports of cadmium.

One potential source of cadmium is byproduct zinc (sphalerite) from coals in the Illinois basin. (See discussion on "Zinc.") Another potential source is byproduct zinc from marine phosphorites mined for use as fertilizers.

CEMENT

Unlike the other materials described in this report, portland cement is neither an element nor a mineral. It is a complex alumino-silicate compound produced by heating to about 1,400°C raw materials that contain calcium carbonate, silica, alumina, iron oxides, and hydrated calcium sulfate. When combined with water, portland cement sets to a rocklike solid.

The raw materials needed for the manufacture of portland cement are limestone, shale or clay, sand or silt and gypsum. All of these materials are abundant nationally—although low-magnesium limestone, the principal and most critical ingredient, is in short supply in some parts of the country. The availability of portland cement, therefore, depends mainly on the availability of cement production capacity rather than raw materials.

The major use of portland cement is as the binder in concrete. Concrete is a rocklike mixture of cement and aggregate (sand and gravel, crushed stone, or slag) in a ratio of 1 part cement to a range of from 2.5 to 4 parts aggregate by weight, depending on the strength of concrete desired. Although aggregate may be in short supply in some localities, it is not likely to be in critically short supply in the rural or suburban areas where it will be needed most by the energy industries. An adequate supply of cement is less assured.

The amount of concrete projected to be needed by the energy industries 1975–90 is large, much larger than the amount of any other material needed (table 1). Most of this concrete would be used in hydroelectric installations and nuclear plants. The projected total maximum demand for all cement needed for concrete by the energy industries 1975–90 is about 81 million tonnes. Over this period the projected demand averages approximately 5.4 million tonnes per year—about 7 percent of the 1973 U.S. production—but the annual demand would probably be erratic depending on the timing of dam and powerplant construction.

If the cement industry expands at approximately the same rate as that at which it has expanded during the past 20 years and as planned for the near future (McCord, 1975, p. 14; Ames, 1975, p. 150), its annual capacity in 1990 will be about 150 million tonnes, of which an estimated 16 million tonnes, or approximately 11 percent, will be needed by the energy industries. The projected demand does seem within the ability of the industry to satisfy. In recent years, however, the cement industry has been operating at more than 90 percent of capacity and imports have risen from 619,000 tonnes in 1964 to 6,027,000 tonnes in 1973, an increase of almost 1,000 percent. Low profit and environmental restrictions have been suggested as major reasons that the industry has not expanded capacity to meet the growing demand. The high cost of energy and the shortage of oil and natural gas may also inhibit expansion. These factors will certainly drive up prices and may well pose the greatest problems for the industry in the next decade.

CHROMIUM

Chromium is a hard, brittle, silvery metal that provides brilliance to steel, hardens and toughens it, and increases its resistance to corrosion, especially at high temperatures. Its principal uses are in transportation, construction, machinery and equipment, refractories, and plating. In metallic form chromium is used in varying percentages for production of iron castings and all types of steel alloys. In the form of chromite it is used for metallurgical, refractory, and chemical applications.

Chromium is an essential element in the production of energy. It is required in nuclear-fission powerplants, in oil and gas exploration and development, in refineries, in coal-mine transportation systems, and in fossil-fuel powerplants.

Aluminum, nickel, zinc, and plastics can be substituted for chromium for corrosive-resistance purposes; nickel, cobalt, molybdenum, and vanadium can be substituted for chromium in some alloys. Titanium can be used as an alternate for many stainless steels, but the lower performance and higher costs preclude this application. It should be pointed out that, with the exception of molybdenum, the United States is dependent on imports for most other materials that can be substituted for chromium.

The types of refined chromium used in making steel include ferrochromium, high- and low-carbon ferrochromium, and ferrochromium silicon. Ferrochromium is used in making stainless steel, heat-resistant steels, and high-temperature alloys for tools, die material, structural steel, and special alloy steels. In the energy sector, for example, steel that is 17 percent chromium is used for nuclear reactors where heat and pressure are considerable.

The mineral chromite is the only commercial source of chromium. It contains between 15 and 64 percent Cr_2O_3 and varying amounts of iron and aluminum. The ores, which are a mixture of chromite and associated minerals, range from about 33 to 55 percent Cr_2O_3.

High-chromium ores are used in metallurgy, high-aluminum chromium ores mostly in refractories, and high-iron chromium ores as the only source of chromium chemicals. These ores, which are used interchangeably to some extent, are referred to as metallurgical grade, refractory grade, and chemical grade ores.

Primary chromite deposits occur only in certain kinds of ultramafic or closely related anorthositic rocks and are of two major geologic types: stratiform (layered) and pod-shaped. The stratiform deposits have great lateral extent and contain more than 98 percent of the chromite resources of the world. The podiform deposits are lenticular or roughly tabular and range in size from a few pounds to several million tons.

The United States has no chromite deposits that can now be worked economically, and the domestic resources of chromite are very limited. The largest known domestic resource of chromite is in the Stillwater Complex, Mont., which has an estimated resource potential of about 7 million tonnes of chromite (Page and Dohrenwend, 1973, p. 4); this amount is only about 5 to 10 years of domestic demand and constitutes 85 percent of the U.S. identified resources. Other small resources are in Oregon, California, Alaska, Wyoming, and Washington.

The largest known world reserves of chromite are in the Republic of South Africa, Rhodesia, and the U.S.S.R. Other countries with substantial reserves include the Philippines, India, Brazil, Turkey, Greece, Albania, Malagasy Republic, Iran, and Finland.

The United States imports all of its chromite, but in recent years about 20 percent of the domestic requirements have been provided from the government stockpile. Rhodesia, the Republic of South Africa, Turkey, and the U.S.S.R. have been major suppliers of chromium to the United States. The Philippines may supply more in the future.

Because of the 1967 embargo on Rhodesian chromite the production of ferrochromium in the United States has declined. During the embargo, without the assurance of a stable ore supply and because of the enactment of pollution control laws, many companies were unwilling to spend money to modernize plants. In 1972 Rhodesian ore became available to the United States again, but these companies were unable to begin producing ferrochromium. After the embargo was lifted, countries with chromite-ore supply, including Rhodesia, began to export ferrochromium rather than raw chromite; thus it was cheaper for the United States to buy ferrochromium than to produce it domestically. In 1973, the United States imported 100,000 tonnes of chromium in alloys for consumption.

The cumulative demand for chromium 1975–90 for energy production has been estimated at 264,000 tonnes of chromium, equivalent to about 18,000 tonnes per year or 3 percent of the 1973 annual consumption. Because the United States is totally dependent on imported chromium, it is apparent that an increase in demand for chromium would pose supply and other economic strains.

The likelihood of finding large, high-grade, domestic chromite resources is extremely small and the eventual utilization of low-grade resources will depend on the availability of large quantities of energy and (or) new recovery techniques. Although many podiform deposits must occur in serpentine along the Appalachian Mountains and the Pacific coast, most would probably be too small to mine at depths of 30 metres or more, even if means were available to locate them. The possibilities of mining low-grade materials in known districts have not been investigated adequately.

COBALT

Cobalt, a strongly magnetic, refractory metal, is widely used in machine tools, carbides, high-strength permanent magnets, alloys, and high-temperature superalloys. More than 80 percent of cobalt used is in some form of metal; the rest is used as oxides in chemicals, as catalysts in the chemical and petroleum industries, and in other applications. Some energy-related end uses of cobalt are in electrical and transportation equipment, paints, ceramics, and glass. Nickel can substitute for cobalt in many applications.

Cobalt occurs in varying amounts in many minerals. It is found in economically recoverable concentrations in mafic and ultramafic igneous rocks, and in contact-metamorphic, massive-sulfide, stratabound, and hydrothermal deposits. It is also found in manganese nodules on the deep-sea floors.

Only in Morocco is cobalt produced as a major product from vein deposits. Elsewhere, it is a byproduct of the mining and processing of copper, nickel, silver, and iron ores.

The United States has no reserves of cobalt. Its identified resources are about 762,000 tonnes, not including the cobalt contained in nickel-copper deposits in the Duluth Complex at Ely, Minn. Mixed sulfide ores of the Mississippi Valley type are the largest resources of cobalt in the United States.

The world reserves of cobalt are estimated at about 2.5 million tonnes and the world's identified resources at 4.5 million tonnes. Additional large resources are in lateritic iron-nickel deposits of the tropical regions of Southeast Asia, Australia, the Philippines and Latin America, and in the deep-sea nodules.

U.S. production of about 200 tons of cobalt is derived from recycled scrap and from pyrite as a byproduct of iron mining in Pennsylvania. Cobalt has been produced from the Gap nickel mine in Pennsylvania and the lead districts of southeast Missouri. U.S. annual demand of nearly 8,500 tonnes, equivalent to about one-third of the world's production, is met by imports from Zaire, Belgium, Finland, Norway, and Canada.

Cumulative demand for cobalt by the energy sector, 1975–90, has been reported to be about 1,760 tonnes of metal, an average of nearly 120 tonnes per year. This amount is a little more than 1 percent of the annual domestic consumption in 1973. Since the United States is importing nearly all its cobalt from foreign sources, the demand by the energy industry is considered significant.

Cobalt resources in the newly developed Viburnum district of Missouri need to be evaluated. In addition to the nickel-copper deposits near Ely, Minn., the Precambrian rocks of the Lake Superior region are likely to contain massive sulfide deposits, some of which may contain cobalt and nickel. The Appalachian Mountains of the Eastern United States are also a vast target for new cobalt resources.

COPPER

Copper is a very ductile metal that has high electrical and thermal conductivities, good corrosion resistance, and high strength. Copper and its alloys have innumerable applications in the electrical, construction, industrial-machinery, transportation, ordnance, and other industries.

In some applications copper is almost irreplaceable; however, in many uses requiring the conduction of heat and electrical energy, aluminum has been substituted for copper. Steel, plastics, glass, and other materials have displaced copper in other applications.

Copper ores are commonly distinguished as oxide ores or sulfide ores. Associated with the ores are minor amounts of gold and silver and in places lead and zinc. Molybdenum is recovered from several porphyry copper deposits, and minor amounts of platinum and selenium may be extracted in refining copper. Rhenium is recovered from byproduct molybdenum produced from some of the porphyry copper deposits. Cobalt is associated with some copper deposits, particularly in central Africa.

The principal types of copper deposits are: porphyry, replacement and vein, massive sulfide, and sedimentary deposits. Deposits of copper are widely distributed both geographically and geologically. Geologically, most copper-ore bodies are associated both in time and location with igneous activity, but some large deposits are found in sedimentary rocks without any known associated igneous activity.

Copper occurs in three major areas in the United States: the Appalachian province, the Keweenaw Peninsula in northern Michigan, and the Cordilleran province of the Western United States. The greatest concentration of copper is in the Southwestern United States, principally in Arizona and New Mexico as bodies of disseminated sulfide—the "porphyry copper" deposits—but large disseminated deposits are also found in Utah, Montana, and Nevada. Northern Michigan, Wisconsin, and Alaska may provide a large portion of the domestic supply of copper in the future.

U.S. reserves of more than 82 million tonnes of copper (21 percent of the world's known reserves) are sufficient to satisfy the total cumulative demand of the Nation through 1990. The cumulative demand to the year 2000, however, will exceed U.S. reserves by nearly 20 million tonnes. U.S. resources of copper are more than 190 million tonnes, about 33 percent of the total known world resources excluding the copper contained in ocean nodules. (See discussion of nodules under "Manganese.")

The world reserves of copper are estimated at about 390 million tonnes, and the world resources are estimated at 586 million tonnes. Important copper-producing regions of the world other than the United States are: (1) central and western Canada; (2) the western slopes of the Andes in Chile and Peru; (3) the central Africa copper belt in Northern Rhodesia, Zaire, and Zambia; and (4) the Ural Mountains of the Kazakhstan regions of the U.S.S.R. Large copper provinces of the future will include the Oceania belt of Indonesia and New Guinea, the Philippines, Australia, Eastern Siberia, Mexico, and Iran.

Production from developed copper deposits in the United States is nearly sufficient to sustain the Nation's domestic industry. In 1973, the United States consumed about 31 percent of the world's output of primary copper and produced about 88 percent (including secondary) of its own requirements. Principal sources of imports were Canada, Peru, Chile, and the Republic of South Africa.

The cumulative demand for energy needs 1975–90 is estimated at about 4.7 million tonnes of copper, equivalent to about 313,000 tonnes of copper annually, 14 percent of the 1973 U.S. consumption and about 20 percent of the 1973 primary production. Thus the demand for copper by the energy industries may place a strain on the domestic copper industry.

The rocks of the Belt basin of western Montana contain stratabound copper deposits in sedimentary rocks similar to those rocks bearing important copper resources in central Africa. Reconnaissance geologic mapping has identified a series of previously unmapped thrust sheets, relatively rich in copper anomalies, that provide a new place to search for stratabound copper deposits.

FLUORITE

Fluorite (CaF_2), a relatively common glassy mineral, is the major ore of fluorine. Fluorine is also a common minor constituent of many other minerals, such as the apatite group. The major uses of fluorite are for hydrofluoric acid (used mainly in the aluminum and fluorocarbon industries), as a flux in the manufacture of steel, and as a component of glasses and enamels.

Fluorite concentrates, commonly known as fluorspar, are marketed as acid, ceramic, or metallurgical grades depending primarily but not entirely on the CaF_2 content. Acid grade contains more than 97 percent CaF_2, ceramic grade 85 to 97 percent CaF_2, and metallurgical grade more than 60 percent effective CaF_2. ("Effective" refers to the fluorite content above that needed to flux the silica contained in the fluorspar itself.)

A large quantity of fluorite will be required to produce the steel and aluminum needed by the energy industries (table 1). Some fluorite is also used directly by the energy industries, but such use is not reported in chapter A (Albers and others, 1976) of this report.

Fluorite deposits are of many types but most can be grouped as either veins and cavity fillings in all types of rocks or as replacement bodies in carbonate rocks. Much current interest is in disseminated fluorite in lake sediments. The total amount of fluorine in phosphate deposits is large, but fluorine can be produced from them only as a byproduct.

The world's major producer is Mexico. Fluorite has also been produced in large amounts from many other countries, notably the People's Republic of China, France, Italy, Republic of South Africa, Thailand, the United Kingdom, and the U.S.S.R. In the United States, fluorite deposits of commercial interest have been identified in Alaska, Arizona, California, Colorado, Idaho, Illinois, Kentucky, Montana, Neveda, New Mexico, Oregon, Tennessee, Texas, and Utah. The Illinois-Kentucky district is the largest in terms of both production and reserves.

U.S. reserves and resources are estimated respectively at about 5 million tonnes and 34 million tonnes of CaF_2. In 1973, about 90 percent of all grades of fluorite consumed in the United States was imported, most of it from Mexico, but significant quantities also from Spain and Italy.

World reserves are estimated at 95 million tonnes, and world resources at almost 190 million tonnes. If the fluorine contained in phosphate rock were included, world resources of CaF_2 equivalent might be 10 times larger. Higher reserve estimates have been published. Grogan and Montgomery (1975, p. 668) estimate "proved and probable" U.S. reserves of CaF_2 at 10.5 million tonnes and "proved and probable" world reserves at 118 million tonnes.

The amount of fluorite equivalent required for manufacture of steel and aluminum for the energy industries 1975–90 is almost 2 million tonnes. The average annual consumption would be about 58 percent of the 1973 U.S. production and 11 percent of the 1973 U.S. consumption. Such a large percentage would put considerable stress on fluorite supply, but not all of the fluorite equivalent would be supplied by fluorite. Fluorite compounds as a byproduct of the phosphate fertilizer industry accounted for 15 percent of the fluorspar equivalent used by the aluminum industry in 1972 (U.S. Bureau of Mines, 1974, p. 541), and their use can be expected to increase. Nevertheless, there is no sign that U.S. dependence on imports, mostly from one country, for 85 to 90 percent of this essential raw material will change greatly in the next few years.

Research to improve prospecting techniques is needed. Fluorine is a constituent of many minerals that are not potential ores, so that pathfinder elements associated with fluorite deposits need to be identified. Fluorite itself is fairly resistant, so placers may lead to bedrock deposits. The separation of fine-grained fluorite from lake sediments needs to be investigated. Perhaps the most promising source of large amounts of domestic fluorine is the phosphate industry.

INDIUM

Indium is a ductile metal that is softer than lead and has a high density. Its principal applications are in transistors, diodes, and rectifiers used in basic electronic computing equipment and in communications and control systems. It is also used in low-melting alloys, in sealant for glass-to-metal and glass-to-glass joints, and in silverware alloys to keep the metal bright. About 25 percent of indium used in the United States is used in research laboratories. Its reported use by the energy industries is in nuclear reactors.

Substitutes for indium are high-purity silicon in transistors, selenium and tellurium in rectifiers, and gallium in sealing glass joints.

Indium is a dispersed element that does not tend to form distinct minerals. It is found in notable concentrations in sulfide ores, especially sphalerite (ore mineral of zinc). It is also associated with some copper-bearing minerals.

The United States has estimated reserves of 10 million troy ounces[1] (311 tonnes) of indium that may be recoverable from lead-zinc ores. The estimated total world reserves are 49 million troy ounces (1,525 tonnes). The U.S. resources of indium that may be contained in the recoverable identified zinc resources are about 58 million troy ounces (1,800 tonnes), and the world resources are about 109 million troy ounces (3,390 tonnes).

Indium produced in the United States is recovered entirely as a byproduct of processing and smelting domestic and imported zinc ores and concentrates. In 1973, the United States consumed about 1.1 million troy ounces (34 tonnes) of indium, of which about 811,000 troy ounces (25 tonnes) were imported, mostly from Canada and Japan. The leading world producers of indium are Canada, the United States, Australia, Peru, Mexico, and Japan.

The total demand for indium by the energy industries 1975–90 is estimated at 4.6 million troy ounces (143 tonnes), equal to about 309,000 troy ounces (9.6 tonnes) per year. This demand is about 28 percent of the total 1973 domestic consumption. About 50 percent of U.S. indium production is a byproduct of smelting imported zinc ores and concentrates; thus additional demand by the energy industries will place supply and other economic strains on the U.S. zinc industry.

Investigations to improve processing methods and recovery of indium are recommended.

IRON

Iron, a relatively hard metal, is predominantly used in its metallic form and in steel, an alloy consisting of iron and a small amount of carbon and manganese. Alloy steels are iron-based materials that contain appreciable quantities of other elements, such as chromium, nickel, manganese, silicon, vanadium, and molybdenum. Aluminum, plastics, concrete, wood, and glass are among many materials that could be substituted for steel in some

[1] One tonne=32,151 troy ounces.

applications. In many instances steel is used instead because of its high strength and relatively lower cost.

The principal iron-ore minerals are the oxides of iron; iron sulfides and iron-carbonate minerals are also utilized. Many iron-ore deposits are known throughout the world. They have been classified as: (1) bedded sedimentary and bedded oolitic deposits, (2) massive deposits associated with igneous and metamorphic rocks, (3) residual deposits, and (4) miscellaneous deposits.

U.S. iron-ore resources are widely distributed, but the largest quantities of identified iron-ore resources are in the Lake Superior region. Other significant iron-ore resources are in the northeastern, southeastern, central gulf, central western, and western regions.

U.S. iron-ore reserves total about 9 billion tonnes and identified resources about 97 billion tonnes. These resources are sufficient to satisfy domestic needs for many decades. However, because higher-grade foreign ores are available at competitive prices, the United States is importing nearly 30 percent of its iron-ore supply. Canada, Venezuela, Brazil, Liberia, and, more recently, Australia have been substantial suppliers of iron ore to the United States.

The world has more than 250 billion tonnes of iron-ore reserves distributed in six continents. Australia, Brazil, Canada, Venezuela, France, India, Liberia, and Sweden account for nearly 40 percent of the total reserves, and the U.S.S.R. for 40 percent. The estimated world resources are 780 billion tonnes.

Iron and steel are used in almost every energy sector. The total iron requirements for 1975–90 have been estimated at about 213 million tonnes of metal, the equivalent of about 850 million tonnes of ore (U.S. grade, 25 to 30 percent Fe). This is almost one-tenth of the total present-day reserves of iron ore in the United States. The average annual demand by the energy industries 1975–90 is about 14 million tonnes of metal, equal to nearly 23 million tonnes of shipping-grade (60 to 65 percent Fe) ore; this demand by the energy sector is equivalent to 26 percent of U.S. production in 1973. Because the Nation is presently importing about 30 percent of its iron-ore supply and nearly 10 to 20 percent of its steel, such an additional demand might pose a strain on the iron and steel industry.

Much of the iron ore classified as reserves in the United States is low grade. Thus, from about 9 billion tonnes of crude ore only about 4 billion tonnes of shipping-grade ore can be obtained. Magnetic taconites, which constitute the major part of iron-ore reserves of the United States, yield one tonne of concentrate (or shipping-grade ore) for each three tonnes of crude taconite. Technology to treat low-grade nonmagnetic taconites has been developed recently; thus vast quantities of this resource will be available to the iron and steel industry in the near future. However, reserves are determined by economic factors and thus are related to existing and planned capabilities of the industry as well as to the availability of raw material. For example, the iron-formation in the Pike's Peak area, Arizona, occupies a distinctive stratigraphic zone but is concealed by an extensive cover in much of the area. The persistence of this zone is indicated by the discovery of an exposure of massive iron-formation precisely on strike 16 km to the northeast of Pike's Peak. This deposit constitutes a large undeveloped iron resource that lies at the edge of the Phoenix metropolitan area and thus has important economic and environmental implications.

LEAD

Lead is valuable because of its relatively common occurrence, simplicity of treatment, high density, low fusibility, softness and malleability, corrosion resistance, and the brilliance and opaqueness of its compounds. For most uses it is alloyed with other metals, principally antimony and tin.

Major uses of lead are in the transportation (storage batteries and gasoline additive), electrical, construction, paint, and ammunition industries. Large quantities of lead are used in nuclear-fission powerplants, in uranium mining and processing, and in coal-transportation systems.

Cadmium, nickel, mercury, silver, and zinc can be substituted for lead to provide stored electrical energy; plastics, galvanized steel, copper, and aluminum can replace lead in construction and other applications. Barite has been proposed as an alternate for lead in radiation shielding, and the development of new materials continues to offer substitutes for lead.

Lead occurs in nature principally in the form of galena, which in most places is associated with silica and zinc, though it may also be associated with gold and copper. In fact, an important part of the lead supply comes from the mining and processing of zinc, copper, silver, and gold. Lead deposits, which are mined in more than 40 countries, are classified as (1) stratiform and stratabound deposits, (2) vein and replacement deposits, and (3) contact pyrometasomatic deposits.

Most of the lead districts in the United States are in: (1) the Basin and Range region of Nevada, western Utah, southeastern California, southern Arizona, and southern New Mexico; (2) the Rocky Mountain Cordillera, extending from the Canadian to the Mexican borders; (3) the Mississippi Valley; and (4) the Appalachian Cordillera. About 80 percent of the United States lead production comes from Missouri, northern Idaho, and northern Utah. Lead is commonly associated with zinc, and in most districts, except in southeast Missouri, is subordinate to zinc in total tonnage. The deposits of the Mississippi Valley have dominated the domestic lead-mining industry during most of the last century, and mine development and exploration in the region will continue to increase U.S. lead reserves substantially in the future. Much favorable ground remains untested in other parts of the Mississippi Valley and in the Basin and Range province.

The total reserves of lead in the United States are currently about 53.5 million tonnes, or about 37 percent of the world total. The total lead resources of the United States are about 81 million tonnes; world resources are large.

The reserves of lead in the United States, Canada, Mexico, and Australia total nearly 90 million tonnes, or about two-thirds of the world reserves, and in 1973 these four countries produced about 40 percent of the total world output. Other major lead-producing nations are Peru, the U.S.S.R., Yugoslavia, Poland, Bulgaria, and the People's Republic of China.

Production from the developed lead deposits in the United States is nearly sufficient to satisfy domestic needs. In 1973, the United States consumed about 1.4 million tonnes of lead, 40 percent of which was from primary sources. U.S. primary production was about 16 percent of the world's total output of lead, but in 1973 the United States produced only 39 percent of its own requirements. Imports were mainly from Canada, Peru, Australia, and Mexico.

Incomplete data obtained from industry suggest that only about 25,000 tonnes of lead will be required by the energy sector 1975–90. No consideration was given to wide use of battery-powered automobiles or battery storage for wind-generated power. The average annual requirement of fewer than 2,000 tonnes is less than 1 percent of the U.S. annual production. The data on hand suggest that no strain will be placed on the lead industry to provide sufficient lead for energy development.

Although this study has not taken into account the material requirements for fusion power, it is of interest to note that in 1973 Fraas (cited in Rose, 1975, p. 77) estimated that 10 million tonnes of lead will be required for 1 million MWe capacity. The quantity of lead required for this capacity (fusion) is 20 times greater than the 1973 U.S. production of lead and about 2½ times greater than the total 1973 world production.

MAGNESIA

Magnesia (MgO) is a chemical compound derived mainly from seawater, surface and subsurface brines, and magnesite. The two major types are refractory and caustic-calcined magnesia. Refractory magnesia is the product of firing the raw material to temperatures above 1,450°C for enough time to produce a stable refractory. Caustic-calcined magnesia is the product of firing the raw material only to a temperature high enough so that less than 10 percent ignition loss remains and the product shows adsorptive capacity (Wicken and Duncan, 1975, p. 806).

About 80 percent of the magnesia consumed in the United States is used as a refractory by the steel industry—approximately 3 kilograms (7 lb) per tonne of steel.[2] Almost half the remainder is used as a refractory by other industries, and the rest is used in chemical processing, manufacturing, and metallurgy. Much is used in the production of aluminum. All magnesia reported to be needed by the energy industries 1975–90 is caustic-calcined magnesia to be used in insulation. The amount of refractory magnesia needed by the steel industry has been added into the total energy requirements listed in tables 1 and 2.

Worldwide, but not in the United States, magnesite is a major source of magnesia. Most magnesite is interbedded with sedimentary rocks and is probably altered dolomite. Some magnesite is altered serpentine. The major producing countries are the U.S.S.R., North Korea, People's Republic of China, Czechoslovakia, Yugoslavia, Austria, and Greece. Since 1938, the production of magnesia from seawater, brines, and other sources has steadily increased. (Magnesium hydroxide is precipitated

[2] Assuming that 75 percent of the refractory magnesia used in the United States is used by the steel industry (Wicken and Duncan, 1975, p. 816), in 1972 approximately 7.8 lb of magnesia were used per short ton of steel. As a result of technological innovations, the amount of magnesia needed is being reduced to less than 5 lb per short ton in some plants (Wicken and Duncan, 1975, p. 816). Thus, for 1975–90, a ratio of 3 kg (7 lb) of magnesia per metric tonne of steel is estimated.

from seawater or other brine by the addition of lime followed by evaporation. The hydroxide is then calcined.)

In the United States, the largest reserves of magnesite are in Nevada and Washington. Only the deposits in Nevada are being worked. Most U.S. production and 90 percent of capacity are from seawater and brines. In 1973, the United States imported a net 97,000 tonnes of refractory magnesia, 13 percent of its supply, mostly from Greece, Ireland, and Japan.

The total demand for magnesia by the energy industries 1975–90 is projected to be 1,310,000 tonnes, of which 588,000 tonnes is calcined magnesia (about 40,000 tonnes per year or about 28 percent of the U.S. consumption of calcined magnesia in 1973) and 722,000 tonnes is refractory magnesia needed by the steel industry (48,000 tonnes per year or about 7 percent of U.S. consumption of refractory magnesia in 1973). On balance, increased energy production should not place great stress on the magnesia industries. The oceans can be considered an inexhaustible source of magnesia available to the United States and many other countries, and U.S. production 1975–90 will probably be limited primarily by world competition. Production of caustic-calcined magnesia will have to be increased greatly if the United States is to avoid heavy dependence on imports.

MANGANESE

Manganese, a hard, brittle metal, is rarely seen in elemental form. About 95 percent of manganese consumption is for ferromanganese, spiegeleisen, silicomanganese, and manganese metal for making steel and other alloys; the balance goes into manufacture of dry batteries and chemicals. Approximately 7 kilograms (about 15 lb) of manganese is required to make one tonne of steel.

Manganese minerals—oxides, silicates, and carbonates—are widely distributed throughout the world. Literally thousands of deposits have yielded commercial-grade ore or concentrate; however, very few of these have produced large quantities of manganese ore, and many have been depleted.

The more important deposits of manganese are very large bodies of sedimentary origin. Many important high-grade oxide-ore bodies are formed by superficial weathering and oxidation of manganese-carbonate sediments. Much less important, although more common, are deposits formed by hot waters as vein and replacement deposits.

The United States has virtually no reserves of manganese ore containing at least 35 percent manganese. Large but extremely low grade deposits totalling nearly 1 billion tonnes are known, principally at Chamberlin, S. Dak.; in the Cuyuna Range, Minn.; in Aroostook County, Maine; and in the Molango district, New Mexico.

World reserves of manganese are very large and are concentrated in West Africa, the Republic of South Africa, India, Mexico, and Australia. The U.S.S.R. probably contains the largest known reserves, and the People's Republic of China is believed to contain large resources.

There is no production of manganese ore containing more than 35 percent manganese in the United States. Production is limited to very small amounts of ferruginous manganese ores and concentrates produced in New Mexico and the Cuyuna Range in Minnesota. The Nation is totally dependent on imports of manganese ore and ferromanganese alloys, and on the national strategic stockpile. In 1973, the United States imported about 350,000 tonnes of ferromanganese and 1.4 million tonnes of manganese ore, together equivalent to nearly 1.4 million tonnes of manganese metal. Brazil, Gabon, Zaire, and Australia supplied most of the manganese ore, while the Republic of South Africa, France, and India were the major sources of ferromanganese for the U.S. steel industry. Some manganese metal was imported from France. More than 90 percent of all manganese consumed in the United States is used by the steel industry, so the demand for manganese will continue to be closely related to steel output.

Steel is required to develop and produce energy from every source. Manganese has no satisfactory substitutes in steel production and therefore is an essential and basic material for energy production and development. The total demand for manganese 1975–90 for increased energy development, estimated at 2 million tonnes, averages about 139,000 tonnes per year, about 10 percent of the 1973 U.S. annual consumption. Because the United States is importing all its manganese supply, the demand by the energy industries may pose a strain on the manganese industry.

The principal hopes of finding domestic reserves or resources of manganese are: (1) Examination of the manganese potentials of southern California where the Pacific rise interesects the rift zone of the Gulf of California. Manganese deposits occur along the rift zone in Mexico, and manganese occurs in brines of the Salton Sea. (2) Study of the geographic and stratigraphic distribution of manganese in miogeosynclinal terranes, particularly in limestone terranes of the Appalachian, Ouachita, and Rocky Mountain miogeosynclines. (3) Study of eugeosynclinal belts of the North American shield areas where manganese-carbonate deposits might be found without the oxidized capping. (4) Evaluation of manganese resources on the deep-sea floor.

Extensive areas of the ocean floor have concentrations of nodules, the populations and metallic content of which differ from place to place. Details on which resource estimates can be based are not publicly available, but the resources of manganese in these nodules, at depths between 2,500 and 6,000 metres, are known to be vast. It is understood that a few areas, each of 2,600 square kilometres or more, have been located in which the nodules average more than 25 percent manganese, 1.0 percent copper, 1.0 percent nickel, and 0.25 percent cobalt (Dorr and others 1973, p. 391). The resources of the seabed will undoubtedly have a great impact on the supply of manganese and also on the supply of other metals. The technology for mining and extracting the valuable elements from ocean nodules is nearly perfected. The principal block to commercial exploration is the present uncertainty as to the legal ownership of deposits on the sea floor. Until this has been settled, the very large investment needed to industrialize this potential resource cannot be made.

MICA

Mica is the general name given to a group of minerals that can be split into thin, more-or-less flexible sheets. The major mica of commercial value is muscovite, a complex hydrous potassium-aluminum silicate common in igneous, metamorphic, and sedimentary rocks. Phlogopite, a complex hydrous magnesium-aluminum silicate, also has commercial importance. Most commercial mica in the United States is a byproduct of feldspar production from pegmatites and of kaolin from clay deposits.

Commercially, mica is classified into two major groups, sheet mica and scrap mica, the latter of which includes flake mica. To be classified as sheet mica, the sheets must meet minimum specifications as to the area. Smaller sizes are scrap, but scrap and synthetic mica can be built up or reconstituted into a form of mica suitable for some of the same uses as sheet mica. The major uses of sheet mica are in electrical components such as vacuum tubes and in electrical insulation. Scrap mica is used principally as an inert component of joint cement, paint, and roofing.

The United States imports almost all its natural sheet mica from India and Brazil. It produces almost all its scrap mica in North Carolina and six other States. Annual U.S. consumption of sheet mica has declined in the past 25 years from about 6,000 tonnes in the early 1950's to about 2,700 tonnes in the early 1970's. Annual U.S. consumption of scrap mica during the same period has increased from about 68,000 tonnes to about 120,000 tonnes.

Sheet mica is a critical commodity in that U.S. production and reserves are small. Although changing technology has reduced the need for sheet mica drastically, some is still stockpiled. In 1973, exports of sheet mica from the stockpile exceeded imports. The present study revealed no substantial demand for sheet mica by the energy industries.

The major use of scrap mica by the energy industries is for insulation. The estimated demand for about 5,400 tonnes of scrap mica by the energy industries 1975–90 is about 360 tonnes per year, only 0.2 percent of 1973 production. Both reserves and resources are so large that they cannot be quantified. Increased energy production should place no undue stress on the scrap-mica industry.

MOLYBDENUM

Molybdenum, a refractory metal, is an important alloying metal in the iron and steel industry, and is important also in chemicals, catalysts, lubricants, pigments, and agriculture. In the energy field, because of its hardening and strengthening properties, molybdenum finds its application in oil and gas pipelines and drilling equipment, abrasive-resistant castings for the mining industry, and powerplant equipment. It is used in catalysts to remove sulfur from high-sulfur crude.

Molybdenum can generally be replaced by graphite as a refractory material in electric furnaces. Chromium, tungsten, and tantalum can be substituted for molybdenum in some applications, but at higher cost. Boron can replace molybdenum in some steels where hardening is the only desired effect.

Molybdenite (MoS_2), the ore mineral of molybdenum, is extremely widespread and occurs in almost every country of the world. Deposits of commercial significance, however, are restricted to relatively narrow, well-defined tectonic belts and are associated with zones of volcanic activity.

Molybdenite occurs alone or intimately associated with quartz and pyrite in granitic or monzonitic rocks, as at Climax and Urad-Henderson in Colorado and at Questa, N. Mex. This type of occurrence accounts for the bulk of the world's molybdenum reserves. Much more commonly, however, molybdenite occurs in small amounts with copper sulfides in the typical porphyry copper deposits of the Western Cordillera of North and South America. Molybdenum-bearing copper ores have provided a significant portion of the world output of molybdenum as a byproduct. Rhenium, recovered as a secondary byproduct from molybdenum, is a high-temperature metal and is attracting growing interest as a catalyst and alloying metal.

Three-fourths of the world's reserves of molybdenum are in the Western Cordillera of North and South America, extending from British Columbia in the north to Argentina in the south. These reserves are in large, low-grade, disseminated deposits that occur in clusters throughout the length of the Cordillera. Of the remaining one-fourth of the world's reserves, half are in the U.S.S.R., and the rest are in parts of Europe and southwest Asia, Southeast Asia including the People's Republic of China, the islands of the South Pacific, and Australia. The bulk of the molybdenum resources, estimated at more than 28 million tonnes, is divided among the United States, Canada, Chile, and the U.S.S.R.

The United States, a net exporter of molybdenum, produced about 64 percent of the world production in 1973. Production outside the United States was principally in Canada, the People's Republic of China, Chile, and Peru.

The total amount of molybdenum reported to be required by the U.S. energy industries 1975–90 is nearly 80,000 tonnes, for an annual average of about 5,300 tonnes. This amount is about 10 percent of the 1973 U.S. production and 16 percent of the 1973 U.S. consumption. In addition, it is estimated that nearly 18 million tonnes of high-quality steel will be needed to build some of the major oil and gas pipeline projects now planned, and about 2.5 kilograms (5½ lb) of molybdenum is needed for each tonne of high-quality steel. About 45,000 tonnes of molybdenum will be required for this purpose alone.

The U.S. reserves of molybdenum are sufficient to satisfy the overall needs of the Nation to the end of this century and beyond, and its resources are large. Additional demand by the energy sector is not likely to pose any strain on the supply or the production of molybdenum in the foreseeable future.

NICKEL

Nickel, a ductile and partially magnetic metal, belongs to the iron-colbalt family. An important alloy in steel, it adds strength and corrosion resistance over a wide range of temperatures.

Manufacturers of chemicals and petroleum refineries are the principal users of nickel. Major uses are in stainless steel, high-nickel alloys, nickel plating, copper alloys, and catalysts. In the energy field, nickel is used in nuclear-fission powerplants, oil and gas industries, uranium mining and processing, fossil-fuel powerplants, and storage batteries.

Possible substitutes for nickel are chromium-manganese alloys in stainless steel; niobium, chromium, molybdenum, and vanadium in some steel alloys; and colbalt-chromium and niobium-based materials in superalloys. Plastics and titanium can replace high-nickel alloys in some applications.

Nickel-iron sulfide (pentlandite), the principal nickel mineral in economic ores, is usually associated with chalcopyrite and pyrite. Nickel also occurs associated with pyrrhotite and pyrite, particularly where these minerals are in mafic and ultramafic rocks. Nickel-magnesium hydrosilicate (garnierite), usually referred to as nickel-oxide ore, is the economically important ore mineral in lateritic nickel deposits, which are found in mantles formed by weathering of mafic and ultramafic rocks in many tropical and subtropical regions of the world. (Garnierite is actually a mixture of nickeliferous serpentine, nickeliferous talc, and possibly other silicates.)

Massive and disseminated sulfide, lateritic, and vein deposits are the three major types of nickel deposits. Sulfide deposits are the most important, in both quantity of nickel and the number of deposits; however, lateritic deposits are becoming more and more important because large accessible tonnages are near the surface and can be mined by open-pit methods. Colbalt is also recovered from lateritic deposits as a coproduct or byproduct. Vein deposits are of relatively minor importance as sources of nickel. In some places, nickel is produced as a coproduct of copper mining.

In the United States, nickel was once produced from sulfide deposits at the Gap mine in Pennsylvania, but now is produced only from lateritic deposits at Nickel Mountain, Riddle, Oreg. Large low-grade resources of nickel are contained in sulfide deposits in Minnesota, Montana, Missouri, Maine, and the Brady Glacier region, Alaska. Smaller sulfide deposits occur in California, Colorado, Nevada, Pennsylvania, and Washington. Large nickeliferous lateritic depisits exist in Oregon, California, Washington, and North Carolina.

The U.S. reserves of nickel are estimated at about 181,000 tonnes of contained nickel, and low-grade resources contain more than 15 million tonnes. The world's reserves of nickel are estimated at nearly 45 million tonnes, and the world resources are conservatively estimated at about 70 million tonnes.

Canadian reserves of mineable sulfide ores are the largest in the world; Australia, the Republic of South Africa, Burma, Yugoslavia, and the U.S.S.R. are among the other countries with large reserves of this type. Large lateritic deposits of nickel exist in the Philippines, Indonesia, New Caledonia, Australia, the Solomon Islands, Cuba, Guatemala, Venezuela, Colombia, Puerto Rico, Brazil, and Greece. Manganese nodules in the Pacific Ocean contain about 1 percent nickel and are a large source of nickel for the future.

The United States has annual primary production of about 16,000 tonnes of nickel and consumes more than 200,000 tonnes annually, almost one-third of the world's total production. Nickel is imported mostly from Canada and Norway; small amounts are imported from other countries. Canada produced about 35 percent of the world's production in 1973; other large producers were New Caledonia, Greece, Yugoslavia, and Cuba.

The total U.S. requirements of nickel for energy development and production 1975–90 are estimated at about 264,000 tonnes. The average annual requirement of nearly 18,000 tonnes is about 8 percent of the U.S. 1973 consumption but exceeds the U.S. annual production. Furthermore, the Nation's available reserves of about 180,000 tonnes are only about 69 percent of the total cumulative demand by the energy sector.

Several new deposits of nickel are being developed throughout the world and will come into production by 1980. Thus, the world supply of nickel seems adequate to meet the U.S. demand. However, because the United States is importing nearly 85 percent of its annual requirements of primary nickel or about 73 percent of all the nickel it uses, it is apparent that increased demand by the energy sector will pose a serious economic problem.

Vast quantities of nickel would become available to the Nation's industry if techniques were developed for economical mining and processing of low-grade resources in the United States. The very large low-grade resources in the Duluth Complex, near Ely, Minn., deserve much attention. These resources promise to be the largest in the United States, but much study is needed to determine their extent, tonnage, and grade as well as to develop exploration models to aid in examining the rest of the Complex for similar deposits.

NIOBIUM (COLUMBIUM)

Niobium is a relatively soft ductile metal whose principal ore minerals, pyrochlore and columbite, are mostly associated with alkalic or granitic rocks. Pyrochlore is a complex oxide of niobium, sodium, calcium, and other elements, and columbite is a complex oxide of niobium and tantalum. Many pyrochlore deposits are found in carbonatites; columbite deposits are commonly in pegmatites. Some niobium is produced as a byproduct of tin mining. Because of their high specific gravity, pyrochlore and columbite are also concentrated in placers.

The major use of niobium is as an alloy in specialty steels, including stainless steel and high-strength, low-alloy steel used in many construction materials. In the energy industry the largest amounts reported would be used in oil and gas pipelines.

A few metals can substitute for niobium in various degrees in various alloys. Vanadium can substitute to a large degree, and tantalum, chromium, molybdenum, and tin to a lesser degree. For some uses, ceramics and glass-reinforced plastics are possible substitutes. Nevertheless, industry's reliance on niobium for alloys has depended on desirability as well as cost. For some potential uses, such as superconductors to contain magnetic fields in fusion reactors, niobium may be essential.

Most of the world's niobium resources lie outside the United States, and the United States can expect to remain dependent on imports in the foreseeable future, largely from Brazil, Canada, and Nigeria. The United States does have low-grade reserves in Colorado and Idaho estimated at 68,500 tonnes and resources estimated at about 110,000 tonnes. The "reserves," however, are so marginal that the deposits cannot be mined except under government subsidy and have not been worked since 1958. Resources may be increased substantially by the recent discovery of niobium associated with a large titanium deposit in southwestern Colorado (Wall Street Journal, 1976, p. 6). About 2,745 tonnes of niobium were used by all U.S. industry in 1973, all of which was from imports and shipments from government and industry stocks. Most imports were from Brazil.

The estimated demand for 915 tonnes by the energy industries 1975–90 averages about 61 tonnes per year or about 2 percent of the 1975 U.S. consumption, a figure that appears to be far too low. In 1975, about 494 tonnes were used by the oil and gas industries, 20 percent of U.S. consumption in that year.

In order to stimulate exploration for new or additional deposits of niobium, intensive investigations using geological, geochemical, and geophysical techniques should be conducted in areas of known deposits and in potentially mineralized areas. Basic geologic research in the geochemistry of niobium and tantalum to understand the genesis and distribution of these elements in rocks and ores should lead directly to the targeting and modeling of deposits and possibly to the discovery of new types of deposits.

SILICON

Silicon is a lightweight, brittle metalloid whose principal uses are as silicon, ferrosilicon, and other silicon compounds in the metallurgy of steel and aluminum. Its largest potential use reported by the energy industries is in photovoltaic cells. Its use in photovoltaic cells, as in the electric industry in general, depends on its property as a semiconductor and requires a high degree of purity.

As a deoxidizer in the production of iron and steel, silicon could be replaced by other deoxidizers, such as aluminum, manganese, and zirconium. As an alloy with aluminum, it could be replaced by a metal such as copper. As a semi-conductor it could be replaced, within limits, by germanium. All substitutes are more expensive than silicon.

Silicon does not occur in elemental form in nature. It is produced from quartz, one of the most abundant minerals in the Earth's crust. The U.S. and world deposits of quartz are so vast that the supply of silicon can be considered limited only by demand.

The preparation of ferrosilicon and the separation of silicon from quartz do require large amounts of electrical energy, which accounts in part for the geography of its imports. In 1973, the United States imported about 64,000 tonnes of silicon, 11 percent of its requirements, from Norway, Sweden, France, Canada, and other countries. In 1968, the United States imported only 2 percent of its requirements; in fact, the United States was a net exporter.

Only 3,500 tonnes of silicon were reported needed by the energy industries 1975–90, about 0.7 percent of the 1973 U.S. production and 0.6 percent of the 1973 U.S. demand. Much more silicon would be used to produce the steel and aluminum needed by the energy industries 1975–90, so that the total requirement would be closer to 815,000 tonnes or an average of 54,000 tonnes per year, 10 percent of the 1973 U.S. production.

Neither the United States nor the world need ever be concerned about the supply of raw materials to produce silicon and ferrosilicon. The critical factor in producing silicon is the cost of energy to separate it from its oxide. The United States will probably continue to increase its reliance on foreign imports as long as cheaper energy is available abroad.

SILVER

Silver has the highest electrical and thermal conductivity of all metals; it is exceptionally ductile and malleable and is stable in air and water. Silver is the key to excellent performance in photography, which application accounts for about 30 percent of total U.S. consumption. Silver is used also in electrical switching, brazing and soldering, batteries, bearings, catalysts, electronic components, sterling and plated ware, coins, jewelry, and in other applications.

Incomplete data from industry suggest that a major use of silver by the energy sector is in nuclear-fission powerplants. Not reported but necessary to consider are its uses in development of mirrors for utilization of solar energy, in magnetic equipment, in lead storage batteries, and in corrosion-resistant, long-lasting anodes for protection of offshore drilling rigs. As an example, industry estimates (Metals Week, 1975, p. 6) indicate that about 1 tonne (32,151 troy ounces) of silver would be required to silverback about 260 hectares (1 square mile) of an array of mirrors in a solar energy system to supply 100,000 people. Aluminum, though not as efficient, could be a substitute for mirror backing.

Stainless steel, aluminum, rhodium, and tantalum may be substituted for silver in some applications; but the total substitution if made will be very small compared to the total U.S. consumption.

Minerals in which silver occurs are numerous; they can be roughly classified as native silver, carbonates, sulfides, halides, oxides, and sulfates. Deposits of silver are of two types: (1) mineral deposits in which silver is recovered as a byproduct and coproduct, and (2) deposits in which silver is the major constitutent. The principal sources of silver are copper, lead, zinc, and nickel ores, from which it is recovered as a byproduct.

Porphyry copper deposits as a group are the major sources of silver in the United States, accounting for nearly 20 percent of domestic production. Although the percentage of silver in the copper ores is low, the amount of silver recovered is large because vast tonnages of ore are mined; however, with the introduction of in-situ leaching and recovery of copper from low-grade porphyry deposits, some of the silver recovered by conventional mining and processing may not be recovered in the future.

Silver is also a byproduct of lead and zinc, but the lead and zinc industry is increasingly dependent on eastern ores that are low in silver. Future silver production in the United States will thus depend principally on copper-silver deposits of several types and upon such ores in which silver is the main product.

The leading silver-producing areas in the United States are Idaho, Arizona, Utah, Montana, Colorado, Missouri, and Michigan. The Coeur d'Alene district of Idaho, the leading single producing area, is one of the few active mining districts in the world where significant amounts of ore are mined for their silver content. Canada, Peru, and Mexico are the largest producers of silver in the Western Hemisphere.

U.S. reserves of silver are estimated to be 1,500 million troy ounces (46,650 tonnes), and the identified resources are nearly 2,300 million troy ounces (71,500 tonnes). The world reserves are estimated at 6,000 million troy ounces (186,600 tonnes).

The United States produced about 38 million troy ounces (1,180 tonnes) of silver in 1973, and the world production was about 306 million troy ounces (9,500 tonnes). The U.S. consumption of primary metal was about 162 million troy ounces (5,000 tonnes), more than half of the world's primary production. Imports of about 131 million troy ounces (4,000 tonnes) of silver from Canada, Mexico, Peru, Honduras, Ireland, Australia, and other areas provided nearly 61 percent of the total U.S. supply. Secondary recovery of silver accounted for a significant portion of U.S. supply.

The total reported requirement by the energy sector is about 36 million troy ounces (1,120 tonnes) of silver 1975–90. The average annual requirement of 2.4 million troy ounces (75 tonnes) of silver is small, only about 1.2 percent of U.S. annual consumption.

Resources of silver in the United States will be increased substantially when economic conditions will justify exploration and mining of large low-grade deposits. The stratabound copper deposits may be one of the world's largest potential sources of silver. Possible economic concentrations of copper-silver in the Precambrian rocks (Belt Supergroup) of Montana and Idaho have been recognized only recently. Perhaps one of the greatest silver anomalies in the United States is in southeast Missouri and the Appalachian Mountain belt; large areas in Alaska are favorable targets, and the Western United States is still considered prime prospecting ground.

TIN

Tin is a nontoxic metal that melts easily and is extremely fluid in its molten state. It has many applications in construction and in communication systems. Tin plating accounts for more than 40 percent of all tin consumed and soldering for about 25 percent. It is also used in printed circuit boards for the electronic industry, in bronze, in casting alloys, and in bearings.

In the energy field, use of tin is reported in nuclear-fission powerplants, in uranium mining and processing, and in coal transportation systems. An alloy of tin and niobium has been developed as a superior superconductor for possible use in thermonuclear fusion power generation.

With the exception of soldering, where no satisfactory replacement for tin has been found, several materials may substitute for tin in various applications: plastics, glass, aluminum, and paper in tin plating for cans; copper, aluminum, and zinc products in construction; low-tin aluminum-, copper- or lead-base roller bearings and ball bearings for babbitt metal; other chemicals in insecticides and similar applications.

Practically all the tin of commerce comes from the mineral cassiterite (SnO_2), which is heavy and chemically resistant. Some tin sulfide minerals such as stannite are produced along with cassiterite in the Bolivian mines. Tungsten is the most important coproduct or byproduct of tin mining.

Tin displays a well-marked geologic association with specific rock types. All the large tin deposits except those in Bolivia are related to acidic granitic rocks or rhyolites that are chemically equivalent. In Bolivia the tin deposits are associated with dacites and rhyodacites.

In gerneral, three types of tin deposits—lode, pegmatite, and placers—are mined commercially for tin.

Because of cassiterite's weight, chemical inertness, and tendency to occur disseminated widely in granitic rocks, placer deposits of great size have formed. Subsequent leaching and weathering tend to remove the sulfide minerals from these placer deposits leaving a residue of cassiterite and other chemically inert minerals such as monazite, columbite, tantalite, ilmenite, and in a few places small amounts of gold. Hence, cassiterite ores derived from placer deposits are easily concentrated and yield other valuable minerals. However, concentrates rich in sulfides, as in Bolivia, require further treatment in hydrometallurgical or other plants.

Proved tin reserves of about 40,000 tonnes in the United States are the equivalent of only 60 percent of U.S. annual consumption of the metal. New resources of some magnitude were discovered recently by drilling near the Lost River area, Alaska. However, in these deposits production of tin will depend upon a commercially viable byproduct such as fluorite, tungsten, or beryllium. Continuing work in the Seward Peninsula, Alaska, has led to discovery of nearly 60,000 tonnes of lode tin. However, the total identified reserves and resources of the United States are less than 3 year's supply at the 1973 level of annual consumption.

Most of the world's reserves of tin are in Malaysia, Thailand, and Indonesia. Australia, Bolivia, Brazil, Nigeria, Zaire, the U.S.S.R., and the People's Republic of China also have significant reserves of the metal. Of great interest is recent exploration activity in Brazil, Australia, and Cornwall, England, with significant production from those countries possible in the near future.

Although large resources of tin are available in Bolivia and Brazil, most resources are in Southeast Asia and Australia, and possibly the People's Republic of China and the U.S.S.R. Large resources are likely to be developed in Burma.

The U.S. annual production of tin has been estimated at less than 100 tonnes and is principally the byproduct of molybdenum mining and processing in Colorado and the coproduct of placer gold operations in Alaska. The United States is therefore almost totally dependent on imports from Malaysia, Thailand, Indonesia, and other countries. Secondary recovery accounts for a significant portion of U.S. supply. The United States consumed about 67,000 tonnes of tin in 1973, of which more than 51,000 tonnes were imports. The remainder was provided by secondary recovery and by sales of surplus inventories of tin from the national stockpile.

Incomplete data reported by industry indicate that about 1,500 tonnes of tin will be required by the energy sector 1975–90, or about 100 tonnes of tin annually. However, Rose (1975) suggested that 80,000 tonnes of tin will be required to develop 1 million MWe capacity in nuclear fusion reactors. This amount is greater than the total 1973 U.S. annual consumption of tin.

North America generally lacks tin deposits; however, recent geological investigations in Alaska indicate a new belt of previously unmapped granitic rocks which has potential for tin. Recent discoveries of numerous occurrences of tin in central Idaho suggest that potential tin resources may have been overlooked and that this area should be the subject of intense geological investigations. The presence of tin sulfide minerals in several old lead-silver mines in Idaho suggests a similarity to the Bolivian tin-silver deposits; early mining efforts might have overlooked this potential. Tin occurrences associated with acidic volcanic rocks in the Southwestern United States, which resemble tin occurrences in similar rocks in Mexico and elsewhere in the world, warrant geological investigations.

TITANIUM

Titanium is a lightweight metal that has high strength and resistance to corrosion. Although discovered in 1790, it was not produced commercially until the 1950's. The two most abundant titanium minerals are ilmenite ($FeTiO_3$) and rutile (TiO_2). Rutile is the major ore of titanium metal because extraction of titanium from rutile costs less and produces less waste than extraction from ilmenite. Ilmenite is primarily a source of titanium oxide.

About 85 percent of all titanium metal is used in the structural components of aircraft and space vehicles, where a high strength-to-weight ratio is desired. Most titanium oxide is used as a pigment because of its whiteness, high refractive index, and inertness. The major projected use of titanium metal reported by the energy industries 1975–90 is as a heat exchanger. (The amount of paint, which contains much titanium oxide, needed by the energy industries was not included in this study.).

Rutile is a widespread accessory mineral in metamorphic and igneous rocks. Because of its high specific gravity, rutile is concentrated with other heavy minerals such as magnetite and zircon in placers. Ilmenite is found in commercial quantities almost entirely in anorthositic or gabbroic rocks, generally associated with magnetite, hematite, or rutile, and in placers. Ilmenite is also found in carbonatites and metamorphic rocks.

About 585,000 tonnes of titanium, of which 27,000 tonnes was metal, was used for all purposes in the United States in 1973. Imports, mostly from Australia, amounted to 95 percent of the U.S. supply of rutile, the major ore of titanium. Taking into consideration the imports of titanium metal from Japan and the U.S.S.R., the United States was directly or indirectly almost 100-percent dependent on imports for titanium metal.

The domestic reserves of rutile are only about 450,000 tonnes. The identified domestic resources are also small, about 3 million tonnes, mostly in ancient beach deposits scattered along the southeast coast. The Trail Ridge deposits in Florida and Georgia have been the major sources for domestic production. Some rutile has been produced from bedrock deposits in Virginia.

The domestic reserves of ilmenite are about 91 million tonnes. The identified domestic resources are also large, about 508 million tonnes. The major lode-deposits are titaniferous magnetite bodies in the Sanford Lake District, N.Y., from which more than 10 million tonnes of ilmenite have been recovered since the early 1960's. Ilmenite is also recovered from sands in Florida, Georgia, and New Jersey. Substantial resources of ilmenite are in Arkansas, California, North Carolina, Virginia, and Wyoming. A deposit recently discovered in Colorado (Wall St. Journal, 1976) may contain about 27 million tonnes of titanium. Smaller deposits are found in other States.

World reserves of rutile are about 8 million tonnes, and identified world resources (including a closely related mineral, anatase) are about 38 million tonnes. The largest deposits are in Brazil, Australia, the United States, Mexico, and Sierra Leone. The world reserves of ilmenite are about 410 million tonnes and world resources about 3.3 billion tonnes. Major deposits are found in Australia, Brazil, Canada (Quebec), Mexico, Norway, and many other countries.

Some 7,000 tonnes or 98 percent of all the titanium projected to be used by the energy industries is in geothermal powerplants. This amount averages 470 tonnes per year 1975–90, less than 0.5 percent of the 1973 U.S. consumption.

Though the demand for titanium for energy-related uses is small, any demand is severe because the titanium industry relies almost entirely on imports. The basic problem is technological. Titanium metal can be produced from ilmenite, the reserves of which are large, but at higher cost in both terms of dollars and damage to the environment. For the long run, then, chemical and metallurgical research on the recovery of titanium from ilmenite offers the most promise for decreased dependence on imports. An appraisal of the resource potential of titanium in ultramafic rocks, such as the Duluth gabbro, is also recommended. For the short run, while the titanium industry depends on rutile imports, geologic exploration for new deposits of rutile is urgently needed. Aeroradioactivity coverage of much of the outer Atlantic Coastal Plain would aid in the search for placer deposits.

TUNGSTEN

Tungsten, a hard and heavy metal, has unique physical and mechanical properties. It is best known as a base metal for tungsten-carbide tool bits and as an alloying ingredient in steel. The uniqueness of tungsten is based on two physical characteristics—it has a very high density, exceeded only by noble metals, and it has exceptionally strong cohesion between its atoms. It imparts to its alloys and compounds extreme hardness, high tensile strength, adequate conductivity, high wear-resistance, and the ability to retain hardness and strength at elevated temperatures.

Principal uses of tungsten are in carbides, high-speed tools, filaments for electric lamps, high-temperature alloys, space crafts, and powder metallurgy. In the energy field, tungsten is used in equipment for oil and gas exploration and development, uranium mining and processing, coal-transportation systems, and fossil-fuel powerplants. Tungsten is frequently the selected metal for structural parts requiring good radiation-shielding properties.

Molybdenum can replace tungsten in some uses; so can tantalum, but at higher costs, Titanium, tantalum, and zirconium carbides can be substituted for tungsten carbides, although the unique properties of tungsten in carbides restrict such substitution.

Of the dozen or more minerals that are known to contain tungsten, only those of the wolframite group (ferberite, wolframite, and huebnerite) and scheelite are of economic importance. Tungsten is found in a wide variety of occurrences, but almost all the world resources are associated with areas of granitic intrusive rocks or their related porphyries. The principal types of tungsten deposits are vein, contact metamorphic (tactite), replacement, stockwork, and placer. Some hot springs associated with deep-seated magmatic activity discharge appreciable tungsten, and in a few instances this tungsten has been deposited in sufficient concentrations that it has been economically exploited. At least in one instance, at Searles Lake, Calif., hot springs have supplied tungsten, boron, and other materials to the lake waters, which have been further concentrated by evaporation into brines that are a potential tungsten resource.

Worldwide, vein deposits have been the most productive and probably contain the largest world resources, but in the United States contact metamorphic deposits account for nearly 75 percent of total domestic production. The economic recovery of tungsten in many deposits is materially assisted by the value of associated metals, including molybdenum, tin, copper, silver, and gold.

The United States has reserves of about 118,000 tonnes of tungsten and total identified resources of 300,000 tonnes. Except for the tungsten deposits near Henderson, N.C., all known tungsten deposits in the United States are located in the Western

States. Tungsten is produced from several localities in Arizona, Colorado, Montana, Utah, and Nevada, but the two largest deposits, near Bishop, Calif., and near Leadville, Colo., account for 75 percent of domestic production. A significant amount of tungsten is produced at Climax, Colo., as a coproduct or byproduct of molybdenum mining and processing operations.

The most important tungsten region of the world outside of the United States is in the People's Republic of China, which produced nearly 20 percent of the 1973 world output. Other major tungsten regions are the U.S.S.R., the Republic of Korea, North Korea, Thailand, Burma, Bolivia, Brazil, Canada, and Australia.

In 1973 the United States produced about 3,400 tonnes of tungsten and consumed nearly 7,000 tonnes. About 5,000 tonnes were imported and nearly 680 tonnes were released as surplus inventory from the national stockpile. Some of this material was added to industry stocks; the net imports supplied nearly 70 percent of the total U.S. demand.

The total cumulative domestic demand for tungsten 1975–90 has been estimated at nearly 215,000 tonnes, exceeding the total reserves of the United States. The total demand by the energy industries 1975–90 is estimated at about 40,100 tonnes or an average annual requirement of nearly 2,700 tonnes of tungsten. This demand by the energy sector is about 78 percent of the 1973 U.S. annual production, and thus will pose supply and other economic strains.

Tungsten will continue to be an important commodity for which only limited substitution can be projected, and thus exploitation of lower grade deposits and discovery of new resources are essential. The brines of Searles Lake, in addition to known deposits at Mineral Ridge, Idaho; Redlick, Nev., Wah Wah district, Utah; Canyon Creek, Mont.; and other scattered areas in Colorado and Arizona, are potential sources of tungsten. Of great interest is recent exploration of two new large tungsten deposits in Nevada that may improve the U.S. resource position. On the basis of available geological information and the distribution of known tungsten deposits in the United States, the most promising regions for the discovery of new tungsten districts or extension of known districts are in the Basin and Range provinces of Nevada and adjoining States and in central Idaho and Montana.

VANADIUM

Vanadium is a metal used mainly to toughen, strengthen, and control grain size in ferrous and nonferrous alloys. Its major use is in specialty steels, including high-strength, low-alloy steel for such products as bridges, high-pressure pipe, and storage tanks. Large percentages of the total consumption go into full-alloy, carbon, and tool steels. Its major identified uses by the energy industries are in oil and gas pipelines and fossil-fueled powerplants.

A few metals can substitute for vanadium in various degrees in various alloys. Among them, niobium can substitute to a large degree and molybdenum and tungsten to a lesser degree. Nickel-bearing steels can substitute for chromium-vanadium steels. Except for molybdenum, these substitutes are in short domestic supply.

In the United States vanadium is presently recovered mainly from altered sedimentary and igneous rocks along the boundary of an alkalic intrusive in Arkansas and as a coproduct from western uranium ores and phosphate rock. Like uranium, vanadium is most soluble in its most highly oxidized state and therefore is transported by water until it is precipitated in a reducing environment; thus it tends to be concentrated in such deposits as phosphorites and oil shales. In igneous rocks, its highest concentrations are generally in mafic rocks. It is also concentrated in natural asphalts and in wastes recovered from refining or burning of some crude oil.

U.S. reserves of vanadium are estimated at about 100,000 tonnes and world reserves at about 10 million tonnes, but U.S. and world resources are large. Most of the vanadium that can be recovered economically in the near future is in deposits of magnetite; in fact, the major world reserves are in the titaniferous magnetites of the Republic of South Africa. Potential vanadiferous magnetite deposits have been identified in Alaska, Wyoming, and New York. Magnetite deposits in Canada and many other countries also show promise. Vast quantities of vanadium are disseminated in black shales and phosphorites, although the vanadium cannot be extracted economically in the foreseeable future, except as a byproduct.

About 7,750 tonnes of vanadium were used by all U.S. industry in 1973, of which 43 percent was from net imports and shipments from government and industry stockpiles. Most of the imports were from the Republic of South Africa and Chile. The estimated demand for 3,810 tonnes of vanadium by the energy industries 1975–90 averages about 250 tonnes per year or 3 percent of the 1973 U.S. consumption and 6 percent of the 1973 domestic production.

Thus, in terms of future energy production alone, the amount of vanadium needed is small. In terms of all U.S. needs, however, the supply picture is not favorable. Consumption has outpaced production so that within the past decade the United States has changed from a net exporter to a net importer of vanadium. In fact, imports or shipments from stocks supply almost half of the U.S. demand. Moreover, present production is largely as a coproduct from uranium-bearing sandstones, and the reserves of vanadium in this type of deposit are small. Other production, as that from western phosphorites, flue dust, and some iron slags, is as a byproduct—thus dependent on demand for the major product.

Because of the rapid increase in use of vanadium that has led the United States into dependency on imports, the vanadiferous magnetites in the United States should be identified, mapped, and sampled in considerable detail so that in an emergency the United States could greatly increase domestic production.

ZINC

Zinc is chemically active and alloys readily with other metals. It is used principally in metallic form in castings and rolled zinc, as a major alloying ingredient in brass, as a protective coating for iron and steel, and in chemical compounds in paints and rubber. In the energy field, zinc has been reported to be needed in uranium mining and processing, in nuclear-fission powerplants, and in coal-transportation systems.

No substitute for zinc in large anti-corrosion claddings has been developed. However, in some applications, the following can substitute for zinc: aluminum, plastics, and high-strength alloy steel in electrical goods, transportation, and construction; zinc-coated, galvanized iron and steel in corrosion-resistance applications; aluminum and plastics in castings and moldings; and aluminum and magnesium in die castings.

Sphalerite, the zinc sulfide, is the most important ore mineral of zinc; though some deposits are composed of zinc oxides, silicates, and carbonates. In most deposits zinc is intimately associated with lead. In the United States the ores range from the zinc-rich ores of the Eastern United States to the complex lead-zinc ores of the Western United States. Cadmium, silver, germanium, gallium, indium, and thallium are recovered as smelting byproducts of some zinc ores and concentrates.

Zinc deposits occur most frequently in veins cutting igneous rocks or sedimentary strata or as replacements in limestone and dolomite. The resource potential of zinc is dominated by massive sulfide ores in metamorphic rocks, in which zinc occurs chiefly with copper and lead, and by stratabound and stratiform deposits in carbonate rocks, in which lead is an essential product and cadmium is a byproduct. Contact-metamorphic, vein, and residual deposits also contribute significantly to the potential resources of zinc.

In the United States, zinc deposits are widely distributed. Tennessee has the largest reserves, and New York, New Jersey, and Virginia have significant reserves. U.S. reserves of zinc are estimated to be about 45 million tonnes of metal, about 20 percent of the total world reserves of about 250 million tonnes. U.S. resources of 120 million tonnes are about 10 percent of the total world resources of about 1,300 million tonnes. In addition to identified resources, vast potential resources exist in Arizona, Montana, Nevada, Washington, Virginia, and Illinois.

The world zinc reserves of nearly 250 million tonnes are distributed in about 50 countries. The United States, Mexico, and Canada account for 40 percent of the total. The major known zinc deposits outside of North America are in Australia, People's Republic of China, Peru, Morocco, southwest Africa, Ireland, Poland, Yugoslavia, and the U.S.S.R.

Most U.S. production comes from States east of the Mississippi River. In 1973, the United States consumed about 1.5 million tonnes of zinc, of which 435,000 tonnes were from domestic primary production, about 8 percent of total world output. Secondary recovery provided about 6 percent of the domestic needs and was supplemented by release from the national stockpile and imports from Canada, Mexico, Peru, Australia, and Japan.

Incomplete data indicate that at least 3,300 tonnes of zinc will be required by the energy sector 1975–90, equal to an average annual demand of about 220 tonnes of metal. This amount is less than 1 percent of the total 1973 U.S. consumption.

The U.S. reserves of zinc are sufficient to meet the total cumulative demand of the Nation for conventional and increased energy uses during this century. However, because of inadequate production and processing capacity, the Nation will necessarily depend on imports to supply about 50 percent of its requirements. It is also important to note that the source of all cadmium—possibly an essential metal for solar energy utilization (but not reported by the industry)—is sphalerite, the chief ore mineral of zinc.

Although the resource potentials of zinc suggest several hundred million tonnes of contained zinc metal in known mining districts, the increasing dependence on imports makes the discovery of new large resources of zinc imperative. Research should be undertaken in a number of areas: exploration for deposits in platform carbonate rocks such as the Mississippi Valley type and in dolomitic evaporites and related deposits; improved technology for beneficiation of zinc-bearing pyrite.

In some coal deposits, particularly in the Illinois basin, zinc occurs in anomalously high amounts. The occurrence of zinc as sphalerite in coal in the Illinois basin may be characteristic of other coals in the midcontinent region. In one four-county area in Illinois, it is estimated that 10,000 tonnes of sphalerite (approximately 4,250 tonnes of zinc) are lost annually in coal production. Considering the total amount of coal being produced in the basin, a tremendous amount of zinc that could be recovered as a byproduct of coal is wasted. Studies should be made to determine how this zinc can be recovered. Removal of sphalerite (a sulfide) from coal will reduce the amount of sulfur emitted by coal-fired powerplants.

ZIRCONIUM

Zircon ($ZrSiO_4$), a hard, heavy mineral that resembles diamond in luster, is the source of most zirconium and zirconium compounds. Other important zirconium minerals are baddeleyite (ZrO_2), and eudialyte, a complex silicate. Zirconium minerals are inert and have high melting points; zirconium metal has a low neutron-absorption cross section.

Zirconium minerals are associated geologically with alkalic rocks but rarely in a concentration high enough for exploitation. Because they have a high specific gravity and are chemically resistant, however, they are concentrated in placers.

More than 80 percent of commerical zirconium is used directly as mineral concentrates in foundry sands, refractories, and ceramics. Zirconium and zirconium compounds have many other industrial uses. A major use of zirconium metal is as a structural material in nuclear reactors, the only use reported by the energy industries.

Zircon and zirconium compounds have many substitutes: chromite and other materials in molds; titanium in ceramic glazes; titanium, tantalum, stainless steel, and other metal alloys for other uses. Where zirconium is the most desirable material, its availability and moderate cost do not warrant substitution.

The U.S. reserves of zirconium are estimated at about 5 million tonnes and the identified resources at 6 million tonnes, mostly in placer concentrations along with rutile, ilmenite, magnetite, and other heavy minerals. About 50 percent of the identified resources are in Florida; most of the remainder are in California, New Jersey, and South Carolina. In 1973, the United States consumed about 68,000 tonnes of zirconium and imported about 45,000 tonnes, almost all from Australia.

The world identified resources of zirconium are estimated roughly at 18 million tonnes (other estimates are as high as 21 million tonnes), mostly in placer deposits in the United States, Australia, the U.S.S.R., and India. Australia is by far the largest producer.

The projected demand of about 27,500 tonnes of zirconium 1975–90 by the nuclear-energy industry averages about 1,800 tonnes per year, less than 3 percent of both the 1973 U.S. consumption and production of zirconium in all forms. (No estimate was made as to the quantity of zirconium that would be consumed in the manufacture of steel and aluminum used by energy industries.) In 1973, of about 55,000 tonnes of zirconium materials produced in the United States, 1,900 tonnes were used in nuclear reactors.

A critical factor in assessing the availabilty of zirconium is that almost all production is a byproduct of the mining of rutile, ilmenite, and magnetite. Exploration for zirconium has not been necessary because more zirconium can be produced than the market demands. The continued supply of zirconium thus depends on the continued exploitation of heavy-mineral placer deposits, an availability that may be diminished by environmental restrictions.

In the next few decades, while zirconium reserves are adequate, favorably located sand and gravel deposits worked now only for aggregate and specialty sands, offshore sand deposits, and sandstones that might contain ancient placer deposits should be investigated for concentrations of zirconium minerals. The tailings of some beneficiated ores, such as Florida phosphate deposits, contain potentially economic concentrations of zircon and should be assessed. Finally, research must be undertaken to find primary deposits of zirconium minerals in igneous rocks.

CONCLUSIONS

With due allowances for expected discoveries and developments that would increase U.S. reserves and identified resources of the mineral commodities we have discussed, the question must be asked: To what degree will increased energy production strain mineral supply? Only a qualitative answer can be given.

Energy is fundamental, and energy production must have first call on materials. Because energy independence is the Nation's goal, the total demand for energy-related materials must be judged in terms of *domestic* supply. If the energy industries consume a large portion of a commodity in short supply, other parts of the economy may suffer. At this time, no one knows how the economy could adjust to shortages induced by accelerated consumption by the energy industries. Certainly consumption of 100 percent of the annual production of any commodity by the energy industries is highly improbable. Consumption of 1 percent would seem to offer no problem in supply. Somewhere in between, however, lies a maximum percentage of additional demand that could be placed on production of any given commodity by energy-related uses without cause for grave concern. In figures 2–5, we endeavor to evaluate this relationship between domestic supply of minerals and energy demand in the light of our general knowledge of the commodities but without absolute, quantitative guidelines. Until better information is available on both demand and supply, we feel a qualitative interpretation most closely approximates reality.

The United States is self-sufficient in bentonite, copper, and molybdenum (figs. 2, 3); boron, magnesium metal, scrap mica, and silicon (table 2); and beryllium, hafnium, helium, lithium, and rare earths, for which the needs of the energy industries have not been determined (table 3). Reserves are also considered adequate to meet the national demand 1975–90 for barite, iron ore, lead, and zinc (fig. 3).

The United States has no reserves of chromite, cobalt, manganese, and niobium and is totally dependent for these commodities on imports, supplemented by industry inventories and release from government stockpile, which in 1973 also supplied a significant part of the domestic supply of lead, sheet mica, tin, tungsten, vanadium, and zinc. Imports provide more than two-thirds of the supply of aluminum (bauxite), fluorite, nickel, and tungsten, for which the 1975–90 energy demand will be large, and of asbestos and tin, for which the demand will be much less critical.

Some commodities for which we are dependent on imports for one-third to two-thirds of our supply are expected to pose no supply problems as long as imports are secure; these include antimony, cadmium, silver, and titanium. Others—barite, zinc, and zirconium—are available in large quantities domestically (fig. 3); future supply problems will be those posed by production capacities that are inadequate to meet the national demand. The indium supply is closely related to zinc production, and expanded demand for indium by the energy industries may therefore put additional strain on the zinc industry. Industry expansion is likewise the only major problem posed by demand for cement.

Expanded energy development and production 1975–90 will necessitate a significant increase in domestic production above that of 1973 for most materials. Averaged over 15 years, the quantities of some materials needed for energy will be a large percentage of 1973 production (fig. 4): for example, aluminum (30 percent), barite (100 percent), bentonite (30 percent), fluorite (58 percent), shipping-grade iron ore (26 percent), and tungsten (78 percent). Figure 5 graphs the data in terms of the percentage of U.S. reserves needed to meet the total energy demand, 1975–90.

A minimum of about 2.5 billion barrels of oil-equivalent (1 bbl=5.8×10^6 Btu's) may be required to produce 20 selected mineral commodities (see table 5) needed by the energy industries 1975–90, and 18.5 billion barrels of oil-equivalent to produce sufficient supply to meet the overall domestic demand for those minerals during the same period. This amount of energy, equal to more than half of the known U.S. recoverable petroleum reserves, is only a fraction of the energy required to produce the 90 or more mineral commodities used in the total economy. Thus, imports of mineral raw materials (see table 2) and semifabricated or processed material also constitute energy imports. Substitution of domestically produced materials for imports will further stress domestic energy production.

Adequacy of mineral supplies for a sustained economy should be a matter of deep concern, particularly in view of the large quantities of minerals and materials required for energy production and the serious consequences in the event of deficiencies. As was evident in the 1973 oil embargo, political and economic changes and mineral shortages can occur swiftly. Our mineral inventory developed and ready for immediate extraction is nil in the case of some commodities, and in many cases is not equivalent to projected requirements for a decade of U.S. consumption.

Basic geologic research—including mapping rock units and determining their geologic interrelationships, geochemistry, geometry, and global distribution—is essential in assessing the geologic availability of mineral resources. Such basic research, often overlooked as the foundation on which exploration projects are planned, must be accelerated and

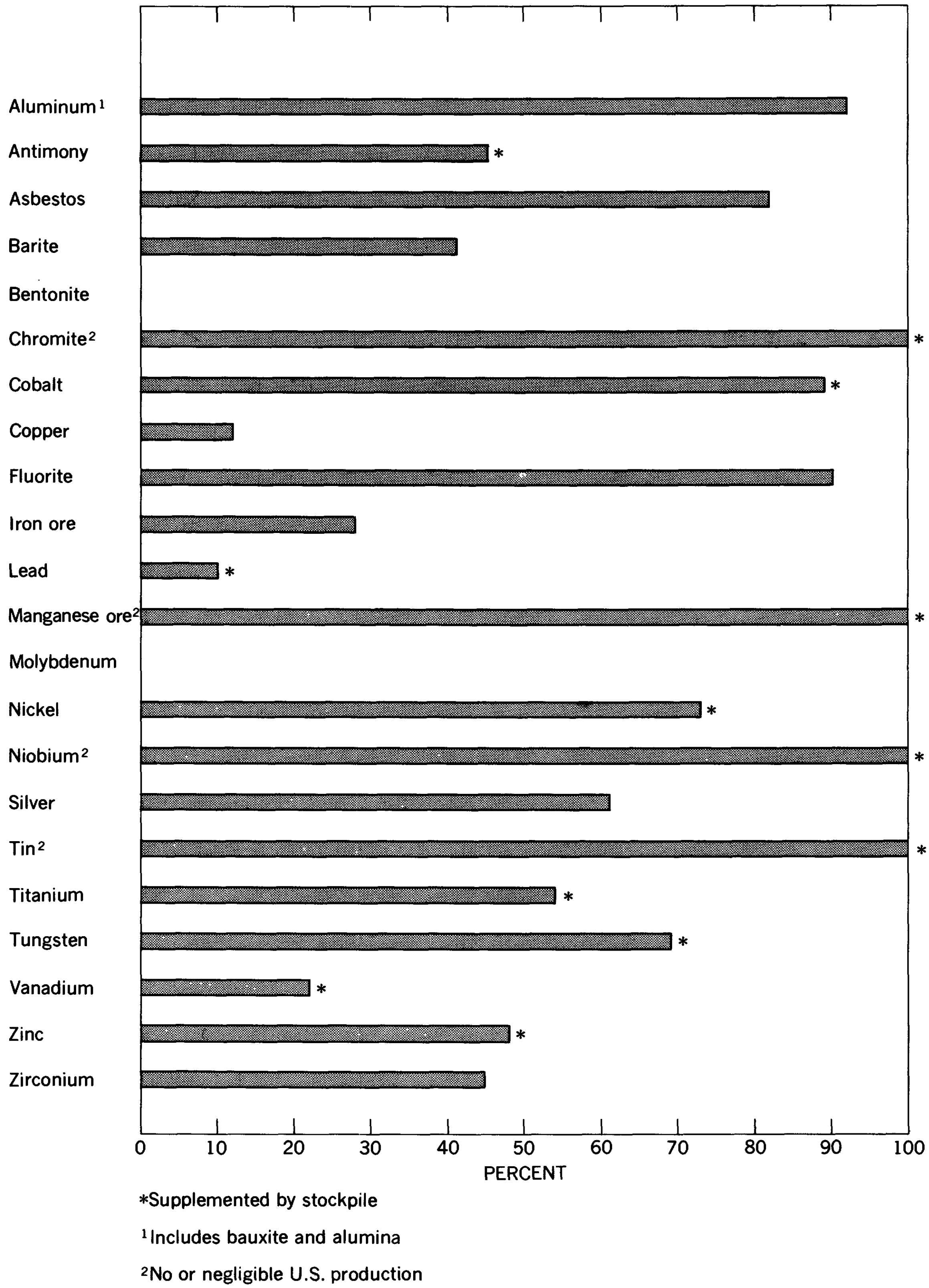

FIGURE 2.—U.S. dependency on imports in terms of percentage of total consumption in 1973.

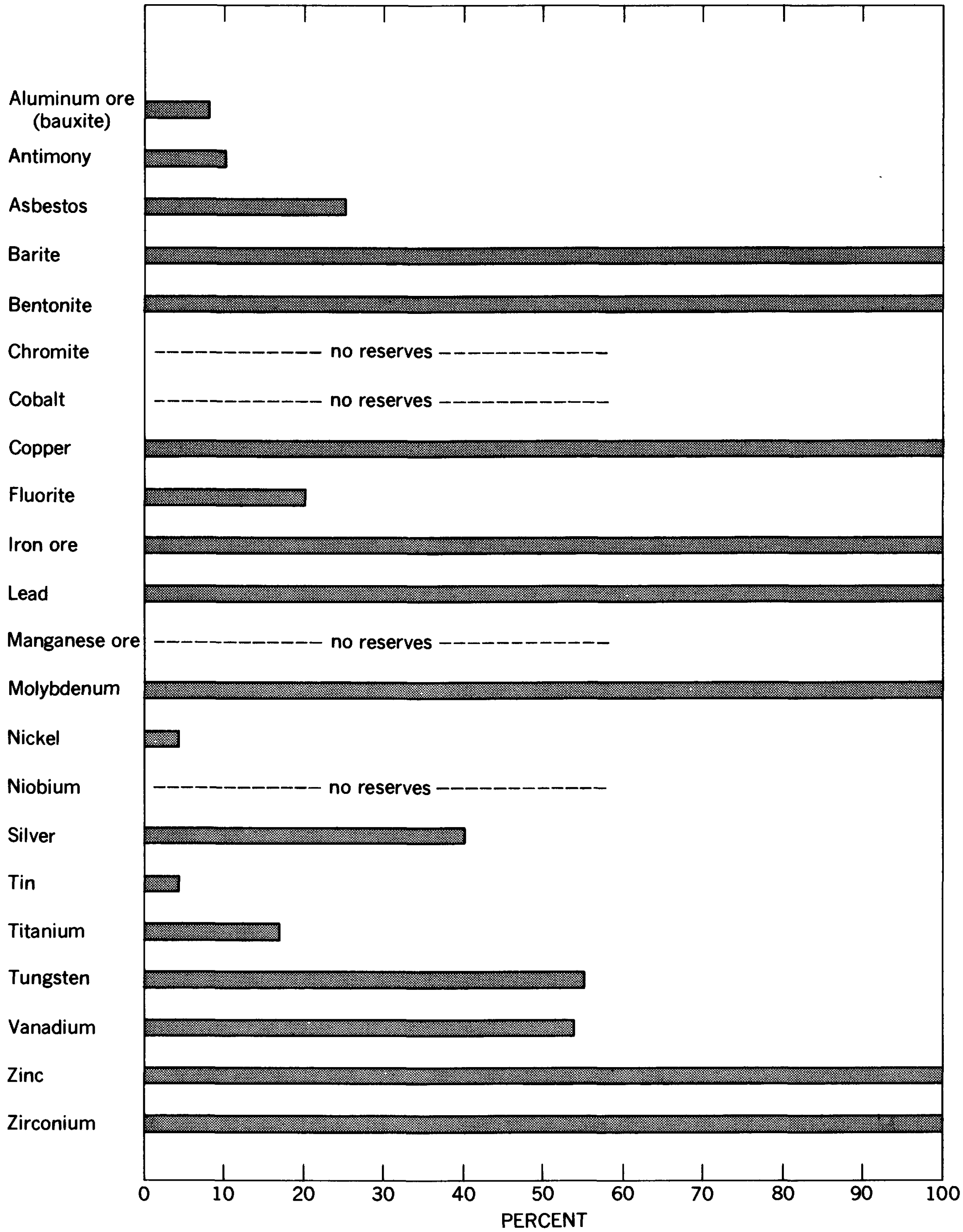

FIGURE 3.—Percentage of total U.S. cumulative demand for some commodities, 1975–90, that can be met by U.S. reserves.

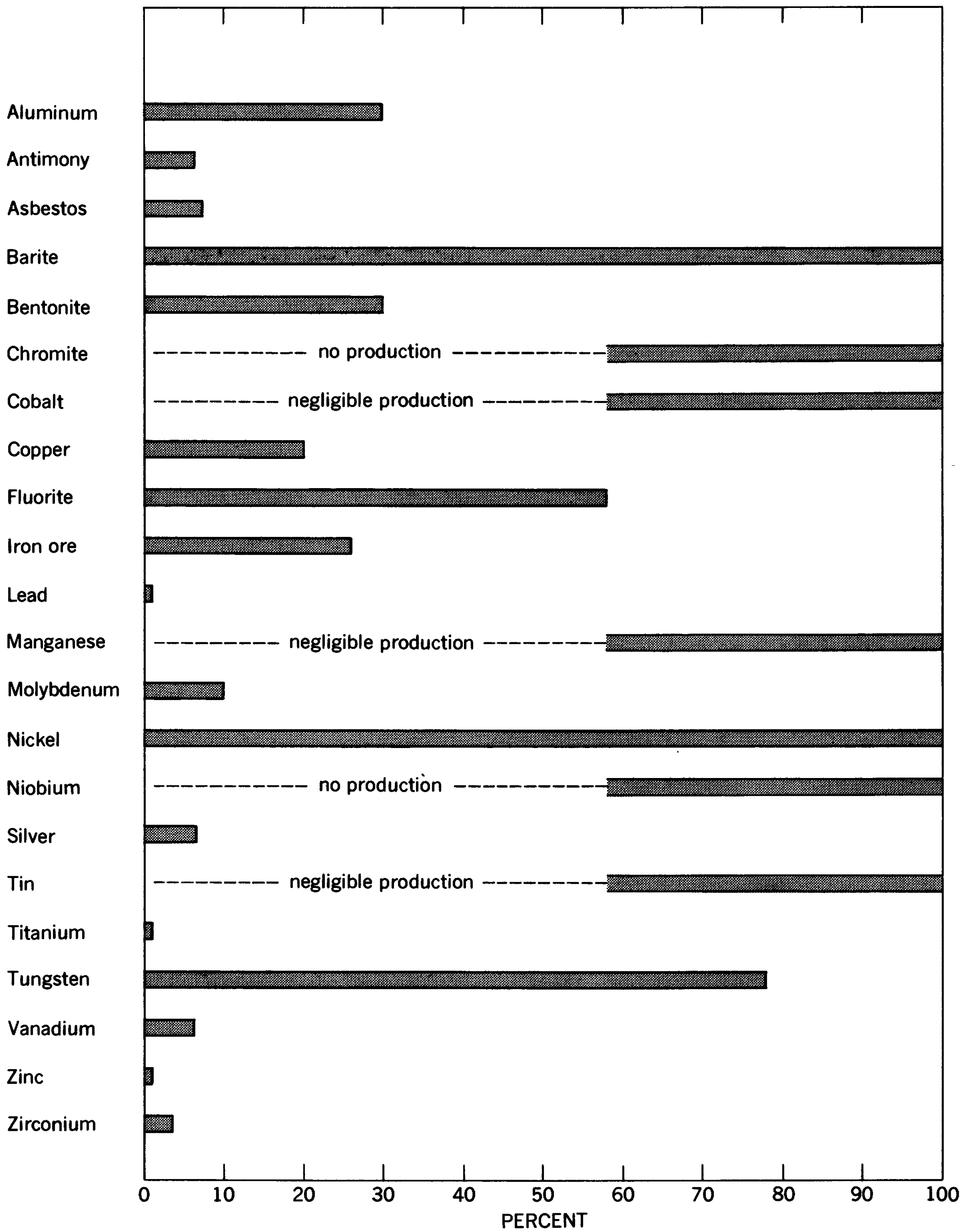

FIGURE 4.—Average annual demand by energy industries for some commodities, 1975–90, as a percentage of U.S. production in 1973.

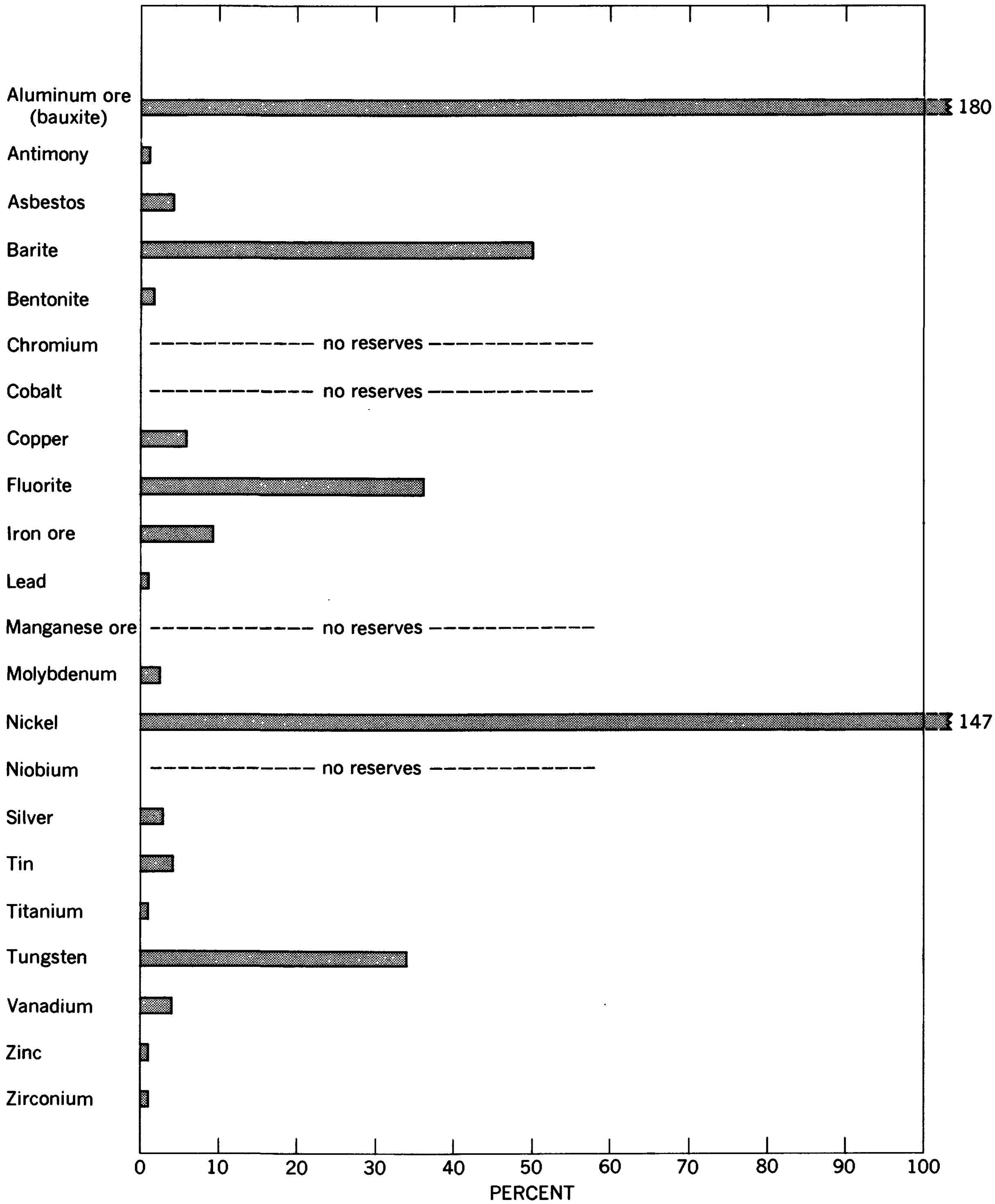

FIGURE 5.—Percentage of U.S. reserves needed to meet total energy demand for some commodities, 1975–90.

continued into the future as long as industrial society survives. Any delay reduces the Nation's flexibility to cope with mineral-supply problems, which are inevitable. Because of the lead-time required, as much as 20 years, crash programs are no substitute.

The United States will not become self-sufficient in all minerals, but for most the Nation can become nearly self-sufficient through development of new resources. For commodities for which domestic resources are not available, adequate supplies may be assured by developing alternate sources of imports.

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