Information Circular 8861

Alumina Availability—Domestic

A Minerals Availability System Appraisal

By Gary R. Peterson, Robert L. Davidoff,
Donald I. Bleiwas, and Richard J. Fantel

UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary
BUREAU OF MINES

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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PREFACE

The Bureau of Mines Minerals Availability Program is assessing the worldwide availability of nonfuel minerals. The program identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is part of a continuing series of MAS reports to analyze the availability of minerals from domestic and foreign sources. Analysis of supply from other minerals is currently in progress. Questions about the MAS program should be addressed to Director, Division of Minerals Availability, Bureau of Mines, 2401 E Street, N.W., Washington, D.C. 20241.

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by

G. R. Peterson,[1] R. L. Davidoff,[1] D. I. Bleiwas,[2] and R. J. Fantel[2]

ABSTRACT

In order to determine the potential availability of alumina to feed U.S. aluminum smelters, the Bureau of Mines evaluated 39 domestic mines and deposits of bauxite, alunite, and high-alumina clays and found that substantial increases in alumina prices would be necessary before nonbauxitic deposits could become competitive with bauxite. As part of the study, a price-tonnage relationship was developed indicating the quantity of alumina that could be produced from known deposits at various alumina prices and at a 15-pct discounted cash flow rate of return on the required capital investment. All capital and operating costs were calculated in August 1980 dollars.

The domestic bauxite reserve base comprises three operating bauxite mines in Arkansas containing some 15.6 million metric tons of recoverable alumina (Al_2O_3). Ferruginous bauxites, clays, and alunites fall into the subeconomic category of identified aluminum resources, which, at the demonstrated level, contain over 4,000 million metric tons of alumina that are estimated to be recoverable. Analyses indicate that, at the demonstrated resource level, a total of some 15.6 million metric tons of alumina, all from three active Arkansas bauxite mines, is recoverable at a 1980 price of $0.12 per pound ($264 per metric ton) of alumina. A price of approximately $0.26 per pound ($573 per metric ton) of alumina would be required for production of the total U.S. resource. Thus, unless new technological breakthroughs occur that could make alternate sources of alumina competitive with bauxite, U.S. dependence upon imported bauxite will continue to increase.

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[1] Mineral economist.

[2] Geologist.

All authors are with the Minerals Availability Field Office, Bureau of Mines, Denver, Colo.

INTRODUCTION

Aluminum use exceeds that of all other metals except iron, yet 90 pct of the bauxite ore used in the domestic production of aluminum is supplied from foreign sources. Through the years, many technological improvements have been made in producing aluminum from bauxite, but the basic processes have been unchanged since the metal first became available in commercial quantities over 90 years ago. These processes consist essentially of surface mining of bauxite, followed by hydrometallurgical processing to produce alumina (99.5 pct Al_2O_3), and then the reduction of the alumina to aluminum metal by fused-salt electrolysis in a molten bath of fluoride salts (*20*, p. 1).[3] For each 4.5[4] tons of bauxite fed into the alumina refinery, 2 tons of alumina are produced, which in turn produces about 1 ton of aluminum.

The United States had become highly concerned about its growing dependence on imported bauxite and alumina by 1970, when the National Materials Advisory Board was requested to prepare a report on "Processes for Extracting Alumina From Nonbauxite Ores." It was felt that a thorough investigation of the potential of alternative sources of alumina from domestic ores was in the national interest. Processing technologies for clays have been tested by the Bureau of Mines at the miniplant stage since July 1973, and processing technologies for alunite have been tested in small pilot plants by private companies. The Bureau of Mines also operated a pilot plant in Laramie, Wyo., to produce alumina from anorthosite. Costs developed for this report were derived from feasibility studies based on these tests using state-of-the-art technology. None of these processing technologies has yet been developed at a commercial scale.

U.S. concern over growing dependence on foreign sources of bauxite intensified with the formation of the International Bauxite Association (IBA) in 1974. The IBA is comprised of 11 member nations and accounts for 75 pct of the world production of bauxite and 48 pct of the alumina. The fundamental objective of the IBA has been to raise the revenues that its member nations receive from their bauxite-alumina industries and, for the longer term, to maximize the benefits from their respective industries through national control of the industry, collective purchasing agreements, and the sharing of information and technology (*17*, p. iii). Amid fears that the IBA would attempt to become a strict cartel in emulation of the Organization of Petroleum Exporting Countries (OPEC), the Bureau of Mines intensified its investigation of the domestic potential of nonbauxitic sources of alumina.

Currently, the only domestic commercial source of alumina is bauxite ore. Although nearly 90 pct of U.S. primary aluminum consumption is produced domestically, domestic mine production represents less than 10 pct of the bauxite consumed in the United States. Some 70 pct of domestic alumina consumption is produced in this country, which reflects the growing reliance upon both imported bauxite and alumina.

Dependence upon imported bauxite and alumina for the production of aluminum could be alleviated by developing alternate sources of alumina in the United States. Possible sources include other bauxite (ferruginous), clay, alunite, anorthosite, dawsonite contained in oil shale, and coal ash.

The purpose of this study is to evaluate the potential availability of cell-grade alumina from domestic resources. Such an evaluation is an inherent element in the formulation of a national mineral policy. The methodology of this study is as follows:

1. To estimate capital investments and operating costs for each deposit from the mining through refining stages of production.
2. To evaluate the quantity and quality of potential alumina production from domestic aluminum resources in relation to physical, technological, institutional, and other conditions that affect production from each deposit.
3. To perform an economic analysis for each deposit. The results of these analyses indicate the associated tonnages of alumina that could potentially be produced at specific prices.
4. To combine and analyze the price-tonnage relationships for all deposits to illustrate the domestic alumina production potential at various prices and a 15-pct return on investment.

Results of this study are presented in terms of alumina. One assumption of this study is that alumina containing the same physical characteristics as alumina produced from bauxite can be produced from nonbauxitic sources. Preliminary evaluations indicate that alumina, meeting current specifications, can be produced from alternate sources. In order to increase revenues, many bauxite-exporting countries are integrating forward into the production and export of alumina. As this occurs, the United States will be forced to import increasing quantities of alumina, rather than bauxite, to feed domestic aluminum smelters. The higher cost of these imports may make domestic nonbauxitic sources of alumina more attractive if processing technologies can be developed on a commercial scale. As a result, the Bureau of Mines is focusing this study on potential domestic nonbauxitic sources of alumina rather than production of aluminum metal.

The data collected for this report are stored, retrieved, and analyzed in a computerized component of the Minerals Availability System (MAS) (*23*). An economic analysis is performed on each deposit to estimate its average total cost of production at a 15-pct discounted cash flow rate of return (DCFROR). This determines a project's "incentive price" for alumina; that is, the price at which a firm would be willing to produce alumina over the long-run, where revenues are sufficient to cover full costs, including a return on investment high enough to attract new capital (*1*, p. I-25).

A total resource availability curve can be constructed to show potential alumina production based upon each deposit's "incentive price" to produce alumina. The total resource availability curve is different from the supply curve of traditional economic theory. It is an aggregate or sum of total production potential from each deposit at a stipulated commodity price that covers the full cost of production for each deposit. Each deposit's incentive price and its level of output (or capacity) are assumed to remain constant over the entire producing life of the mine. The curve provides a concise, easy to read, graphic analysis of the potential availability of a commodity at specified long-run prices. Annual curves, as presented in this report, are the total resource availability curve disaggregated on an annual basis. The assumptions inherent in the total resource availability curve also apply for the annual curves.

The data required for this study were developed at Bureau of Mines Field Operations Centers in Denver, Colo., Pittsburgh, Pa., and Spokane, Wash. Personnel

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[3] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

[4] Unless otherwise noted, "tons" in the report refers to metric tons.

in these offices obtained this information from company data, published data, and trips to the mines and deposits. Where necessary, data were calculated by the evaluator.

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Eastern Field Operations Center, Pittsburgh, Pa.:
David G. Hartos
Joseph A. Hrabik
C. P. Mishra
Dale R. Spangenberg
David R. Wilburn

Intermountain Field Operations Center, Denver, Colo.:
R. Craig Smith
Richard A. Salisbury

Western Field Operations Center, Spokane, Wash.:
David S. Lindsey
Burton B. Gosling
David A. Benjamin
George B. Gale

Minerals Availability Field Office, Denver, Colo.:
Edward H. Boyle, Jr.
Catherine C. Kilgore
Jim F. Lemons, Jr.
Dean P. Reynolds
Paul R. Thomas

STRUCTURE OF THE ALUMINUM INDUSTRY

Currently, the only domestic commercial source of primary aluminum is bauxite ore. Bauxite is a rock containing aluminum hydroxide minerals and impurities. Metallurgical-grade bauxite in Arkansas is mined using open pit methods with pit depths reaching as much as 200 feet. In other countries, such as Jamaica and Australia, there is very little overburden, and mining is little more than an earth-moving operation. Operating costs for open pit mining and onsite beneficiation can vary greatly depending on transportation methods, deposit location, technology used, scale of operation, and the characteristics of the overburden. Mining and beneficiation costs for domestic bauxite (not including transportation) range up to $15.00 per ton of bauxite ore (August 1980 dollars). Imported bauxite costs approximately $32 per ton including taxes and transportation. Transportation costs can amount to as much as 50 pct of the bauxite price.

Using the standard Bayer process, bauxite is leached with caustic soda under heat and pressure to convert the aluminum hydroxides to sodium aluminate, which can then be converted to cell-grade alumina (+99.5 pct Al_2O_3). The IBA has estimated that a new "green fields" alumina refinery in the Caribbean would be able to produce alumina for a total operating cost of approximately $275 per ton (*10*, p. 31). The most important production elements from a cost point of view are the cost of bauxite (including taxes), return on capital, energy, and depreciation. A representative market price for domestically produced alumina is currently around $255 per ton.

The alumina, in turn, is reduced to metallic aluminum using the Hall-Heroult process. This process uses large electrolytic cells and is extremely energy intensive, requiring 15,000 to 20,000 kwhr of electricity per ton of primary aluminum. Energy can account for 40 to 50 pct of the total costs of producing aluminum ingot from bauxite (*15*). Domestic aluminum smelters consumed some 78 billion kwhr of electricity in 1978 to produce 10.4 billion pounds of primary ingot, 10 pct of total electricity consumption by U.S. industry in that year (*8*, p. 24). Technological improvements have enabled energy usage in aluminum smelting to decrease slightly over the past several years. A new process developed by ALCOA, under development at the ALCOA plant in Palestine, Tex., claims up to a 30-pct saving in energy consumption (*14*, p. 2).

A representative cost (in August 1980) for smelting aluminum metal from alumina, including the cost of the alumina, was approximately $0.69 per pound of aluminum ($1,521 per ton) for a typical smelter having a capacity in the range of 100,000 to 150,000 tons per year of output. Information on the smelting of alumina into aluminum is given by Herbert and Castle (*5*), Hoppe (*6*), and the IBA (*8*).

Approximately 86.8 million tons of bauxite was produced in the world in 1979 (table 1), of which 22 pct was provided by Jamaica, Guyana, and Surinam. Australia and Guinea accounted for an additional 46 pct. In all, the 11 IBA countries accounted for approximately 75 pct of the world's bauxite output in 1979. The United States imported 13.8 million tons of bauxite in 1979 (table 2), 69 pct from the Caribbean. The above statistic illustrates the regional character of trade in bauxite because of high shipping costs. Most of Australia's output is exported to Japan, while bauxite produced in West Africa is sold in Europe.

The United States also imported 3.8 million tons of alumina in 1979 (table 3), of which 76 pct originated in Australia. The trend towards refining alumina in bauxite-producing countries is an important structural change in the alumina industry that began about 20 years ago and has continued to evolve. In order to reduce shipping costs and to take advantage of lower quality reserves, the aluminum companies began to build alumina plants in the bauxite-producing countries to

Table 1.—World bauxite production

(1,000 metric tons)

	1976	1977	1978	1979
IBA member countries:				
Australia	24,084	26,086	24,293	27,583
Dominican Republic	517	583	568	570
Ghana	272	244	328	300
Guinea	11,316	11,300	12,000	12,500
Guyana	2,686	2,731	2,400	2,400
Haiti	660	588	580	530
Indonesia	940	1,301	1,008	1,000
Jamaica	10,312	11,433	11,736	11,574
Sierra Leone	651	745	716	720
Surinam	4,587	4,856	5,025	5,000
Yugoslavia	2,033	2,044	2,566	3,012
Total IBA	58,058	61,911	61,220	65,189
Other countries:				
Brazil	827	1,120	1,160	2,400
France	2,330	2,059	1,990	2,000
Greece	2,551	2,984	2,630	2,915
Hungary	2,918	2,949	2,899	3,000
India	1,448	1,511	1,653	1,600
Malaysia	660	616	615	700
United States	1,989	2,013	1,669	1,821
U.S.S.R.	4,500	4,600	4,600	4,600
Others	2,182	2,611	2,593	2,589
Total other countries	19,405	20,463	19,809	21,625
World total	77,463	82,374	81,029	86,814
Percent IBA	75	75	76	75

Table 2.—U.S. imports of crude and dried bauxite

(1,000 metric tons)

Country	1977	1978	1979
IBA member countries:			
Australia	0	19	0
Dominican Republic	583	628	551
Guinea	3,030	3,363	3,924
Guyana	380	419	425
Haiti	587	588	572
Jamaica	6,354	6,448	6,469
Sierra Leone	80	107	141
Surinam	1,918	2,259	1,520
Total IBA	12,932	13,831	13,602
Other countries:			
Greece	57	3	10
Trinidad	0	13	0
Brazil	0	0	168
Grand total	12,989	13,847	13,780
Percent IBA	99.5	99.9	98.7

Table 3.—U.S. imports of alumina

(1,000 metric tons)

Country	1977	1978	1979
IBA member countries:			
Australia	2,590	2,879	2,938
Guyana	54	30	18
Jamaica	629	628	587
Surinam	382	382	239
Total IBA	3,655	3,919	3,782
Other countries	105	48	55
Total	3,760	3,967	3,837
Percent IBA	97	99	99

convert the bauxite before shipping. Shipping costs can be cut in half by converting bauxite into alumina at the point of bauxite production. The bauxite-producing countries have also pushed for more at-home alumina production because of the economic contribution provided by the value added from the further processing of bauxite into alumina. Overall, 1 ton of alumina is worth approximately 7 tons of bauxite exported as raw ore. In 1960, only 10 pct of the total world production of alumina was in the lesser developed country (LDC) bauxite producers. This percentage has grown steadily, to 34 pct in 1975 (*13*, p. 14).

The world aluminum industry is an oligopoly dominated by six multinational firms: Alcan Aluminum Ltd., Aluminum Company of America (ALCOA), Reynolds Metals Co., Kaiser Aluminum and Chemical Corp., Pechiney Ugine Kuhlmann (PUK), and Swiss Aluminum Ltd. (Alusuisse). These companies are fully integrated, occupying strategic positions in the industry from raw materials production to marketing both the metal and end-products. Nearly 50 pct of total world capacity of bauxite, alumina, and aluminum is under their control. Moreover, through a variety of consortia arrangements, one or several of these firms is associated with practically all new projects of international significance within the industry.

In addition to these major international firms, there are some 50 others whose aluminum operations are more restricted in scope but which account for about one-fourth of world production capacity for bauxite, alumina, and metal. Most of these producers are nonintegrated, and some are owned by, or associated with, governments or the six large international aluminum companies (*20*, p. 4). Some 19 percent of world aluminum production capacity is controlled by the communist governments, and the balance is accounted for by governments of other countries.

Of the 12 domestic firms producing primary aluminum metal in the United States in 1979, seven owned bauxite and/or alumina facilities in the Caribbean area, South America, Guinea, or Australia and imported these raw materials.

The six large international aluminum companies dominate the market for aluminum metal and metal goods. Producers' prices show a high degree of correspondence and stability. A growing free market exists in which metal from nonintegrated producers is offered on the London Metal Exchange (LME) on both a spot and forward basis. The prices on the LME are tied less to the producers' prices and, more commonly, tend to fluctuate in consonance with those of the LME quotations for other nonferrous metals (*18*, p. 115). Aluminum prices stayed remarkably stable, both in current dollar and in real terms, throughout the 1960's. Since 1974, worldwide inflation, costs for bauxite from IBA member countries and the rising costs of energy have been factors in causing the aluminum price to increase approximately threefold as of August 1980.

LOCATION OF DOMESTIC REFINERIES AND SMELTERS

Locations of domestic alumina refineries and aluminum smelters including operating facilities and projects in the planning or building stages are shown in figure 1.

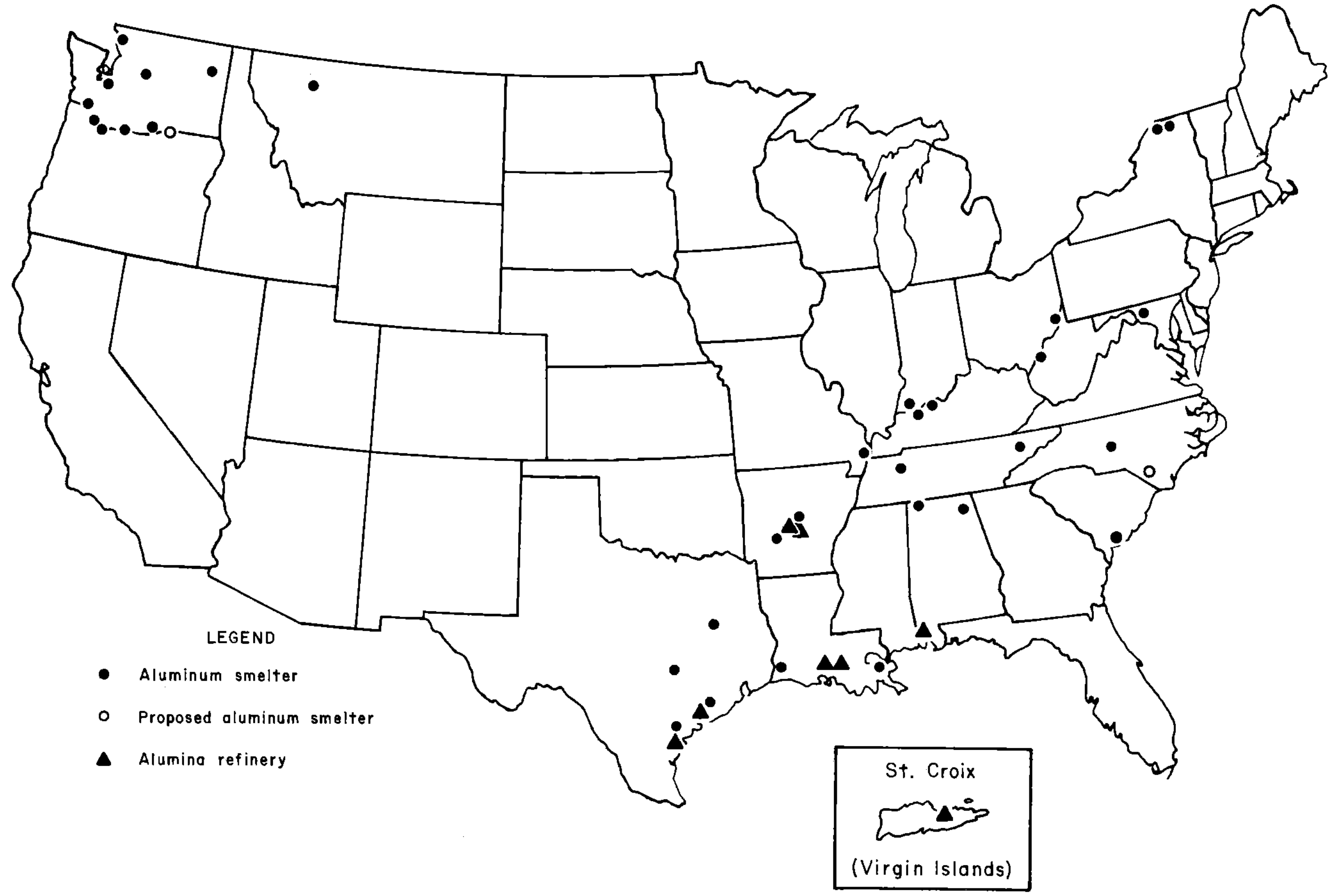

Figure 1.—Location of domestic alumina refineries and aluminum smelters.

The Arkansas operations utilize both locally mined and imported bauxite and energy from nearby sources. Most domestic alumina refineries are located along the Gulf Coast near deep-water ports to receive bauxite imported from the Caribbean area, and use natural gas or oil from local sources.

The aluminum smelters are located near large electric energy sources because of the large quantities of electric power necessary to convert alumina to aluminum. Hydroelectric power is the cheapest form of energy for smelters, and, as a result, most smelters are located near hydroelectric power installations in the Pacific Northwest, the Tennessee Valley Authority (TVA) area, and Niagara Falls. Some plants in the East receive their energy mainly from coal- or oil-fired thermal powerplants or from nuclear installations. Some of these smelters have a competitive disadvantage in terms of energy cost, but are located close to the markets that they serve.

Some 35 pct of the total domestic aluminum capacity is in the Pacific Northwest, which receives hydroelectric power from the Bonneville Power Authority (BPA). These power contracts with aluminum companies expire in the mid-1980's, after which the BPA is required by law to reassign its hydroelectric power to utility companies before making any direct allocations to smelters (*8*, p. 24). Any direct allocations will most certainly be at a much higher cost. Moreover, there has been an increase in population and industrial growth in the area, providing further competition to the aluminum industry for energy. Utilities in a position to negotiate regular price reviews, like TVA, are tending to insist on new prices reflecting costs of coal- or oil-fired power stations (*13*, p. 31). Increased fossil fuel costs, environmental restrictions on smelters, and the current moratorium on nuclear energy construction are problems that affect other domestic regions as well.

As a result, the industry has been reluctant to expand domestic primary production capacity, and companies have instead focused their attention towards developing "green field" projects offshore in countries such as Australia, Brazil, Cameroon, Ghana, and Indonesia.

IMPORTANCE OF SECONDARY (SCRAP) RECOVERY TO THE INDUSTRY

Recovery of purchased scrap contributes some 25 pct of the total domestic supply of aluminum. Scrap is divided into two main categories: new scrap and old scrap. New scrap is generated in the manufacture of primary aluminum, semifabricated aluminum mill products, or finished industrial and consumer products. It is aluminum that is not sold in the form of an end-use product and includes solids, such as new casting scrap; clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; and residues, drosses, skimmings, spillings, sweepings, and foil (*20*, p. 7). Old scrap comes from discarded, used, and worn-out products. It includes aluminum engine or body parts from junked cars, used aluminum cans and utensils, and old wire and cable. The proportion of total dometic metal consumption met by the recovery of old scrap amounted to about 10 pct in 1979 (*11*).

DEMAND FOR ALUMINUM

Between the years 1975 and 2000, primary aluminum demand is expected to increase threefold with an average annual rate of growth estimated from 4 pct (*12*) to 5.3 pct (*20*). This rate of growth is slightly lower than the estimated rate of growth for the world as a whole over the same period. The United States will likely remain the world's largest consumer and one of the world's largest producers of aluminum during this period.

U.S. dependence on foreign primary aluminum production is growing. One estimate (*28*, p. 33) forecasts that domestic bauxite production will satisfy a decreasing share of demand, that alumina refining will drop from over a 70-pct share in the U.S. market in 1977 to under 40 pct by the year 2000, and that domestic aluminum smelting will drop from over 90 pct to 80 pct during the same period. At the same time, user segments of the domestic market continue to grow. In 1979, the major domestic markets, in descending order of market share, were building and construction, transportation, electrical, consumer durables, and machinery and equipment. In housing, the demand is growing for roofing, window frames, aluminum siding, and insulation. In durables more aluminum is being used to improve efficiency and to increase service life. In the electrical sector, aluminum is mainly used for overhead power transmission lines. In transportation the weight of vehicles is decreased by substituting aluminum alloys for steel. Finally, in packaging, the use of recyclable beverage cans is increasing.

ESTIMATION OF DOMESTIC ALUMINUM RESOURCES AND COST DATA

Currently, the only domestic production of alumina is from bauxite. Other potential domestic sources of alumina include ferruginous bauxites, clays, alunites, and anorthosites, none of which are currently being exploited. The extraction of alumina from all these potential sources, except for anorthosites, is presently considered feasible from an engineering view; however, none is currently economic.

For the deposits analyzed in this report, tonnage estimates were made at the demonstrated and identified resource levels according to the new mineral resource-reserve classification system developed jointly by the U.S. Geological Survey and the Bureau of Mines (*27*). The demonstrated resource category includes measured plus indicated tonnages, and the identified resource category includes measured plus indicated plus inferred tonnages.

Selection of deposits for this study was limited to significant, known deposits that have demonstrated or identified reserves or resources. Reserves are material that can be mined, processed, and marketed at a profit under the economic and technologic conditions prevailing at the time of the evaluation. Resources are concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.

Most reserve and resource tonnage and grade calculations presented in this paper have been computed partly from specific measurements, samples, or production data and partly from estimations made on geologic evidence. Using these estimates, domestic aluminum resources were classified into two main categories: the domestic bauxite reserve base and subeconomic aluminum resources.

The bauxite reserve base is the in-place portion of demonstrated resources from which reserves are estimated. The reserve base includes resources that have the probability of being economically available and is composed of resource categories that are economic (reserves), marginally economic (marginal reserves), and a portion of subeconomic (resources). The position of the bauxite reserve base within the classification of mineral resources is illustrated in figure 2.

The domestic reserve base for aluminum is comprised of three bauxite deposits in Arkansas. Bauxite deposits in Alabama and Georgia are not included in this category because they are mined primarily for alumina used in abrasives, chemicals, and refractories. Ferruginous bauxites, clays, and alunites fall into the subeconomic category of identified resources, shown below the reserve base category on figure 2. The subeconomic category of identified resources was not considered in this study as constituting part of the reserve base for aluminum owing to the technological uncertainty inherent in processing nonbauxitic sources of alumina. As the processing technologies for nonbauxitic sources of alumina approach development on a commercial scale, these deposits will likely be reclassified as part of the reserve base for aluminum. The anorthosites fall into the "other occurrences" of identified resources. They are categorized as such owing to the extremely high energy requirements for processing anorthosite using the lime-soda sinter process and the unresolved problem of gelation in liquid-solid separation. However, anorthosites would

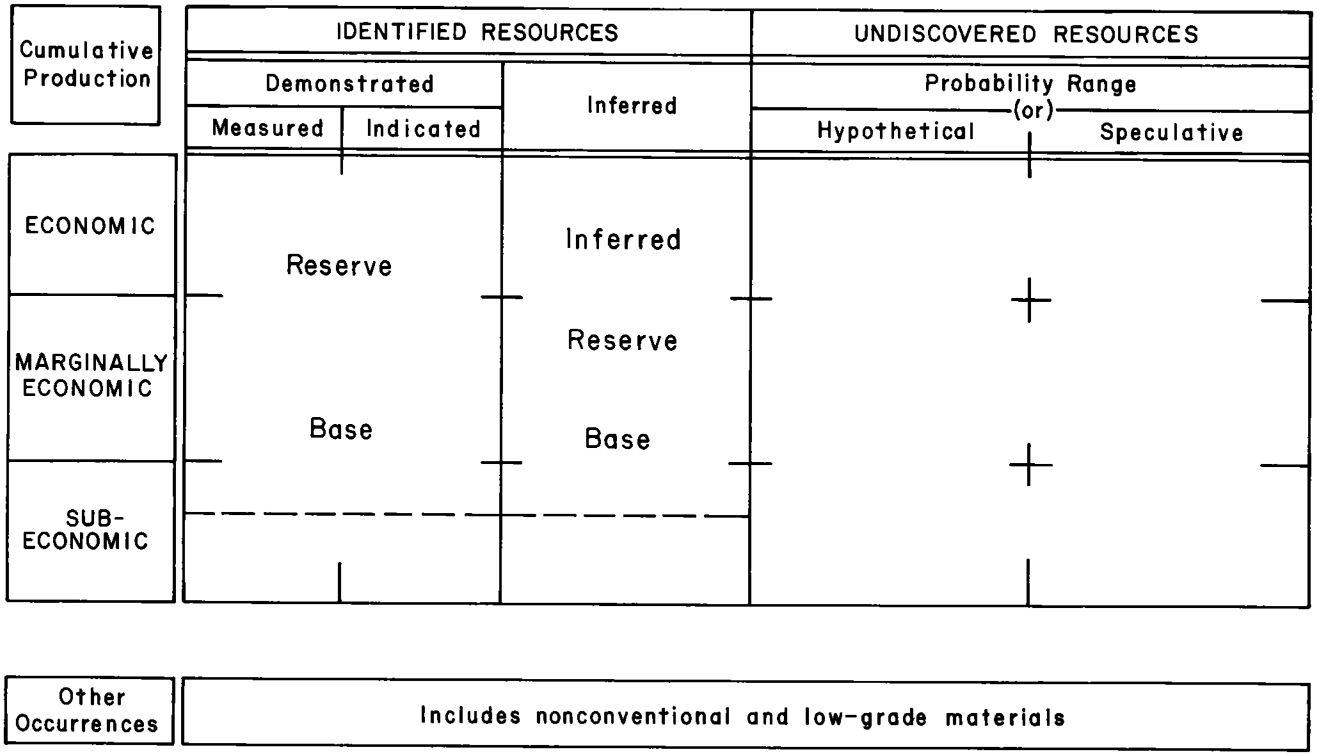

Figure 2.—Reserve base and inferred reserve base classification categories.

likely be reclassified as part of the reserve base for aluminum as well, pending future technological developments.

After a deposit had been selected for inclusion in the analysis, an evaluation of the property was begun. The flow of the MAS evaluation process from deposit identification to development of supply information is illustrated in figure 3. This flowsheet demonstrates the various evaluation stages required to estimate the potential availability of domestic alumina.

For bauxite mines currently in production, the designed mining and processing production rates and capacities and other available production specifics were adapted for use in this study. For deposits not in production, appropriate mining and concentrating methods, production rates, and other production parameters were assumed using operating open pit mines as models and current engineering principles.

Where available, actual mining capital and operating costs were used. However, because of a lack of cost data available, in many cases costs were either estimated by standardized costing techniques or derived from the Bureau of Mines capital and operating cost manual (*22*). Estimates based on this manual have historically shown a reliability within 25 pct of actual costs.

Processing methods and their costs for nonbauxitic sources of alumina were estimated using feasibility studies based on data obtained from pilot plant and miniplant testing.

Information on the average grades, ore tonnages, and different physical characteristics affecting production from domestic alumina deposits was obtained from numerous sources, including Bureau of Mines, Geological Survey and State publications, professional journals, industry publications, annual reports, company 10K reports and prospectuses filed with the Securities and Exchange Commission, and data made available to the Bureau of Mines by private companies. The knowledge and expertise of Bureau of Mines personnel were utilized in many cases.

Capital expenditures were calculated for exploration, acquisition, development, mine plant and equipment, and for constructing and equipping the mill plant. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, facilities and utilities, and working capital. Facilities and utilities (infrastructure) is a broad category that includes the costs of access and haulage facilities, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, taxes, and insurance.

The total operating cost of a project is a combination of direct and indirect costs. Direct operating costs include materials, utilities, direct and maintenance labor, and payroll overhead. Indirect operating costs include technical and clerical labor, administrative costs, facilities maintenance and supplies, and research. Other costs in the analysis are fixed charges, including local taxes, insurance, depreciation, deferred expenses, interest payments (if any), and return on investment.

The next step of the evaluation process was to perform an economic evaluation for each property. Using the data developed by the Bureau's Field Operations Centers, computerized analysis of each property was performed. For properties not now in production, all capital costs were converted to August 1980 dollars. For bauxite mines currently producing, the undepreciated capital investment remaining in 1980 was calculated. All reinvestment, operating, and transportation costs were converted to August 1980 dollars.

The Bureau of Mines has developed the Supply Analysis Model (SAM) to determine the deposit's primary commodity "incentive price" required to stimulate production and provide a stipulated rate of return on the required investment (*3*). The rate of return used in this study is the discounted cash flow rate of return (DCFROR), which is most commonly defined as the rate of return that makes the present worth of cash flow from an investment equal to the present worth of all after-tax investments (*21*, p. 232). For this study, a 15-pct DCFROR was considered as a necessary rate of

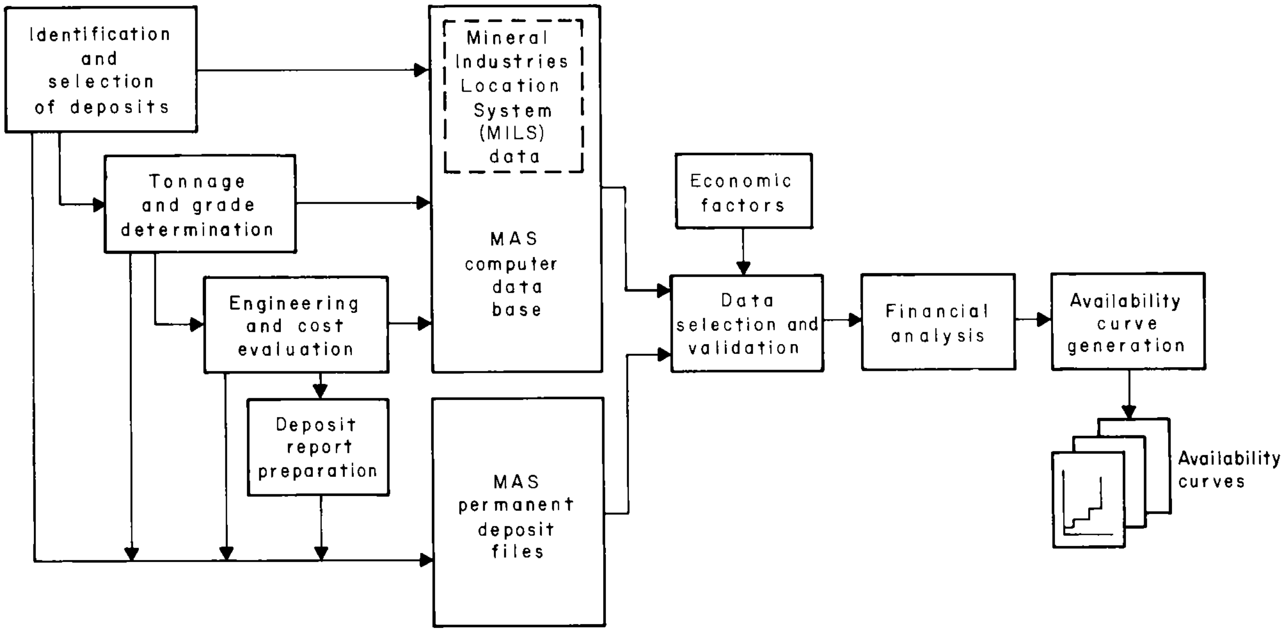

Figure 3.—Flow chart of evaluation procedure.

return in order to cover the opportunity cost of capital plus risk.

Individual deposit tonnage-price data were then aggregated by the SAM to construct the resource availability curves presented in this study. The study was conducted in constant August 1980 dollars. No escalation of either costs or prices was included, since it was assumed that any increase in costs would be offset by an increase in prices.

Tables 4 and 5 present individual deposit information by type of deposit and state, and figure 4 shows the location of the properties. The numbers on the map (fig. 4) refer to the map index number for the deposit shown in tables 4 and 5. Ownership and control data for each property are presented in the appendix (table A-1).

Tonnage estimates presented in this study are reported in metric tons. For converting from metric tons to short tons, multiply by 1.10231.

Table 4.—Property type, status, and resource data[1]

Property type and name	State	Map index numbers[2]	Current status[3]	Grade, pct Al_2O_3	Demonstrated, million tons		Identified, million tons	
					Mineralized material	Contained Al_2O_3	Mineralized material	Contained Al_2O_3
ALUNITE								
Pat Property	Arizona	30	Exp	W	0	0	91	11
A-C Property	Colorado	29	Exp	12.00	0	0	91	11
Calico Peak	Colorado	27	Exp	12.00	0	0	W	W
L-C Property	Colorado	28	Exp	W	0	0	W	W
N-G Property	Utah	23	Exp	W	W	W	W	W
P-V Property	Utah	24	Exp	W	W	W	W	W
S-X Property	Utah	25	Exp	W	W	W	W	W
White Mountain	Utah	26	Exp	W	W	W	W	W
Total	NAp	NAp	NAp	NAp	186	26	764	101
BAUXITE								
Alcoa bauxite	Arkansas	35	Prd	W	W	W	W	W
Quapaw bauxite[4]	Arkansas	36	Prd	W	W	W	W	W
Reynolds	Arkansas	37	Prd	W	W	W	W	W
Total	NAp	NAp	NAp	NAp	38	18[5]	38	18
FERRUGINOUS BAUXITE								
Kauai (EC)	Hawaii	3	Exp	17.60	44	8	93	16
Kauai (NE)	Hawaii	2	Exp	16.70	66	11	98	16
Kauai (SE)	Hawaii	1	Exp	17.40	37	6	54	9
Maui	Hawaii	4	Exp	22.20	0	0	43	10
Columbia County	Oregon	8	Exp	W	W	W	W	W
Salem Hills bauxite	Oregon	9	Exp	W	W	W	W	W
Washington-Multnomah	Oregon	7	Exp	W	W	W	W	W
Cowlitz-Wahiakum	Washington	6	Exp	W	W	W	W	W
Total	NAp	NAp	NAp	NAp	224	47	378	77
CLAY								
Saline County clay	Arkansas	38	Exp	35.00	75	26	100	35
Ione clays	California	21	Ppd	26.00	49	13	162	42
Americus	Georgia	42	Dev	26.70	2,400	641	3,600	961
Sandersville Macon	Georgia	43	Dev	26.60	2,400	638	3,600	958
Wrens kaolin	Georgia	44	Dev	29.20	9,600	2,803	12,000	3,504
Bovill clay	Idaho	13	Prd	19.50	21	4	43	8
Canfield/Rogers	Idaho	14	Ppd	14.50	12	2	204	30
Olson/Stanford	Idaho	12	Exp	17.50	114	20	114	20
Union County clays	Illinois	39	Ppd	28.30	98	28	294	83
North District fireclay	Missouri	34	Exp	33.00	450	149	450	149
Wilcox kaolin	Mississippi	41	Dev	27.50	11	3	50	14
Belt clay	Montana	18	Ppd	26.10	0	0	28	7
Kiowa County clays	Oklahoma	32	Exp	23.00	0	0	53	12
Hobart Butte	Oregon	11	Ppd	24.40	64	16	94	23
Molalla clay	Oregon	10	Exp	19.10	67	13	94	18
Ackerman kaolin	Tennessee	40	Dev	26.70	11	3	54	14
Medley kaolin	Texas	31	Exp	26.00	6	2	23	6
Monkton kaolin	Vermont	50	Ppd	24.20	17	4	33	8
North Bennington	Vermont	51	Ppd	23.30	9	2	11	3
Cowlitz clay	Washington	5	Exp	19.70	0	0	137	27
Total	NAp	NAp	NAp	NAp	15,404	4,367	21,144	5,922
Grand total	NAp	NAp	NAp	NAp	15,852	4,458	22,324	6.118

W Withheld to avoid disclosing individual company confidential data. NAp Not applicable.

[1] All mines/deposits are mined or proposed to be mined by open pit methods.

[2] Map index numbers refer to map on figure 4.

[3] Prd—Producer; Dev—Developed deposit; Exp—Explored deposit; Ppd—Past producer.

[4] Quapaw currently produces bauxite for chemical uses only. This bauxite is amenable to processing into alumina if needed.

[5] Domestic reserve base.

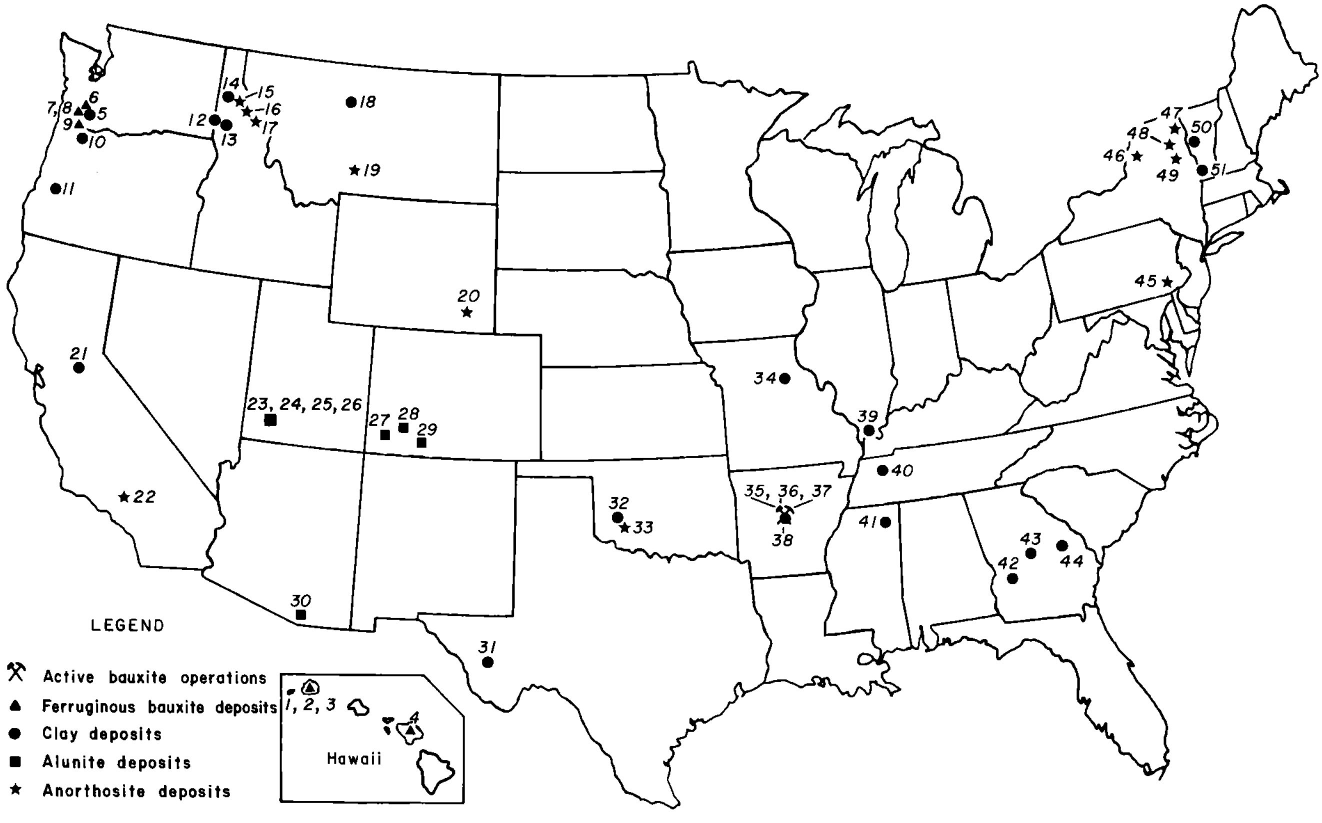

Figure 4.—Location of domestic alumina properties.

Table 5.—Property type, status, and resource data for anorthosite deposits[1]

Property name	State	Map index numbers[2]	Current status[3]	Grade, percent Al_2O_3	Demonstrated, million tons: Mineralized material	Demonstrated, million tons: Contained Al_2O_3	Identified, million tons: Mineralized material	Identified, million tons: Contained Al_2O_3
San Gabriel	California	22	Exp	27.00	16,200	30,000	8,100	60,000
Boehls	Idaho	17	Exp	29.00	1,000	290	2,000	580
Cedar Creek	Idaho	16	Exp	29.00	1,600	464	3,200	928
Goat Mountain	Idaho	15	Exp	29.00	2,000	580	4,000	1,160
Stillwater anorthosite	Montana	19	Exp	30.00	4,000	1,200	8,000	2,400
13th Lake anorthosite	New York	49	Dev	25.50	10,200	2,601	10,200	2,601
Adirondack Park	New York	48	Exp	25.50	350,000	89,250	350,000	89,250
Carthage anorthosite	New York	46	Exp	25.50	500	128	500	128
Rand Hill anorthosite	New York	47	Exp	24.50	2,660	652	2,660	652
Raggedy Mountain Gabbroic	Oklahoma	33	Exp	28.00	1,380	386	5,000	1,400
Corry Peat Products	Pensylvania	45	Exp	25.50	1,000	255	2,000	510
Laramie Range	Wyoming	20	Exp	27.00	65,000	17,550	130,000	35,100
Total	NAp	NAp	NAp	NAp	469,340	121,456	577,560	150,909

NA Not applicable.

[1] Anorthosites are not included in the reserve base but have potential for future production.

[2] Map index number refers to map on figure 4.

[3] Exp—Explored prospect; Dev—Developing prospect; all deposits are proposed to be mined by open pit methods.

TYPES OF DEPOSITS

GENERAL

Aluminum, the third most abundant element in the Earth's crust, occurs in combined form in virtually every geologic setting. In this study, a deposit is considered as a potential source of alumina if it contains aluminum significantly greater than the average crustal abundance, may be amenable to chemical separation on a commercial scale, and has future economic potential. Currently, only bauxite ore is mined and refined to alumina and smelted to metallic aluminum. One of this study's criteria for a potential alumina source is that smelting grade alumina can be produced.

General types of deposits analyzed in this study are described in the following paragraphs.

BAUXITES

Bauxite, the principal ore of aluminum, is composed of aluminum hydroxide minerals with impurities of free silica, clay, silt, and iron hydroxides (*24*). Bauxite is formed as a residual soil in humid, tropical, or subtropical regions where good drainage is present. Under the extreme weathering conditions common to tropical climates, the iron and aluminum silicates are decomposed and silica, with many other elements, is removed by leaching through downward percolation of water. Bauxite deposits typically assay 28 to 55 pct Al_2O_3.

Domestic metallurgical-grade bauxite deposits analyzed include the ALCOA, Quapaw, and Reynolds deposits of Arkansas and the ferruginous bauxite deposits located in Oregon, Washington, and Hawaii.

CLAYS

Clays are fine-grained, earthy materials composed mainly of hydrous aluminum silicates (*24*). They may be predominantly one clay mineral or mixtures of clay minerals and nonclay materials. Clay minerals include kaolin, montmorillonite, illite, and halloysite. Domestically, the best clays are high-alumina kaolinites formed by chemical weathering of crystalline rocks. Kaolin clays are the only clays considered in this study as a potential raw material for aluminum based upon known processing technology. A typical representation of kaolinite deposits in this study are those located in Georgia, which average 28.3 pct Al_2O_3.

Twenty clay deposits were analyzed in this study, including those found in Arizona, California, Georgia, Idaho, Illinois, Mississippi, Missouri, Montana, Oklahoma, Oregon, Tennessee, Texas, Vermont, and Washington.

ALUNITES

The mineral alunite is a sulfate of potassium and aluminum formed by sulfateric action of hot acid waters upon feldspathic rocks. Alunite deposits can occur as fine-grained and massive rock but can also be altered under similar conditions to alunite with clays and, in some cases, to mostly kaolinitic clays.

Alunite contains an average of 37 pct Al_2O_3, but the eight deposits analyzed in this study are diluted with country rock to as little as 11 pct Al_2O_3. These deposits are located in Arizona, Colorado, and Utah.

ANORTHOSITES

Anorthosite is a plutonic igneous rock composed almost entirely of plagioclase feldspar, which is usually labradorite. Labradorite is a lime-soda aluminosilicate, a plagioclase feldspar intermediate between anorthite and albite. Anorthosites are usually large rock bodies exposed in the cores of older mountain ranges. As a group they constitute possibly the largest potential resource of aluminum, with grades averaging about 27 pct Al_2O_3; unfortunately, current state-of-the-art technology does not provide a feasible process for alumina recovery from anorthosites. Therefore, anorthosite deposits are not included in this study's analysis of availability from domestic resources. A list of anorthosite deposits is given in table 5. (See figure 4.)

DAWSONITE

A potentially economic occurrence of the mineral dawsonite is located in the so-called oil shales of the Piceance Creek Basin in Colorado. Oil shale averages some 12 pct dawsonite, which in its pure form $Na_3Al(CO_3)_3.2Al(OH)_3$ contains 35.4 pct Al_2O_3 and is considered 65 to 75 pct recoverable (*7*). However, as a percentage of whole rock, recoverable alumina from dawsonite amounts to only 2 to 3 pct. While oil shale resources may amount to billions of tons, demonstrated reserves of dawsonite have not yet been delineated, and any economic recovery of alumina is entirely dependent upon the mining of oil shale; therefore, dawsonite can only be considered as a potential aluminum resource prior to development of an oil shale industry.

REFINERY TECHNOLOGY

The physical nature and chemical composition of potential ore dictate the type of extraction technology. All the refining techniques considered in this report require chemical leaching of ore followed by the precipitation of an alumina-bearing intermediate product. Usually, the intermediate product, hydroxide or chloride (depending on the extraction process), is then calcined to aluminum oxide (alumina).

The following processes have been selected for treatment of the various aluminum-bearing resources included in this study.

BAYER PROCESS FOR BAUXITES

High-silica bauxites presently mined in Arkansas are amenable to the combination Bayer process, whereas the ferruginous bauxite of Hawaii and the Pacific Northwest could possibly use a modified classic Bayer process. Approximately 2 pct of mineralized material at the demonstrated level may be processed using this technology.

In the classic Bayer process, aluminum and other soluble elements in bauxite are dissolved at elevated temperatures and pressures in a hot, strong alkali solution, generally NaOH, to form sodium aluminate. After separation of the "red mud" tails, the sodium aluminate solution is cooled and seeded, and aluminum trihydrate is precipitated in a controlled form. The trihydrate is dewatered and calcined to the anhydrous crystalline form, alumina. This is the most suitable form for later use in the electrolytic reduction to aluminum metal using the Hall-Heroult process. This form is traded commercially and can be used in feedstock, abrasives, or chemical alums.

High-silica bauxites such as those from Arkansas require additional processing for optimum separation of alumina. The Combination Process is applied to the red mud residue from the standard Bayer processing to extract additional amounts of alumina and to recover sodium values (*26*).

The additional extraction step consists of mixing the red mud with limestone and sodium carbonate, and then sintering the mixture. The silica is converted to calcium silicate and the residual alumina to sodium aluminate. The sintered products are water leached to produce sodium aluminate solution, which is filtered to remove undigested solids and rejoined with the mainstream from Bayer processing for precipitation or separately precipitated. The residual solids (brown mud) are slurried to a waste lake.

The purification standards required for producing refined alumina from the raw ore are very strict. Under present technology, substitutes for bauxite must yield aluminum at least equal in quality to that obtained from bauxite. Any increase in impurities will decrease the recovery efficiency of the electrolytic cells (used in reducing alumina to aluminum), and impurities may be carried through to the metal.

HCl LEACH OF CLAYS

High-alumina kaolinitic clays may be a preferred raw material for alumina production in place of bauxites. They are abundant, have a comparatively high alumina grade, have a high ratio of acid-soluble alumina to impurities, and do not consume large amounts of reagents during processing (*2*, p. 219).

Based on Bureau of Mines test-scale processing of clays, optimum results are obtained by hydrochloric acid extraction with HCl gas-induced crystallization (*16*). Approximately 97 pct of the mineralized material studied at the demonstrated resource level may be amenable to such technology.

In this process, the prepared clay ore is calcined to change the alumina into an acid-soluble form. Calcination also removes free and combined water and destroys any organic matter in the clay as mined. The calcined clay is then digested with hot hydrochloric acid at atmospheric pressure to produce aluminum chloride-rich liquor. The liquor is settled and filtered, and the washed mud residue is sent to waste ponds. Dissolved iron is removed by solvent extraction and thermal conversion and then reacted with calcined clay to form aluminum chloride and iron oxide, which is sent to the waste pond. The iron-free liquor is concentrated by evaporation and then the alumina crystallized as aluminum chloride hexahydrate by HCl gas. The crystals are separated mechanically from the mother liquor and then decomposed thermally to the product alumina. Reagents are recycled and waste heat recovered under the most efficient operating conditions.

Although the potential recovery of alumina from kaolin clays was investigated in this study based on hydrochloric acid extraction using HCl gas induced crystallization technology tested at the "miniplant" level, there are other existing experimental technologies for the extraction of alumina from kaolin clays. A hydrochloric acid process has been studied in detail by Anaconda, which operated a successful pilot plant during the 1960's capable of extracting 6.4 tons per day of alumina from kaolin (*13*, p. 81). The Bureau of Mines investigated a nitric acid extraction process during miniplant testing in 1975 (*2*, p. 247); Arthur D. Little, Inc., also investigated a nitric acid process.

ALUNITE PROCESSING

Before chemical processing, the raw alunite ore is crushed, ground, and sized. The prepared ore is first fed to a roaster where free and combined water are volatilized. The hot calcine is then fed to a reducing roast where most of the sulfur is removed. The removed sulfur passes to a sulfuric acid plant in the proposed commercial-scale operation. Some of the sulfur remains bound with potassium. The reduced calcine is again roasted to oxidize iron and other sulfides so that they do not interfere with the modified Bayer process recovery of alumina. The temperatures and residence time for the different roasts must be carefully controlled in order to remove water and most of the sulfur, and to avoid converting alumina to a caustic insoluble form.

Potassium sulfate is leached from the reoxidized calcine by dissolution in hot, dilute recycled potassium sulfate solution and potassium hydroxide. The potassium sulfate product may be processed in a separate circuit to manufacture fertilizer.

The solids left after leaching sulfate and potassium are about 20 pct Al_2O_3, and the balance is mainly silica with small amounts of iron and titanium oxides. This slurry is washed and then treated in a modified Bayer process to recover alumina. Leaching in lime and soda solution to separate alumina as the trihydrate and then decomposition of the trihydrate to the product alumina follow the conventional Bayer process. Waste heat and reagents are recycled for operating efficiency with the additional recovery of sulfate and potassium in a commercial-scale operation.

A commercial-scale plant for the extraction of alunite has been operated in the Soviet Union, and small pilot plants have been operated in Mexico and in Golden, Colo. The Alumet Consortium partnership, comprised of Earth Sciences Inc., National Steel Corp., and Southwire Corp., reported favorable results from tests at their pilot plant in Golden, which was shut down in 1978.

LIME SINTER OF ANORTHOSITE

The largest domestic potential resources of alumina are contained in anorthosite rock bodies (*4*, p. 2). Anorthosite is an almost monomineralic igneous rock of plagioclase feldspars. The feldspars are near the calcium-rich end of the soda-lime isomorphous series. These deposits are a potential source of virtually unlimited amounts of alumina, if the alumina can be extracted on a competitive basis. The alumina is in a very strong chemical combination with silica, calcium, sodium, and potassium. Major amounts of limestone and fuel, such as coal, are required for the processing of anorthosite. A large amount of solid material similar to cement clinker is the main byproduct of commercial-scale processing of anorthosite.

The separation of alumina from anorthosite by sintering with lime and soda was tested by the Bureau of Mines at a pilot-plant scale (*19*). For the processing considered here, the mined, crushed, and classified anorthosite ore is mixed with water and lime, then is dried, pelletized, and sintered. The sintering step ties the alumina with the alkalis, combines silica into dicalcium silicate, and produces large amounts of CO_2 flue gas. The sinter product is soaked in a rotary calciner to produce self-disintegrating crystal. Leaching is by a concentrated sodium carbonate solution with approximately 75 pct of the contained alumina extracted. Gelation in the leaching step is a technical problem that has delayed development of alumina extraction from anorthosite. Almost two-thirds of the feed weight is removed as solid waste after leaching. The disposal of such large amounts of solid waste may present significant problems. Under proper market conditions, however, this solid waste could possibly be processed to portland cement.

The silica is next removed from the pregnant liquor by seeding. The desilicated solution is seeded and carbonated with washed flue gas to precipitate aluminum trihydrate. Coarse aluminum trihydrate crystals are separated, washed, and dewatered. Calcining decomposes the crystals to the alumina product. Waste heat and reagents are recovered and washed flue gas used in the process.

Although the problem of gelation during separation of alumina from anorthosite appears to have been solved on a laboratory scale, larger scale work has not confirmed the laboratory studies, necessitating further Bureau of Mines research in this area. For this reason, plus the extremely high energy requirement of the lime-soda sinter technique, this process is not considered feasible on a commercial scale. Because of their enormous potential, anorthosite deposits are listed on table 5, but they were not included in this analysis to determine the domestic potential availability of alumina.

AVAILABILITY OF ALUMINA FROM DOMESTIC DEPOSITS

GENERAL

Alumina availability in this study was determined at the demonstrated and identified resource levels. Tonnages potentially available at these levels from each deposit are shown in table 4.

The bauxite reserve base, established to estimate aluminum reserves and resources, is that portion of demonstrated resources that has a probability of economic availability (*27*). The subeconomic resources of aluminum-bearing materials analyzed in this study may have a probability of economic availability in the future depending upon the economics of the industry and technological improvements but, as yet, are not considered part of the reserve base for aluminum.

For 1980, the domestic bauxite reserve base was estimated to be 38 million tons of ore containing 18 million tons of alumina, of which approximately 15.6 million tons is estimated to be recoverable. Total resources at the demonstrated resource level (Arkansas bauxite plus subeconomic alternate sources) were estimated to be about 4,500 million tons of contained alumina with slightly over 4,000 million tons estimated to be recoverable. Total resources at the identified resource level are approximately 6,000 million tons of contained alumina, with a little more than 5,500 million tons considered to be recoverable.

Resource availability curves have been developed to illustrate potential total and annual domestic alumina production based upon each deposit's "incentive price" for alumina. The computed incentive price equals an individual mine's average total cost of production over its entire life including a 15-pct rate of return on investment. These curves show the quantity of alumina that is recoverable after all mining and processing losses. Approximately 93 pct of domestic alumina resources are estimated to be recoverable using state-of-the-art technology.

This study is a static analysis based on the current bauxite reserve base and identified resource estimates and on proven and experimental technology. However, as exploration and development yield additional knowledge of grades and tonnages, and as experimental processing technologies become feasible on a commercial scale, portions of this material may be reclassified. Historically, domestic mineral resources that can be produced economically have increased because of exploration and technologic improvements that enable the mining of lower grade materials or the processing of materials previously considered as waste. Also, as prices for alumina produced from bauxite increase, nonbauxitic sources of alumina will likely become more competitive in the future. The analyses of nonbauxitic sources of alumina in this study are based on nascent technologies, which will likely be proven at a commercial scale in the future, thereby improving the competitive position of these sources.

In order to determine the quantity of alumina that could potentially be produced on an annual and cumulative basis over the life of each deposit and the cost of this production, the following assumptions have been made:

1. Development of each deposit began in 1980.
2. Each operation can produce at full operating capacity throughout the life of the mining operation.
3. Each operation will be able to sell all of its output at the alumina price required to receive at least the desired 15-pct rate of return.

The assumptions used for this study were based upon the desire to determine potential availability of domestic alumina under an emergency situation. As a result, time lags involved in filing environmental impact statements and receiving necessary permits, financing, etc., are not included in this study. Under existing laws and regulations, production from some deposits included in this study would likely be limited by environmental, political, legal, or other constraints. For example, it is highly unlikely that the State of Hawaii would allow the mining of bauxite on the picturesque islands of Maui and Kauai, for obvious reasons.

TOTAL RECOVERABLE ALUMINA

For this study, the portion of the resource availability curves representing potential alumina production from resources other than Arkansas bauxite mines have been shaded in order to emphasize the technological uncertainties inherent in estimating the cost of producing alumina from nonbauxitic sources based on miniplant test date. The shaded areas is not intended to represent a confidence interval. The portion of the curves accounted for by the Arkansas bauxite properties is not shaded since the Bayer process technology is well established. Figure 5 shows total recoverable alumina at various alumina prices including at least a 15-pct rate of return. Analyses indicate that, at the demonstrated resource level, a total of 15.6 million tons is recoverable from Arkansas bauxite properties that are currently producing, and 4,114 million tons from nonbauxitic and ferruginous bauxite deposits that have been explored. At a 1980 price of $0.12 per pound ($264 per ton), all 15.6 million tons of alumina from Arkansas bauxite deposits are recoverable. At an alumina price of $0.26 per pound ($573 per ton), 4,130 million tons of alumina is potentially recoverable. At these prices, all properties could produce alumina and earn at least a 15-pct return on investment.

Potential total production of alumina at the identified resource level is shown in figure 6. Analyses indicate that a total of 15.6 million tons of alumina is recoverable from Arkansas bauxite properties that are currently producing, and 5,649 million tons is recoverable from explored nonbauxitic and ferruginous bauxite deposits.

In general, the lower cost deposits on both the curves are bauxitic, followed by a mix of ferruginous bauxite, clays, and alunite deposits. The clay deposits form the majority of the resource tonnage on both curves. (See table 4.)

POTENTIAL ANNUAL ALUMINA PRODUCTION

Annual production curves for alumina at various price levels, including at least a 15-pct rate of return, are illustrated in figure 7 at the demonstrated resource level. The curves are based on current and expected production capacities at producing mines and nonproducing deposits. The curves were generated in order to reflect the fact that an increase in production cannot be obtained immediately. The time required to initiate production depends on factors such as the relative location of the deposit and the necessity for

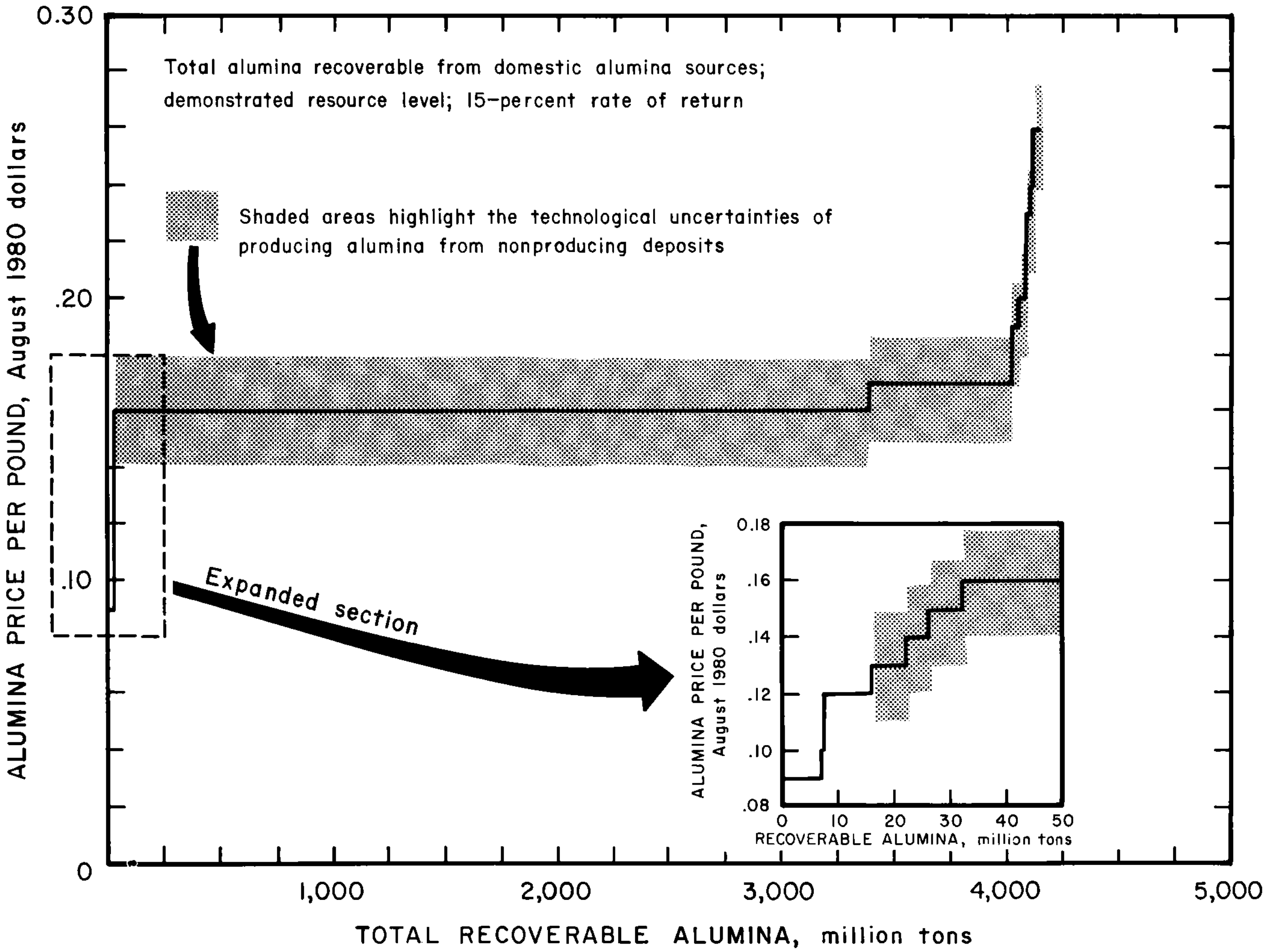

Figure 5.—Total domestic aluminum resources potentially available at various alumina prices—demonstrated resource level.

exploration, development, and plant construction. Thus, an examination of the curves indicates that if all nonproducers had begun preproduction development in 1980, very little increase in production would be noted immediately. Substantial increases could occur by 1983, when production could be as much as 8.2 million tons of alumina per year. Full production could be realized by 1986, when 10.5 million tons of alumina could be produced. After 1986, production of alumina from all sources would appear to slowly decline until 2005, which is also when the exhaustion of known low-priced bauxite deposits would occur. This is reflected in an upward shift of the curve from the $0.08 per pound ($176 per ton) range in 1980 to the $0.15 per pound ($331 per ton) range in 2005.

Alumina production from domestic bauxites could be approximately 1.15 million tons in 1986. Domestic demand for alumina in that year is expected to be almost 20 million tons (*20*, derived from aluminum demand forecast in its table 11). Thus the share of alumina production from domestic bauxite will continue to drop from the current 10 pct to 5.8 pct by 1986.

Annual production curves at the identified resource level are illustrated in figure 8.

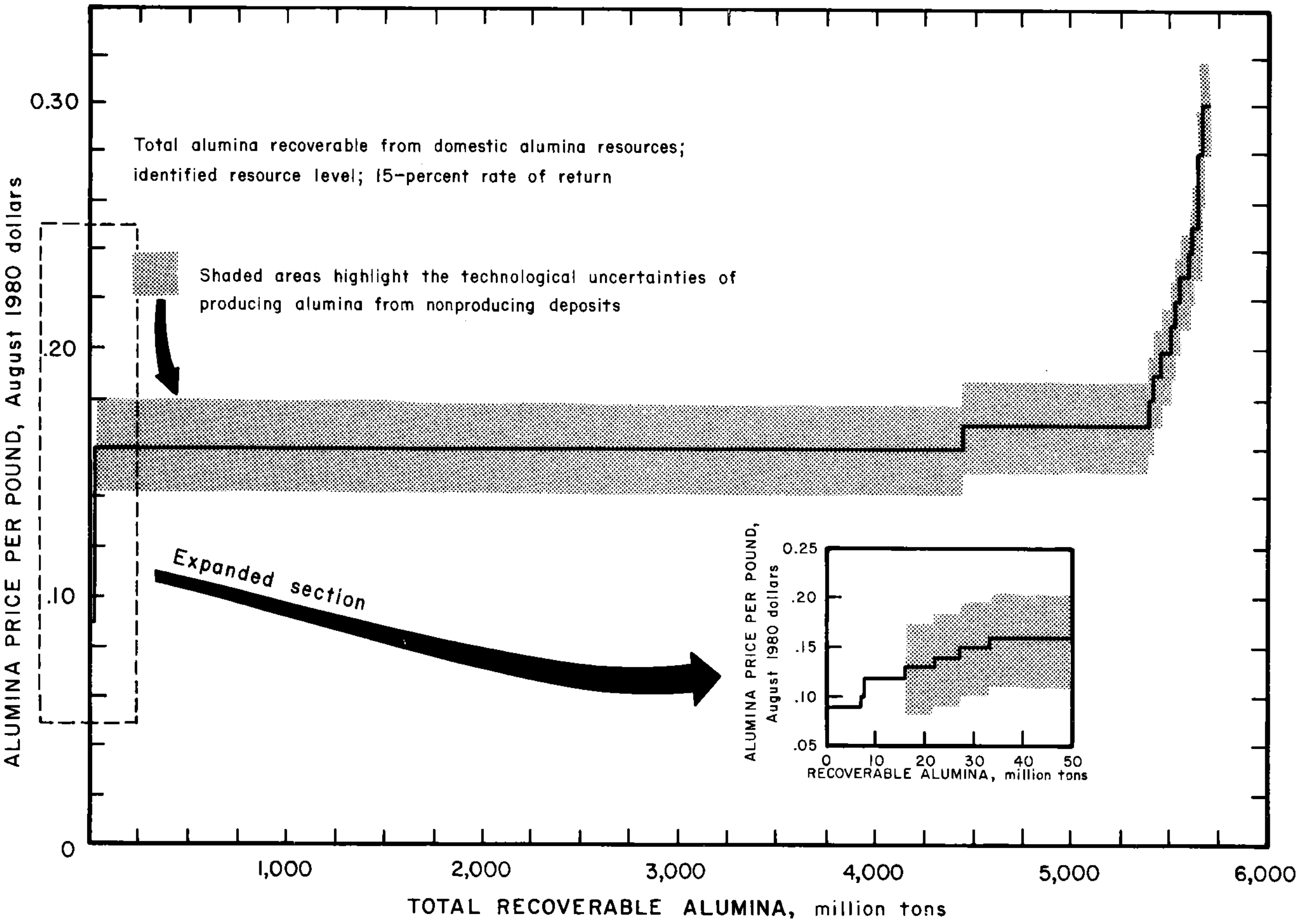

Figure 6.—Total domestic aluminum resources potentially available at various alumina prices—identified resource level.

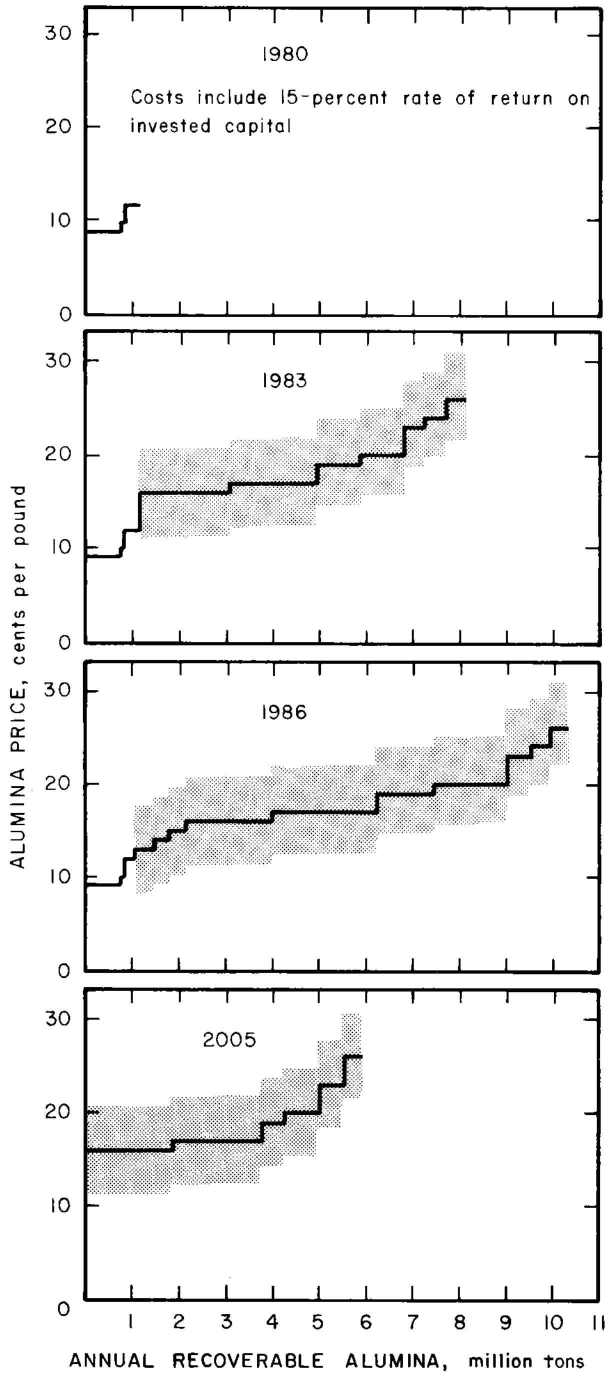

Figure 7.—Potential domestic annual alumina production in selected years at various alumina prices—demonstrated resource level. The shaded areas highlight the technological uncertainties of producing alumina from nonproducing deposits.

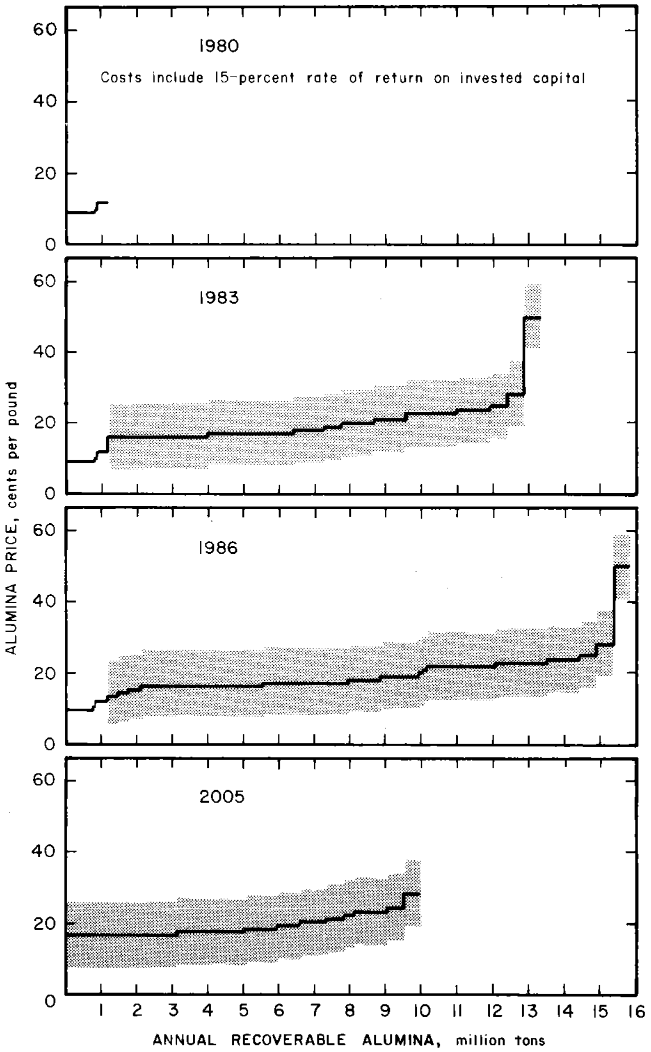

Figure 8.—Potential domestic annual alumina production in selected years at various alumina prices — identified resource level. The shaded areas highlight the technological uncertainties of producing alumina from nonproducing deposits.

CONCLUSIONS

The demonstrated and identified resource levels for domestic alumina are comprised of 31 and 39 properties, respectively. These properties are inclusive of three different types of deposits; bauxites (primarily ferruginous bauxites), clays, and alunites. All of these properties were analyzed to determine the quantity of alumina available from each deposit and the alumina price required to provide each operation with a 15-pct rate of return. The 1980 domestic bauxite reserve base (demonstrated resource level) is 18 million tons of alumina, of which approximately 15.6 million tons are recoverable. Subeconomic aluminum resources at the demonstrated level amount to 4,440 million tons of alumina, of which 4,114 million tons of alumina is considered recoverable. Total contained alumina at the identified resource level is 6,117 million tons, with 5,665 million tons of alumina considered to be recoverable.

For those properties classified as subeconomic resources, an alumina price of $0.26 per pound ($573 per ton) would be required if all properties, producing and nonproducing, were to produce alumina and receive at least a 15-pct rate of return. Including those properties at the identified resource level, the needed alumina price would be $0.50 per pound ($1,102 per ton), which is almost 5 times the current price.

There are only three Arkansas bauxite deposits currently comprising the U.S. bauxite reserve base, and the amount of alumina contained in these deposits is small. In fact, the alumina contained in these three deposits comprises less than 1 pct of total domestic alumina resources. Although the Bureau of Mines, in conjunction with the private sector, is continually researching alternative methods of processing alumina from other known aluminum-bearing deposits (that is, alunite, clays, anorthosites), this study indicates that these deposits as yet cannot economically compete with the rest of the world's huge economic bauxite reserves. As a result, the United States will likely continue to import the majority of the bauxite and alumina necessary to meet current and projected aluminum consumption at least through the year 2000.

Domestic nonbauxitic resources represent a large potential source of alumina. Continuing efforts by the Bureau of Mines and cooperating companies to improve technologies for recovering alumina from these sources will be necessary to provide stable supplies of alumina in the next century. Supplies of alumina from nonbauxitic sources would be required much sooner if the Nation were to face an embargo or cutoff of bauxite and alumina supplies from foreign sources. Furthermore, the existence of the ongoing U.S. program to develop new technologies to recover alumina from nonbauxitic sources could restrain foreign bauxite producers from raising prices above the point that would make domestic sources of alumina competitive with them.

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APPENDIX

Table A-1.—Ownership and control of domestic alumina properties, as of January 1980

Property name	Map index No.	Type	Domain	Type of mineral holding	Owner-operator	Status	Percent of ownership
Arkansas:							
Alcoa Bauxite	35	Bauxite	Private	Fee ownership	ALCOA	Owner-operator	100
Saline Co. Clay	38	Clay	..do	..do	NA	NA	NA
				Private lease			
Quapaw Bauxite	36	Bauxite	..do	Fee ownership	American Cyanamid	Owner-operator	100
Reynolds	37	..do	..do	..do	Reynolds Metal	..do	100
Arizona:							
Pat Property	30	Alunite	..do	Federal lease	Earth Sciences	Owner	50
					National Steel	..do	25
					Southwire Co.	..do	25
California:							
Ione Clays	21	Clay	Mixed	Fee ownership	Numerous misc.	..do	100
				Private lease			
San Gabriel	22	Anorthosite	National forest	Federal lease	U.S. Forest Service	..do	NA
				Fee ownership			
Colorado:							
A-C Property	29	Alunite	BLM Admin.	Federal and State lease	Earth Sciences	..do	50
					National Steel	..do	25
					Southwire Co.	..do	25
Calico Peak	27	..do	..do	Federal lease	D.H. & A.J. Peaker	..do	100
L-C Property	28	..do	..do	Federal and State lease	Earth Sciences	..do	50
					National Steel	..do	25
					Southwire Co.	..do	25
Georgia:							
Wrens Kaolin	44	Clay	Private	Private lease	NA	NA	NA
				Fee ownership			
Americus	42	..do	..do	Private lease	..do	..do	NA
				Fee ownership			
Sandersville Macon	43	..do	..do	Private lease	..do	..do	NA
				Fee ownership			
Hawaii:							
Kauai (SE)	1	Bauxite	..do	Other	Grove Farm	Owner	72
					Knudsen Estate	..do	28
Kauai (NE)	2	..do	..do	..do	American Factors	..do	54
					C. Brewer Co.	..do	46
Kauai (EC	3	..do	..do	..do	American Factors Co.	..do	58
					Numerous misc.	..do	29
					State of Hawaii	..do	12
Maui Fe-Bauxite	4	..do	..do	..do	Agribusiness	NA	74
Idaho:							
Boehls	17	Anorthosite	National forest	Federal lease	U.S. Forest Service	Owner	NA
Olson/Stanford	12	Clay	Private	Fee ownership	Robt. and Al. Olson	Operator	NA
					Troy Fire Brick	..do	NA
					A. P. Green Co.	Owner	NA
					Moscow Fire Brick	..do	NA
Canfield/Rogers	14	..do	..do	NA	Anaconda	..do	NA
Bovill Clay	13	..do	State	State lease	Potlatch	..do	NA
				Fee ownership	A. P. Green Co.	..do	NA
					J. R. Simplot Co.	..do	NA
Cedar Creek	16	Anorthosite	National forest	Federal lease	U.S. Forest Service	..do	NA
Goat Mountain	15	..do	..do	..do	..do	..do	NA

NA Not available.

Table A-1.—Ownership and control of domestic alumina properties, as of January 1980—Continued

Property name	Map index No.	Type	Domain	Type of mineral holding	Owner-operator	Status	Percent of ownership
Illinois:							
Union Co. Clays	39	Clay	Private	Fee ownership	NA	NA	NA
				Private lease			
Missouri:							
N. Dist. Fireclay	34	..do	..do	Fee ownership	..do	..do	NA
				Private lease			
Mississippi:							
Wilcox Kaolin	41	..do	National forest	Federal lease	..do	..do	NA
				Fee ownership			
				Private lease			
Montana:							
Belt Clay	18	..do	Private	..do	Anaconda	Owner	100
Stillwater Anorthosite	19	Anorthosite	National forest	Federal lease	Numerous misc.	NA	NA
				Located claim			
				Patented			
New York:							
Rand Hill Anorthosite	47	..do	Private	Fee ownership	NA	..do	NA
				Private lease			
				State lease			
Adirondack Park	48	..do	State park	Unknown	New York State	Owner	NA
13th Lake Anorthosite	49	..do	State forest	Fee ownership	..do	NA	60
				Private lease	Private owners	..do	40
				State lease			
Carthage Anorthosite	46	..do	Private	Fee ownership	NA	..do	NA
				Private lease			
				State lease			
Oklahoma:							
Raggedy Mountain Gabbroic	33	Anorthosite	Private	Fee ownership	NA	NA	NA
				Private lease			
				State lease			
Kiowa Co. Clays	32	Clay	..do	Unknown	..do	..do	NA
Oregon:							
Molalla Clay	10	..do	..do	..do	Numerous misc.	Owner	100
Columbia County	8	Bauxite	..do	Fee ownership	Reynolds Metals	..do	75
				Private lease	Miscellaneous	..do	25
Hobart Butte	11	Clay	..do	..do	Willamina Clay	..do	13
				Fee ownership	W.A. Woodward Co.	..do	15
					Weyerhauser Lumber	..do	15
					Miscellaneous	..do	57
Salem Hills Bauxite	9	Bauxite	..do	..do	Reynolds Metals	..do	66
					Miscellaneous	..do	34
Washington-Multnomah	7	..do	..do	..do	Reynolds Metals	..do	68
				Located claim	Miscellaneous	..do	32
Pennsylvania:							
Corry Peat Products	45	Anorthosite	..do	Fee ownership	NA	NA	NA
Tennessee:							
Ackerman Kaolin	40	Clay	..do	Fee ownership	..do	..do	NA
				Private lease			
Texas:							
Medley Kaolin	31	..do	Unknown	Unknown	..do	..do	NA

NA Not available.

Property name	Map index No.	Type	Domain	Type of mineral holding	Owner-operator	Status	Percent of ownership
Utah:							
N-G Property	23	Alunite	BLM Admin.	Federal lease	Earth Sciences	Owner	20
					National Steel	..do.	40
					Southwire Co.	..do.	40
White Mountain	26	Alunite	BLM Admin.	Private lease	Earth Sciences	Owner	20
				Federal lease	National Steel	..do.	40
					Southwire Co.	..do.	40
S-X Property	25	..do.	..do.	..do.	Earth Sciences	..do.	20
				State lease	National Steel	..do.	40
					Southwire Co.	..do.	40
P-V Property	24	..do.	..do.	Federal lease	Earth Sciences	..do.	20
				State lease	National Steel	..do.	40
					Southwire Co.	..do.	40
Vermont:							
Monkton Kaolin	50	Clay	Private	Fee ownership	VT Kaolin Corp.	..do.	100
				State lease			
N. Bennington	51	..do.	..do.	Fee ownership	NA	NA	NA
				State lease			
Washington:							
Cowlitz-Wahkiakum	6	Bauxite	..do.	..do.	Numerous misc.	Owner	100
				Federal lease			
				Fee ownership			
Cowlitz Clay	5	Clay	..do.	..do.	..do	..do.	100
Wyoming:							
Laramie Range	20	Anorthosite	..do.	..do.	..do	NA	NA
				State lease			
				Federal lease			

NA Not available.