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A LOCATIONAL ANALYSIS FOR THE ALUMINUM INDUSTRY

MASTER

WALTER ISARD AND LARRY PARCELS
University of Pennsylvania
Philadelphia, PA

December 1977

Prepared for the
BIOMEDICAL AND ENVIRONMENTAL ASSESSMENT DIVISION
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
DEPARTMENT OF ENERGY AND ENVIRONMENT

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ABSTRACT

A locational analysis for the aluminum industry suggests that its locational pattern is probably even more clear-cut than that of the steel industry. Because the smelting of alumina into aluminum requires a very large amount of electric power, aluminum has become an industry highly oriented to cheap power locations. A quick analysis, taking into account present technological and economic conditions, reveals that the potential advantages of the minimum transport cost location for an aluminum plant are clearly outweighed by the large power cost savings accruing from locating the plant at a cheap power location. This holds true even with a fairly small differential in power rates between the two locations.

CHARACTERISTICS OF THE EXISTING INDUSTRY

The production of aluminum involves two steps: (1) the conversion of bauxite or another aluminum ore into alumina, and (2) the subsequent conversion of alumina into aluminum. The first step of converting bauxite into aluminum involves considerable weight loss, the exact amount depending on the specific characteristics of the ore. Because of the great variability in bauxite characteristics, alumina plants are often designed to handle a specific type of ore. An average of 1.93 tons of alumina are in turn required for each ton of aluminum which is to be smelted.¹ The economies accruing from the colocation of the two processes are usually small in comparison to other cost considerations, and the two operations are most often conducted in separate locations. Because of this country's rather small reserve of bauxite, most of the ore is imported from abroad, chiefly from Jamaica, Surinam, Guyana, Guinea, and Australia. The process of converting bauxite into alumina basically involves a caustic leach of the bauxite at increased pressure and temperature. The resulting solution is then separated, and the hydrated aluminum oxide is precipitated out. Primary aluminum is then produced by the electrolysis of the alumina in a molten bath of cryolite.²

Because of the significant weight loss in converting bauxite to alumina, and because of the similar freight rates of each,² it pays to process the ore into alumina directly at the source of the bauxitic raw material. This is even truer in cases where the source of bauxite is located near a cheap power source, because the production of alumina requires an average of 275 kilowatt-hours of electricity and 10.6 million Btu of gas for each ton produced.¹ Most of the aluminum raw material imported from Australia consists of processed alumina rather than bauxite because of the aforementioned cost advantages. In 1973, alumina imports from Australia equaled 1,826 tons as compared to a mere 122 tons of bauxite imports from that country.²

At present, 90% of the total domestic aluminum raw material supply is imported.² Because of security and trade considerations most alumina production does not occur at the source of raw materials. Often the bauxite is instead processed near the domestic port of origin. Southern alumina plants utilize domestic bauxite reserves found in Alabama and Arkansas as well as foreign ores, however. Since most imports into the West Coast are made up of Australian alumina rather than bauxite, no alumina plants exist there presently. Alumina capacity is currently located mainly in the West South Central and East South Central regions of the country. (See Table 1 and Figure 1).

Table 1
United States Alumina Plants³
Location and Capacity - 1975

	Short ton/yr
Aluminum Company of America	
Mobile, AL	1,025,000
Bauxite, AR	375,000
Point Comfort, TX	1,350,000
Martin Marietta	
St. Croix, VI	370,000
Kaiser Aluminum and Chemical	
Baton Rouge, LA	1,025,000
Gramercy, LA	800,000
Reynolds Metals Company	
Hurricane Creek, AR	840,000
Corpus Christi, TX	1,385,000
Ormet Corporation	
Burnside, LA	600,000
	<hr/> 7,770,000 <hr/>

Figure 1. Location of alumina plants and aluminum smelters in the United States.⁴

The chief requirement for producing aluminum aside from the necessary alumina raw material is power. The following statistics show that most of this power is needed in the form of electric energy:

	<u>MMB</u>
Primary energy for electricity	125.10
Other coal	0.79
Other refined oil products	26.08
Other natural gas	15.67
Derivative fuels (coal based)	<u>5.62</u>
	173.26

Source: Energy Conservation: The Data Base, p. 105.

It currently takes an average of 8 kWk of electricity to smelt each pound of aluminum produced in this country.²

KEY COST DIFFERENTIALS

Were alumina considered to be the only necessary raw material, it would be easy to determine whether the industry would be market oriented or not. Although there is a significant weight difference between the aluminum and the alumina needed to produce it, a higher transport rate on aluminum (its freight rate is ~ 1.8 times the freight rate on alumina,* may effectively make aluminum a weight-gaining, market oriented industry. Multiplying the relative transport rates of aluminum

*These are current freight rates based on information from three major railroads. All rates are based on most efficient load sizes and are therefore minimum figures.

and alumina by their relative physical weights, we see at first glance that the alumina processing location would outdraw the market slightly as a preferred location for aluminum smelting.* It must be remembered, however, that the relative transport rates were calculated on the basis of minimum cost/large load rail rates. Although these rates may apply to alumina shipments traveling in large loads to relatively few plant locations, the rates may not apply to aluminum shipments going to many fabricators in smaller loads. Rates on small loads are considerably higher than those on large loads. This fact combined with the fact that it is often important to fill orders for aluminum rapidly would make the aluminum industry somewhat market oriented, other things being equal.

To calculate the power cost differential required to shift an aluminum ingot plant from its minimum transport cost location (in this case, we will assume the market) to a cheap power location, we will use the concept of a critical isodapane as formulated by Alfred Weber.⁴ One can visualize an isocost line encircling the minimum cost market location which describes a locus of points from which shipment costs per ton of aluminum ingot to the market are the same. There are many of these lines radiating from the minimum transport location, each describing a locus of points a certain transport cost away. If a cheaper power location gives cost savings of \$1 per ton of aluminum ingot, then the \$1 isocost line will mark the critical distance or "critical isodapane" where the increase in freight shipping costs to market is balanced by the energy cost savings. If a cheap power source were located within this radius, the aluminum plant would be drawn to it. If a cheap power location (where production costs are exactly \$1 per ton lower) is not found within this radius, then the shipment cost from it to the market would not be equaled by the energy cost savings, and the minimum transport cost location at the market would remain the

* $1.8 \times 1 < 1 \times 1.93$

minimum total cost location. Thus the crucial test for a cheap power location is whether or not it lies within the critical isodapane determined by its per-ton power cost savings and the relevant transport rate on the finished product.

By examining current freight rates, we can see what the energy cost savings should be in order to offset the increased transport costs to market incurred by shifting production to a cheap power location. For the moment, we do not consider the increased costs that would occur if the cheaper power location is significantly further away from the source of alumina than the market location. After consulting several railroads for current rates, we find that it costs approximately 2.3¢ per ton-mile to ship aluminum ingot.* Thus, to ship a ton of aluminum from one end of the country to the other, say from Seattle to New York, would cost approximately \$70. We wish to determine the power rate differential that would be required for a cheap power location at the extreme distance of 3000 miles to be on a critical isodapane with regard to the New York market \$70 shipment-isocost line. In other words, what mill rate savings will translate into a \$70 energy cost saving to match the \$70 additional transport cost? As mentioned before, it takes an average of 8 kWh of electricity to produce a pound of aluminum ingot, or 16,000 kWh to produce one ton. Ceteris paribus, a 4.4-mill/kW energy cost differential would justify the \$70 increase in transport costs to move the aluminum ingot cross-country from a cheap power source to the hypothesized market in New York. ($\$70/\text{ton} \div 16,000 \text{ kWh/ton} = 0.44¢ \text{ per kWh.}$) This represents the extreme case, however. If a market is closer to the cheap power source which is being considered or, conversely, if another cheap power source is closer to the original market considered, then the power cost differential would need to offset not the \$70 transport cost differential, but

* As before, this is the minimum rate, a somewhat higher rate may apply to smaller shipment or shipments over shorter distances.

a smaller one. Basically, however, every 1-mill differential in power costs will justify a 700-mile shift away from the market to a cheap power location (under current economic and technical conditions).

Cases where overwhelming energy cost savings do not exist require us to look at an additional factor, however. In some instances, it may happen that the transport costs of alumina would be increased if the aluminum plant were shifted from the market to the cheap power source. Given that alumina plants are largely based on imported bauxite and can be economically operated at many ports of entry of the bauxite, these transport costs on bauxite do not seem to be a very critical obstacle to aluminum location at cheap power sites, but this factor may be of importance if a company wishes to build an aluminum smelting facility in association with the alumina production of an existing plant in a particular region of the country.

Examination of current regional cost differentials suggests that the aluminum industry should indeed be oriented to cheap power locations. An aluminum producer in Washington State would pay current cost of electricity from a hydropower plant in the Pacific Northwest of 3 mills/kWh. This compares to the rough estimate of 12 mills/kWh required in the South Atlantic States for coal-based electricity.⁵ This 9-mill differential far exceeds the 4.4-mill differential calculated in the above analysis which would make a cheap power location in the Northwest cost competitive with a South Atlantic location for serving the New York market. As it happens, however, there exist a limited number of cheap hydropower sites on the Saint Lawrence River in New York State itself which have operated as profitable locations for aluminum plants serving the New York market. Thus the analysis becomes somewhat more complicated when one simultaneously considers several cheap power locations which could possibly serve a single market.

LOCATION ANALYSIS

In order to analyze which of several cheap power locations would serve as a production point for any particular aluminum market, we could again use the concept of a critical isodapane. For a given market, the cheap power location lying furthest within its critical isodapane is the most cost-competitive location for serving that market. In other words, the most economical power location is that with the largest difference between its power cost advantage relative to the market and its transport cost disadvantage relative to the market. Alumina transport cost differentials to each of the possible aluminum smelting locations should also be considered, where relevant.*

Though the problem seems quite straightforward at this point, the chief difficulty in projecting the location of new aluminum production facilities is in determining where the cheap power locations of the future will be located and exactly how much the electric power will cost at each. In the past it was easy to identify cheap hydropower locations in the Pacific Northwest, for example. The aluminum industry was welcomed with open arms because it could supply the necessary base-load energy demand which would justify the construction of hydroelectric dams. Today almost one-third of all domestically produced aluminum originates in this region of the country. But the energy situation of today has changed drastically. The choicest hydropower sites have already been utilized. Dam construction at the remaining potential hydrosites faces severe pressure from citizen and environmental groups. Because of the rapid growth in the Pacific Northwest there is no longer a surplus of hydroelectric power, and many residents of the area now respond negatively to the use by large industries of a major portion of their cheap energy supply. Plans for coal-based

*For our analysis we assume an equal price on bauxite and alumina at all ports of entry, however.

electric plants have been considered to meet the growing energy demand. It is possible that energy prices will be averaged between cheap hydropower and more expensive coal-based power so that all users will obtain a "fair" share of the relatively inexpensive electricity.*,⁶ Electric rates will undoubtedly go up in the Pacific Northwest, however, no matter what technology is used to meet the increased electric demand. The difficult question to answer is exactly how great the rate increase will be.

The energy picture has also changed drastically in the Southwest in the last two decades. Whereas formerly, cheap and plentiful natural gas served as a basis for the electric power needs of aluminum plants, today some aluminum plants in the Gulf Coast and West South Central region lie idle.⁵ The tremendous demand for natural gas has bid up its price to a level where some aluminum smelters dependent on this type of energy are no longer cost competitive. Even though natural gas is today a relatively inexpensive source of power, this picture will probably change drastically in a few years. The Edison Electric Institute estimates that in 1974 natural gas generated 91% of the power consumed in the Electric Reliability Region which encompasses most of Texas (this region was designated ERCOT by the National Power Survey). By 1985 only 15% of the electricity consumed in the region will be generated by natural gas, while coal will increase its share of generative capacity from 7% of the total to 50% over the same period.⁷

*Almost all the hydroelectric power consumed by aluminum smelters in the Pacific Northwest is presently supplied by the Bonneville Power Authority, which has announced that it may not renew power contracts with the seven major aluminum companies when the agreements expire between 1984 and 1988. If this were to occur, almost one-third of the domestic aluminum production capability would be affected seriously.

CHANGING TECHNOLOGY

Before proceeding to delineate possible cheap power locations and the power costs associated with each, we will briefly discuss possible changes in aluminum production technology. One of the most important technological improvements, and therefore one most relevant for our analysis, would be a significant reduction in energy consumption.

Technological improvements in energy efficiency have long been important in the aluminum industry, and this trend is expected to continue into the future. Whereas it formerly took 12 kWh to smelt a pound of aluminum using the Hall process, it now takes an average of 8. The most efficient plants in operation today require only 6 kWh/lb; however, a prototype plant constructed in New Palestine, Texas, by Alcoa is expected to reduce the energy requirement by 30% to ~ 4.2 kWh/lb. ⁸ The new process developed by Alcoa for use at this plant involves the chlorination of alumina to aluminum chloride and its subsequent electrolytic reduction in a chloride bath. ² Research aimed at improving the Hall Heroult reduction process which is used at most aluminum smelting plants is being directed towards reducing electrical resistance of the anode, cathode, and electrolyte in the reduction cell which currently wastes 60 to 70% of the power input as heat. ²

It should be noted that substantial improvements in energy efficiency are possible, even with currently available technology. Aluminum producers in some countries such as France and Switzerland are already smelting aluminum with 20% less energy than consumed by United States producers. On the other hand, in countries such as Canada where energy is relatively cheap, significantly more power is used than in the U.S. ¹ Thus as power costs increase, producers in all countries will probably invest capital in the most efficient equipment available.

Aluminum producers do expect to decrease their electric energy inputs substantially in the future. They have established a goal of a 10% reduction from 1972 levels of unit product energy requirements for 1980 and a 30% reduction for the year 2000. Some industry officials estimate that these goals made with the Federal Energy Administration can even be met ahead of schedule.⁹ For this analysis we will assume that the smelting of one pound of aluminum from alumina will require 6.8 kWh of electricity in 1985. This figure will be reduced to 5.6 kWh/lb by the year 2000.

PROJECTIONS OF ALUMINUM PRODUCTION

In making our estimate of United States aluminum production for the years 1985 and 2000, we have relied heavily on U.S. Department of the Interior predictions. For the year 2000, Mineral Facts and Problems predicts that total U.S. primary aluminum demand will equal 20,800,000 tons, 80% of which will be produced domestically.² This compares to a demand estimate of 17,223,000 tons made by W. Malenbaum.¹⁰ His estimate (made in 1973) fits well within Mineral Facts and Problems' forecast range of from 15 to 27 million tons. Perhaps the discrepancy in the two estimates can be partially explained by the very recent trend towards aluminum substitution for steel in the auto industry. Mineral Facts and Problems' most probable estimate of demand for 1985 is 11,100,000 tons, 85% of which will be met by U.S. shipments, i.e., 9,435,000 tons will be produced domestically. This estimate is somewhat conservative compared to a U.S. Industrial Outlook production estimate of 11 million tons for 1985,¹¹ and to a 1980 production estimate of 8.75 million tons published recently in Iron Age magazine.¹²

One advantage in using the Bureau of Mines, Mineral Facts and Problems production estimate is that it specifically breaks down demand by consuming market sectors for the year 2000. This enables us to distribute regionally the demand for U.S.

production by allocating consumption to different markets and by using Commerce Department data¹³ to estimate the future regional distribution of each market sector.

ALLOCATION OF FUTURE CONSUMPTION BY REGION

No projections exist for the breakdown of aluminum consumption by market sector for 1985. Therefore we use the available 1975 aluminum consumption estimates, which are broken down by market sectors conformable to the categories given in the Bureau of Mines' Mineral Facts and Problems breakdown for the year 2000.¹⁴ We then interpolated between the 1975 data and 2000 Mineral Facts and Problems projection to obtain our own estimate for the percentage breakdown of 1985 aluminum consumption, by market sector.

The percentage distributions of sectoral consumption for 1985 and 2000 which were used to calculate regional consumption estimates are recorded in the bottom rows of Tables 2 and 3, respectively. The percentage figures at the bottom of each column were multiplied by the upper figure in each box for each region listed in the far left column. The upper number in each box represents what percentage share of the national industry listed at the head of the column is located in that particular region. Thus, multiplying the upper numbers by the total sectoral consumption for each column yields the lower number in each box. Summing the lower figures across rows, we obtain the percentage of total aluminum consumption, covering all industries, which each region accounts for. Then, by taking the regional percentage of consumption times the tonnage of total national consumption, we can estimate the total amount of aluminum consumed in each region. Subtracting off the hypothesized net foreign imports into each region yields the total demand for U.S. aluminum in each region.

Table 2

Percent of Aluminum Shipments Consumed by Sector and Region: 1985

National	Automotive	Construction	Machinery	Containers	Other	% of Total consumption
New England	0 0	6.2 1.02	6.9 0.52	2.5 0.53	5.7 2.21	4.3
Middle Atlantic	10.0 1.60	18.4 3.04	20.1 1.51	15.0 3.18	17.7 6.87	16.2
East North Central	75.0 12.0	20.4 3.34	31.8 2.39	40.0 8.48	19.5 7.57	33.8
West North Central	10.0 1.60	6.9 1.14	7.9 0.59	5.0 1.06	7.6 2.95	7.3
South Atlantic	5.0 0.80	16.8 3.77	7.9 0.59	10.0 2.12	16.5 6.40	12.7
East South Central	0 0	5.0 0.83	4.9 0.37	2.5 0.53	6.4 2.48	4.2
West South Central	0 0	8.3 1.37	5.5 0.41	2.5 0.53	9.2 3.57	5.9
Mountain	0 0	4.6 0.76	2.1 0.16	2.5 0.53	4.3 1.67	3.1
Pacific	0 0	13.6 2.24	12.9 0.97	20.0 4.24	13.0 5.04	12.5
Total (% of shipments consumed by national sector)	16.0	16.5	7.5	21.2	38.8	100

Table 3
Percent of Aluminum Shipments Consumed by Sector and Region: 2000

National	Automotive	Construction	Machinery	Containers	Other	% of Total consumption
New England	0 0	5.9 1.25	6.2 0.51	2.5 0.43	5.6 1.99	4.2
Middle Atlantic	10.0 1.78	17.8 3.77	19.3 1.58	15.0 2.60	17.8 6.32	16.0
East North Central	75.0 13.35	20.0 4.24	30.4 2.49	37.5 6.49	19.1 6.18	33.34
West North Central	10.0 1.78	6.5 1.38	8.3 0.68	5.0 0.87	7.4 2.63	7.3
South Atlantic	5.0 0.89	17.6 3.73	8.9 0.73	10.0 1.73	17.1 6.07	13.1
East South Central	0 0	5.0 1.06	5.6 0.46	2.5 0.43	6.4 2.27	4.2
West South Central	0 0	8.4 1.78	5.9 0.48	5.0 0.87	9.1 3.23	6.4
Mountain	0 0	4.8 1.02	2.0 0.16	2.5 0.43	4.3 1.53	3.1
Pacific	0 0	14.1 2.99	13.4 1.10	20.0 3.46	13.3 4.72	12.3
Total (% of shipments consumed by national sector)	17.8	21.2	8.2	17.3	35.5	100

In order to check the accuracy of our method of distributing aluminum consumption to the various regions we have tested it. (Because our method probably overemphasizes population as a factor in determining regional consumption, we expect that some inaccuracy has resulted.) Since data were available on the location of aluminum fabricating operations for the years 1964 through 1967,¹⁵ we compared them with the results from the use of our methodology for distributing consumption to regions. We first calculated what percentage of total United States employment in aluminum fabricating industries such as aluminum bare wire, cable, sheet and strip, plate, foil, rolled aluminum bars, rods, and structural shapes, drawn aluminum tubing, and extended aluminum shapes, was located in each of the census regions. We took this to be an approximation of the real 1965 aluminum consumption distribution (see column 2 of Table 5). Then using the 1969 BEA distributions for the relevant market sectors, and 1965 data on aluminum consumption by market sector,¹⁶ we distributed consumption to regions for 1965 in the same manner we did for 1985 and 2000 (see Table 4). A comparison of the two distributions enables us to predict the direction and magnitude of error in the distributions we estimated for 1985 and 2000 in Tables 2 and 3.

In view of the discrepancies between the two distributions of aluminum consumption for 1965 shown in Table 5, we have modified our original consumption distributions for 1985 and 2000. The modified versions shown in columns 4 and 6 of Table 5 bear essentially the same relationship to the preliminary estimated distributions for those years as the actual regional consumption data for 1965 does to our estimated distribution for that year. These modified distributions are the basis for computing the tonnage of aluminum demanded in each region as shown in column 5 of Tables 16 and 17.

Table 4
Percent of Aluminum Shipments Consumed by Sector and Region: 1965

National	Automotive	Construction	Machinery	Containers	Other	% of Total Consumption
New England	0 0	6.3 1.6	8.6 0.7	2.5 0.2	5.8 2.3	4.8
Middle Atlantic	10.0 1.9	18.1 4.6	22.4 1.7	15.0 1.4	18.4 7.2	16.8
East North Central	75.0 14.2	22.4 5.7	35.8 2.7	40.0 3.6	19.8 7.7	33.9
West North Central	10.0 1.9	7.4 1.9	6.8 0.5	5.0 0.5	8.0 3.1	7.9
South Atlantic	5.0 1.0	14.1 3.6	5.4 0.4	10.0 0.9	15.1 5.9	11.8
East South Central	0 0	4.8 1.2	3.0 0.3	2.5 0.2	6.3 2.5	4.2
West South Central	0 0	8.8 2.2	4.2 0.3	2.5 0.2	9.5 3.7	6.4
Mountain	0 0	4.1 1.1	1.6 0.1	2.5 0.2	4.1 1.6	3.0
Pacific	0 0	13.9 3.5	12.2 0.9	20.0 1.8	12.9 5.0	11.2
Total (% of shipments consumed by national sector)	19.0	25.4	7.6	9.0	39.0	100

Table 5
Estimated Regional Distribution of Aluminum Ingot Demand, 1985 and 2000

	Preliminary 1965 estimated distribution (1)	Actual distribution for 1964-1967 (2)	Preliminary 1985 estimated distribution (3)	Modified 1985 distribution (4)	Preliminary 2000 distribution (5)	Modified 2000 distribution (6)
New England	4.8	1.1	4.3	1.0	4.2	1.0
Middle Atlantic	16.8	17.6	16.2	16.8	16.0	16.7
East North Central	33.9	27.3	33.8	27.3	33.4	27.2
West North Central	7.9	7.7	7.3	7.1	7.3	7.1
South Atlantic	11.8	9.8	12.7	10.6	13.1	10.9
East South Central	4.2	14.6	4.2	11.0*	4.2	11.0*
West South Central	6.4	2.3	5.9	7.1**	6.4	7.4**
Mountain	3.0	3.2	3.1	3.3	3.1	3.3
Pacific	11.2	16.4	12.5	15.8*	12.3	15.4*
Total percent	100	100	100	100	100	100

(1) From the last column of Table 4.

(2) Calculated from data on employment in aluminum fabricating plants with more than 20 employees (taken from ref. 22).

(3) From the last column of Table 2.

(4) Modified 1985 distribution calculated on the basis of discrepancies between columns one and two of this table.

(5) From the last column of Table 16.

(6) Modified 2000 distribution calculated on the basis of discrepancies between columns one and two of this table.

* Percentage share was decreased slightly according to our best judgment.

** Percentage share was increased slightly according to our best judgment.

Of course, it is not completely correct to say that the location of aluminum fabricators corresponds to the actual final market for aluminum. Some fabricators locate near smelting operations rather than at the market, but as a rule it is more expensive to ship fabricated material than ingot, so fabricators choose locations as close to the actual point of consumption as possible. In any event, it is fabricators, rather than the final consumers of processed aluminum, who are the actual customers of aluminum ingot. Thus, it is clear that for the aluminum ingot shipments we are concerned with, the distribution of aluminum fabricators is the relevant distribution.

EXPORTS AND IMPORTS

According to Mineral Facts and Problems,² the United States supplied an average of 93% of its own primary aluminum requirement over the decade from 1964 to 1974. The high for the domestic production/consumption ratio was 112% in 1970, and the low was 80% in 1973. The predicted 85% figure for 1985 and the 80% figure for 2000 seem somewhat low, but these estimates are probably reasonable in view of the trend toward production in countries with low energy costs. The exploitation of relatively inexpensive Canadian hydropower may mean an increase in imports from that country, and the gas from Middle Eastern oil fields which is currently underutilized may provide a cheap source of power for aluminum production. Countries that are currently underdeveloped but which have oil and bauxite reserves are potential aluminum exporters, and Australia is another possible strong aluminum exporting country in the future. In view of our prediction of a fairly substantial increase in consumption for 1985, and the recent reluctance of the U.S. aluminum industry to make long-term capital investments, a supply shortage may make an increase in imports a necessity for 1985, even leaving aside questions of the industry's cost competitiveness with foreign producers.

Not only do imports and exports influence the amount of aluminum produced, they also influence the regional supply pattern and thus the regional demand for domestic aluminum. Since regional imports and exports are not proportional to the level of consumption or production in every region, we must account for their influence on the regional supply/demand pattern. For example, if aluminum plants at favorably located hydropower sites in Canada can supply much of New England's aluminum needs, then it is unlikely that a coal-based plant in West Virginia would be most competitive enough to ship some of its ingot production there. Thus when deciding where U.S. production should be located in order to serve New England's aluminum demand, foreign imports to New England should be subtracted from New England's demand. Similarly, if a region produces and exports a large amount of aluminum, then the production of that region cannot be totally assigned to United States markets.

In order to distribute exports we have examined both the present market and also the possible foreign markets of the future. Likewise for imports, we have examined countries which export to the United States today and predicted which countries will be important aluminum exporters in the future. Our hypothesized pattern of imports and exports partially depends on the proximity of each region to the predicted importing or exporting nation. For example, since Asia is currently a large consumer of U.S. aluminum exports and since the Pacific Northwest is a large aluminum producer and is favorably situated with respect to Asian markets, we would expect a sizable percentage of future exports to originate in the Pacific region. The hypothesized distribution of imports and exports are shown in columns 1 and 2 of Table 6. Assuming 3-to-1 ratio of imports to exports, we then calculated the distribution of net imports. Lacking any solid projections for the year 2000 we have used the same regional distribution of

Table 6
Percentage Distribution of Net Imports by Region,
1985 and 2000

	% of Imports	% of Exports	% of Net imports*
New England	3	0	4
Middle Atlantic	20	10	25
East North Central	20	10	25
West North Central	1	0	1
South Atlantic	12	5	16
East South Central	10	17	7
West South Central	15	18	13
Mountain	2	0	3
Pacific	17	40	6
Total	100	100	100

*Based on the assumption that there is a three-to-one ratio between imports and exports in 1985 and 2000.

net imports was different for the two years. Net imports for years 1985 and 2000 are recorded in column 2 of Tables 16 and 17, respectively.

The distribution of secondary aluminum production could influence the regional markets for primary aluminum in much the same way imports do. Previously we distributed the demand for primary aluminum according to both the earnings in various manufacturing sectors and the population in each region. If secondary aluminum production (i.e., production based on aluminum scrap) were concentrated in any geographic region, the distribution of primary aluminum demand would be distorted from the pattern we predicted. However, since secondary aluminum production depends on scrap, and the availability of scrap is proportional to the consumption of aluminum, the location of secondary producers is roughly proportional to aluminum consumption. Thus it would not be a distorting

influence on the consumption pattern we have projected. We have therefore not explicitly taken secondary production into account in this analysis.

IDENTIFICATION OF CHEAP POWER LOCATIONS

Having already located potential markets for aluminum for the years 1985 and 2000, we now try to predict the locations of cheap power installations to serve these markets. We assume that the cost of power at all locations will rise dramatically in the next two decades as well as the cost of transporting alumina and aluminum. Since no reliable predictions exist as to the relative effects of inflation on power and freight rates, we will implicitly make the simplest possible assumption. That is, we will use current cost data for power and freight rates, assuming they will rise at an equal pace in future years.

Although power cost for aluminum producers will be measured in constant 1976 dollars in our analysis, we would expect the cost to increase significantly because of the necessary substitution of more expensive power generation technology as raw materials providing cheap power generation are exhausted. Most importantly, we would expect a decline in the availability of cheap hydropower for aluminum producers and an increasing reliance on fossil-fuel-based electricity. Substitution of different fossil fuel deposits for those which are currently utilized could also affect energy prices, however.

Table 7 shows the conventional hydropower electric generating capacity which currently exists in each census region. The predicted increases in hydroelectric capacity for each region are also listed. These figures are derived from Chapter 7 of the National Power Survey of 1970.¹⁵ Although this publication predicts pumped storage hydroelectric capacity expansion as well as conventional, we excluded these capacity increases from consideration. The higher costs of pumped storage hydropower facilities which result from pumping

Table 7
Conventional Hydroelectric Capacity, by Region¹⁵
(Installed Capacity, MW)

	Existing and under construction 1970	Projected increases through 1990	Projected increases through 1985	Projected increases through 2000
New England	755	960	720	1,008
Middle Atlantic	4,755	518	387	544
East North Central	400	0	0	0
West North Central	3,274	0	0	0
South Atlantic	4,976	2,633	1,975	2,765
East South Central	6,047	1,784	1,338	1,873
West South Central	2,335	818	614	859
Mountain	6,613	7,000	5,250	7,350
Pacific	30,846	8,068	6,051	8,471*

*Does not include projects for hydropower in Alaska.

the water which has gone through the turbines back into a storage reservoir during off-peak hours indicate that this type of power would be relatively costly (it may be relatively inexpensive compared with fossil fuel or nuclear-based plants however) and would exist in areas with an already high peak-load power demand. Quite often these pumped storage plants complement an electric generating system based on fossil fuels. Thus, pumped storage hydropower sites would be inappropriate for aluminum smelters, which are typically located in areas with cheap power rates and relatively low power demand.

Since the figures available project conventional hydropower capacity increases to 1990, we will modify them somewhat to suit our needs. We assume that 70% of the projected expansion will be completed by 1985 and an additional 5% expansion above the 1990 projection will be possible by the year 2000. (See columns 3 and 4 of Table 7.)*,**,^{16,17}

It is very difficult to estimate exactly how much of the increment to hydropower capacity aluminum-makers will be able to use. Clearly, they will not be allowed to utilize all of the increased power supply. If this were true, practically all smelting operations would be currently located in the Pacific Northwest. We do know that certain political and economic pressures exist which limit the amount of power in a cheap power region that may be channeled to the industrial sector. This can come about in two ways. If the supply of cheap

*It is quite possible that the National Power Survey estimate for potential hydropower sites is overly optimistic. Most students of the aluminum industry see potential for further expansion of hydroelectric capacity as being very limited.

**The Joskow-Rozanski article, mentioned previously, projected an increase of 36% in United States hydropower capacity by 1985 compared to our own projection of 19%, and an increase of 64% by 1995 as compared to our projected increase of 27% by the year 2000. Moreover, the Edison Electric Institute predicted a growth in hydroelectric power of 12 and 93% by the years 1985 and 2000, respectively.

hydropower is viewed as being totally inelastic, then political pressures would ensure that private users and industrial and commercial clients other than aluminum smelters would receive their "fair share". Although the supply of power could theoretically be increased in any given area by supplementing hydroelectric capacity with conventional fossil fuel plants, political pressures from current power users might discourage the exhaustion of the cheap power pool by new industries who would wish to relocate there. The power cost increases occurring after the power demand in an area reaches a certain optimum level of minimum power cost would also discourage new industry at some point.

Using the assumption that each ton of aluminum smelting capacity requires 2kW of electric generating capacity,² we can calculate the percentage of each region's hydroelectric generating capacity which is currently used by the aluminum industry. This information as well as projections of population growth and industrial development for each region gives us some idea as to the percentage of hydroelectric capacity in each region that aluminum smelters would be able to utilize. Since 8% of the Pacific regions's hydroelectric capacity is currently utilized for a aluminum smelting, we hypothesize that the aluminum industry will also be able to utilize 8% of the projected increase in hydroelectric capacity there. We hypothesize that 10% of the incremental hydroelectric capacity of the Mountain States will be available to aluminum producers as compared to only 4% of the projected new hydroelectric capacity in the East South Central States. The amount of aluminum smelting in other states expected to be based on new hydropower capacity is negligible. The estimated potential expansion of aluminum capacity which would take place in each region based on hydroelectric capacity increases is shown in the third column of Tables 16 and 17. The sizable increase in the Pacific region for the year 2000 is based on the assumption

that Alaskan hydropower sites will be feasible by that year.*

We also make the assumption for this analysis that aluminum producers will first expand to meet their output requirements by rounding out existing production capacity at each plant, thus increasing capacity in each region by approximately 5%. This may be a rather conservative figure. One major industry executive estimates that his company has a round-out potential of 10%; that is, it could increase production capacity by 10% without constructing any completely new facilities.¹⁸

Table 8

Existing Aluminum Ingot Production Capacity, by Region
(ooo's of short tons)

	Tonnage	Percentage Share
New England	0	0
Middle Atlantic	326	6
East North Central	530	9
West North Central	140	2
South Atlantic	458	8
East South Central	1,174.5	21
West South Central	1,398.5†	25
Mountain	180	3
Pacific	1,408	26
	5,615	100

Source: American Bureau of Metal Statistics, Non-Ferrous Metal Data, 1975. New York: Apex Press, 1976.

†This total reflects the latest addition to capacity of New Palestine, Texas.

*In the May 24, 1976 issue of Iron Age, Frank Bradley, President of Martin Marietta Aluminum Company, predicted that hydroelectric potential in Canada and Alaska would have a good possibility of serving the power needs of the aluminum producers in future years.

Having estimated the potential pool of cheap hydropower in each region available to aluminum producers, we must next estimate exactly how cheap this form of power would be. To estimate power cost differentials, we have relied on rate information from the latest National Electric Rate Book, as well as cost information from Brookhaven and other sources.¹⁹ On the basis of the electricity needs of a typical aluminum smelting operation, we calculated the appropriate power rates for large industrial users of power utilities in several regions of the country. Rates of utilities in the Pacific Northwest which had predominantly hydropower-based generating capacity were compared to rates of a typical utility in Central Illinois with generating capacity based on coal. We then compared the rate differential of power companies which were based on each of the two types of generating capacity to the cost differential we calculated using technical data and other cost information and found that they agreed closely. We feel it is reasonable to use actual published power rates of electric utilities to calculate cost differentials, since aluminum companies purchase three-quarters of the electricity which they consume.²⁰ It may be that even if an aluminum maker generates his own power these rate differentials would approximate the cost differentials he would face. Theoretically, at least, a regulated utility is run as a nonprofit organization which markets its power on the basis of actual operation costs.

In order to calculate power rate differentials from the National Electric Rate Book, we used the most inexpensive rate schedules applicable to large industrial power users. If we assume that it takes 2 kilowatts of electric generating capacity to produce one ton of aluminum per year, it follows that the monthly kilowatt demand per ton of aluminum produced (that is, the demand to produce a ton per month) equals 24 kilowatts.²

Using the predicted 1985 amount of energy usage per pound, we calculated that it would take 13,600 kWh (2000×6.8) to produce each short ton of aluminum. Dividing kilowatt-hour usage by the kilowatt demand (24) yielded an average ratio of 570 kWh/kW. This implies 18.5 hours per day of production at the aluminum smelting plant. This compares to an average ratio of 670 kWh/kW using the current average energy consumption of the aluminum industry of 16,000 kWh/ton and the same kilowatt demand per ton per year. This higher ratio implies an average daily operation of 22 hours for the aluminum smelting facility as compared to 18.5. Thus, we may have slightly overstated the hydroelectric capacity needed to produce a ton of aluminum by assuming the 2 kilowatts per ton per year demand would still hold for 1985. The aluminum plant output which we used to calculate the monthly power usage in computing the electric rates was 13,500 tons per month.

Taking the rates of a power plant in Central Illinois as representative of a coal-based plant, and averaging the dollar per kilowatt-hour rates of many hydroelectric-power-based utilities in the Pacific Northwest, we found the approximate cost differential between coal-based and hydropower-based utilities to be almost 11 mills.

Using Brookhaven data on the capital cost of constructing a kilowatt of coal-steam or hydroelectric generating capacity, and applying an 18% rate to translate total capital cost into annual capital cost, we computed that each kilowatt of hydroelectric capacity costs \$56 per year as compared to \$80 annually for a kilowatt of coal-steam electric generating capacity (these figures are measured in 1974 dollars). Assuming that a hydroelectric facility can produce an average of 700 kWh of electricity per month as compared to 650 kWh for a fossil fuel facility (because of less downtime and fewer power outages¹⁵), we calculated that there is a 3.6-mill/kW capital cost differential favoring a hydroelectric facility

over a coal-fired facility. Brookhaven also estimates a cost differential of 1.3 mills/kWh (measured in 1974 dollars) in operation and maintenance costs which favor a hydroelectric power facility. To calculate the fuel cost differential, we took the estimated 1985 Btu requirement to produce a kilowatt-hour of electricity from a fossil fuel plant, the average Btu content of a pound of coal,¹⁷ and the average 1975 price of coal,²¹ and then estimated the cost of coal per kilowatt-hour of electricity generated.

$$\frac{9575 \text{ Btu}}{\text{kWh}} \div \frac{12,000 \text{ Btu}}{1 \text{ lb of coal}} = 0.798 \text{ lb of coal per kWh of electricity}$$

$$\frac{0.798 \text{ lb of coal}}{\text{kWh}} \times \frac{0.725\phi}{\text{lb}} = 5.8 \text{ mills kWh of electricity}$$

Therefore, adding the capital cost differential, operation and maintenance cost differential, and power cost differential, we see that it costs an average of 10.7 mills less to produce a kilowatt-hour of hydroelectric power as compared to coal-based electric power. This compares fairly closely to an estimate made recently in Iron Age magazine of an 11.5- to 12.5-mill/kWh cost differential and also to the 11-mill differential we previously calculated from power rate statistics.¹⁸

In order to calculate regional electric power rate differentials for coal-based plants, we have used information from a recent paper by Joskow and Rozanski.²¹ This report gives the approximate coal price in each census region as well as an estimated capital cost multiplier for fossil-fuel-based electric plants in each region. The New England region has been arbitrarily assigned the role of numeraire with a capital cost multiplier equal to 1. The coal prices and capital cost multipliers are listed in columns one and two to Table 9 below. Coal prices are measured in 1975 dollars and apply to high sulfur, medium Btu-content coal. In the Joskow-Rozanski

paper, the authors assumed that efficient stack gas desulfurization would be commonplace in 1985 because of improved technology. Making the same assumption, we can use these price differentials between high sulfur coals in different regions to analyze regional power cost differentials. Since the West South Central States have coal available at the average U.S. price of \$14.50 per ton, we arbitrarily measure cost differentials with this region as the base level for our analysis. Capital cost multipliers can be used to compute a mill per kilowatt cost differential when they are applied to the average 10.3-mill/kW capital cost of a fossil fuel plant, which we computed earlier in our calculation of the average coal-hydropower cost differential. Again, we measure the capital cost differentials by arbitrarily taking the West South Central as the base level against which cost in other regions are compared.

The preferred method for calculating power cost differentials would be to use the results of the Brookhaven linear programming model which determines the optimal pattern of energy usage for the United States. The Brookhaven LP model depends partially on the locational analysis described in this paper, however. Thus, the procedure should be an iterative one. The energy costs used in this first-run analysis are merely a starting point. They can be modified later when the results of the linear programming model are available.

Table 9

Cost Differentials Between Regions for Coal-Based
Electric Generating Plants³⁵

	Coal prices (1975 dollars/short ton)	Fossil capital cost multiplier
New England	27.654	1.0000
Middle Atlantic	22.069	1.0126
East North Central	17.653	0.9860
West North Central	15.032	0.9531
South Atlantic	21.683	0.9527
East South Central	15.904	0.8760
West South Central	14.511	0.8718
Mountain	11.629	0.9097
Pacific	19.720	0.9601

Using the 1985 estimate for coal consumption per kilowatt-hour of electricity which we derived previously, we estimate that each dollar's difference in coal prices between regions implies a 0.4-mill/kWh electricity cost differential.* Using the Edison Electric Institute's estimate of 9250 Btu requirement per kilowatt-hour of electricity generated by a fossil fuel electric plant in the year 2000, we estimate that approximately the same 0.4-mill differential will exist in that year for every dollar's worth of difference in coal price between regions. The estimated cost differentials between regions for coal-based electricity generation are shown in Table 10.

$$\begin{aligned}
 &\frac{*9275 \text{ Btu}}{\text{kWh}} \div \frac{12,000 \text{ Btu}}{\text{lb of coal}} = \frac{0.798 \text{ lb of coal}}{\text{kWh}} ; \\
 &\frac{0.798 \text{ lb}}{\text{kWh}} \times \frac{\$1}{2000 \text{ lb}} = \frac{0.4 \text{ mills}}{\text{kWh}} .
 \end{aligned}$$

PROJECTION OF INTERREGIONAL SHIPMENTS

Taking the power cost differentials, we then measured the mill per kilowatt power cost advantage of each region with respect to every other region. These figures are shown in the upper portion of each box in Table 12. If a region has a power rate disadvantage with respect to another, it is simply denoted by an "x" in the appropriate box. Thus, for example, we see that the Middle Atlantic region has a power cost advantage of 2.2 mills over New England. In order to decide whether the Middle Atlantic region could serve the New England aluminum market because of its power cost advantage, we would have to compare the transport cost from the Middle Atlantic region to New England with the power cost differential. If it is less, then the Middle Atlantic region could more efficiently serve New England's aluminum demand than New England itself. Rather than comparing the transport cost per ton of aluminum ingot to the dollar per ton power cost differential (this figure is readily computed by multiplying the power requirement for a ton of aluminum by the mill per kilowatt cost differential), we have instead translated transport costs into mills per kilowatt units by dividing the transport cost per ton mile by the number of pounds in a ton and then divided by the number of kilowatt-hours per pound.*

*For year 1985: $2.3¢ \text{ per ton mile} \div 2000 \text{ lb} \div \frac{6.8 \text{ kWh}}{\text{lb}} \times 1000 = 1.7 \text{ mills per 1000 miles}$
(i.e., a producer is indifferent between 1000 miles of extra transportation and a 1.7 mills per kilowatt power cost advantage).
For year 2000: $2.3¢ \text{ per ton mile} \div 2000 \text{ lb} \div \frac{5.6 \text{ kWh}}{\text{lb}} \times 1000 = 2.1 \text{ mills per 1000 miles}$

Table 10
Cost Differentials Between Regions for Coal-Based
Electricity Generation

	Capital cost differential (mills/kWh)	Coal cost differential (mills/kWh)	Total cost differential for coal-based electricity (mills/kWh)
New England	+ 1.3	+ 5.3	+ 6.6
Middle Atlantic	+ 1.4	+ 3.0	+ 4.4
East North Central	+ 1.2	+ 1.3	+ 2.5
West North Central	+ 0.8	+ 0.2	+ 1.0
South Atlantic	+ 0.8	+ 2.9	+ 3.7
East South Central	+ 0.1	+ 0.6	+ 0.7
West South Central	0	0	0
Mountain	+ 0.4	- 1.2	- 0.8
Pacific	+ 0.9	+ 2.1	+ 3.0

Taking the approximate railroad mileage between regions (see Table 11),²² we then computed the mill per kilowatt transport cost between regions. These are shown in the bottom portion of each box in Table 12. Subtracting the bottom figure in each box yields the net savings per kilowatt-hour in serving the aluminum market in any region from any other region. These figures, for 1985 and 2000, are shown in Tables 13 and 15, respectively. Thus in 1985 a saving of 1.8 mills per kilowatt-hour or \$24.48 per ton would accrue from producing aluminum in the Middle Atlantic region rather than New England for serving the New England market. We see from Table 13 that most likely producing region for serving the New England market in 1985 is the East South Central, however, and it is followed closely by the Mountain and West South Central regions. Thus for any regional market, we know from Tables 13 and 15 which regions will supply the cheapest power locations for that particular market. Note that this procedure is completely analogous to the procedure described earlier for choosing the

Table 11

Approximate Railroad Mileage Between Regions

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
New England	0	200	1,000	1,500	600	1,200	1,900	2,300	3,300
Middle Atlantic		0	900	1,400	400	1,000	1,700	2,200	3,200
East North Central			0	500	800	700	1,200	1,300	2,300
West North Central				0	1,300	900	1,000	800	1,800
South Atlantic					0	700	1,400	2,000	3,000
East South Central						0	700	1,700	2,400
West South Central							0	1,300	1,900
Mountain								0	1,100
Pacific									0

Table 12

Cost Differentials Between Regions for 1985*,**
Regions With Power Cost Advantage

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
New England	0	2.2 0.4	4.1 1.7	5.6 2.6	2.9 1.0	5.9 2.0	6.6 3.2	7.4 3.9	3.6 5.6
Middle Atlantic	x***	0	1.9 1.5	3.4 2.4	0.7 0.7	3.7 1.7	4.4 2.9	5.2 3.7	1.4 5.4
East North Central	x	x	0	1.5 0.9	x	1.8 1.2	2.5 2.0	3.3 2.2	x
West North Central	x	x	x	0	x	0.3 1.5	1.0 1.7	1.8 1.4	x
South Atlantic	x	x	1.2 1.4	2.7 2.2	0	3.0 1.2	3.7 2.4	4.5 3.4	0.7 5.1
East South Central	x	x	x	x	x	0	0.7 1.2	1.5 2.9	x
West South Central	x	x	x	x	x	x	0	0.8 2.2	x
Mountain	x	x	x	x	x	x	x	0	x
Pacific	x	x	0.5 3.9	2.0 3.0	x	2.3 4.1	3.0 3.2	3.8 1.9	0

*The upper number in each box denotes the mill per kilowatt cost differential in generating fossil-fuel-based electricity.

**The lower number refers to the transport cost from the region listed in the far left column to the region listed in the column heading. Costs have been translated into mills per kilowatt hour by dividing dollar cost per ton by the electricity requirement per ton of aluminum.

***x denotes that the region listed at the heading of the column has a power cost disadvantage relative to the region listed in the column at the far left.

Table 13

Regional Cost Advantages for 1985 (Mills per kWh)
Regions With Power Cost Advantage

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
New England	0	1.8	2.4	3.0	1.9	3.9*	3.4**	3.5**	x
Middle Atlantic		0	0.4	1.0	0	2.0*	1.5**	1.5	x
East North Central			0	0.6**		0.6**	0.5**	1.1*	
West North Central				0**		x	x	0.4*	
South Atlantic			x	0.5	0	1.8*	1.3**	1.1	x
East South Central						0*	x	x	
West South Central							0*	x	
Mountain								0*	
Pacific			x	x		x	x	1.9*	0

*Denotes most promising location for serving the particular market in question

**Denotes other possible locations which could be cost competitive.

Table 14

Cost Differentials Between Regions for 2000***
Regions With Power Cost Advantage

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
New England	0	2.2 0.4	4.1 2.1	5.6 3.2	2.9 1.3	5.9 2.5	6.6 4.0	7.4 4.8	3.6 6.9
Middle Atlantic	x***	0	1.9 1.9	3.4 2.9	0.7 0.8	3.7 2.1	4.4 3.6	5.2 4.6	1.4 6.7
East North Central	x	x	0	1.5 1.0	x	1.8 1.5	2.5 2.5	3.3 2.7	x
West North Central	x	x	x	0	x	0.3 1.9	1.0 2.1	1.8 1.7	x
South Atlantic	x	x	1.2 1.7	2.7 2.7	0	3.0 1.5	3.7 2.9	4.5 4.2	0.7 6.3
East South Central	x	x	x	x	x	0	0.7 1.5	1.5 3.6	x
West South Central	x	x	x	x	x	x	0	0.8 2.7	x
Mountain	x	x	x	x	x	x	x	0	x
Pacific	x	x	0.5 4.8	2.0 3.8	x	2.3 5.0	3.0 4.0	3.8 2.3	0

*The upper number in each box denotes the mill per kilowatt cost differential in generating fossil-fuel-based electricity.

**The lower number refers to the transport cost from the region listed in the far left column to the region listed in the column heading. Costs have been translated into mills per kilowatt hour by dividing dollar cost per ton by the electricity requirement per ton of aluminum.

***x denotes that the region listed at the heading of the column has a power cost disadvantage relative to the region listed in the column at the far left.

Table 15

Regional Cost Advantages for 2000 (Mills per kWh)
Regions With Power Cost Advantage

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
New England	0	1.8	2.0	2.4	1.6	3.4*	2.6	2.6	x
Middle Atlantic		0	0	0.5	x	1.6*	0.8	0.6	x
East North Central			0	0.5**		0.3**	0	0.6*	
West North Central				0**		x	x	0.1*	
South Atlantic			x	0	0	1.5*	0.8	0.3	x
East South Central						0*	x	x	
West South Central							0*	x	
Mountain								0*	
Pacific			x	x		x	x	1.5*	0

*Denotes most promising location for serving the particular market in question.

**Denotes other possible locations which could be cost competitive.

cheap power location which lies farthest within its critical isodopane.

The tonnage of United States produced primary aluminum which will be demanded in each region is shown in Table 16 for the year 1985 and in Table 17 for the year 2000. We assume that the hydroelectric power available to aluminum producers in each region will be fully utilized. Presumably, aluminum from new plants which are based on hydroelectric power will be consumed in the immediate region or shipped to the nearest surrounding region if a local surplus of aluminum exists. Existing capacity and new capacity based on hydropower will not meet all the demand for aluminum, however. Regional deficits (or, in some cases, surpluses) are shown in the sixth column of Tables 16 and 17. These deficits will have to be met by plants powered by electricity from fossil fuels. The cheap power regions which will make up these deficits were found by examining the cost differences in Tables 13 and 15.

The hypothesized shipments from cheap power regions to supply deficit regions are shown in Tables 19 and 20. Adding these shipments together, we can estimate the total aluminum capacity expansion which is necessary in each region. These figures are shown in the last column of Tables 16 and 17 for 1985 and 2000, respectively. An overview of the changing distribution of regional production over time is given by Table 18.

Table 16

Aluminum Supply and Demand, By Region, For 1985

	Existing 1976 aluminum production capacity plus 5% roundout	Assumed net imports (1985)	Projected aluminum capacity increases based on hypothesized hydropower expansion (1976-1985)	=	1985 Supply aluminum (sum of columns 1,2,&3)	-	1985 Projected demand for primary aluminum	=	Net deficit in supply (-) to be met by fossil-fuel- based aluminum capacity for 1985	Hypothesized 1985 aluminum capacity expansion based on fossil fuel
New England	0	67			67		111		- 44	
Middle Atlantic	342	416			758		1864		-1106	
East North Central	557	416			973		3030		-2057	
West North Central	147	17			164		788		- 624	230
South Atlantic	481	266			747		1177		- 430	43
East South Central	1234	117	27		1378		1221		+ 157	995
West South Central	1468	216			1684		789		+ 895	714
Mountain	189	50	263		502		366		+ 136	1025
Pacific	1478	100	242		1820		1754		+ 66	
Total	5896	1665	532		8093		11100		-3007	3007

Table 17

Aluminum Supply and Demand, By Region, For 2000

	Predicted 1985 aluminum production capacity	+	Assumed net imports (2000)	+	Projected aluminum capacity increases based on hypothesized hydropower expansion (1985-2000)	=	2000 Supply of aluminum (sum of columns 1,2,&3)	-	2000 Projected demand for primary aluminum	=	Net deficit in supply (-) to be met by fossil-fuel- based aluminum capacity for 2000	Hypothesized 2000 aluminum capacity expansion based on fossil fuel
New England	0		166				166		208		- 42	
Middle Atlantic	342		1040				1382		3474		- 2092	
East North Central	557		1040				1597		5658		- 4061	
West North Central	377		42				419		1477		- 1058	1479
South Atlantic	524		666				1190		2267		-1077	
East South Central	2256		291		10		2557		2288		+ 269	2510
West South Central	2182		540				2722		1539		+1183	829
Mountain	1477		125		105		1707		686		+1021	1875
Pacific	1720		250		397*		2367		3203		- 836	
Total	9435		4160		512		14107		20800		-6693	6693

* Includes aluminum capacity made possible by the development of Alaskan hydropower sites which were not considered in the 1970 National Power Survey.

Table 18

Aluminum Capacity, By Region, For 1985 and 2000

	1985		2000	
	Tons	Percent	Tons	Percent
New England	0	0	0	0
Middle Atlantic	342	3.6	342	2.1
East North Central	557	5.9	557	3.3
West North Central	377	4.0	1856	11.2
South Atlantic	524	5.6	524	3.1
East South Central	2256	23.9	4776	28.7
West South Central	2182	23.1	3011	18.1
Mountain	1477	15.6	3457	20.8
Pacific	1720	18.2	2117	12.7
Total	9435	99.9	16640	100

Table 19

1985 Primary Aluminum Shipments To Deficit Regions
(Thousands of Tons)

To From	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Total Shipments
New England										
Middle Atlantic										
East North Central										
West North Central			100	130						230
South Atlantic					43					43
East South Central	28	666	543		227	65				1609
West South Central	16	440	603	78	160					1217
Mountain			811	350						1161
Pacific				166						66
Amount of deficit	44	1106	2057	624	430	65				4326

Table 20

Primary Aluminum Shipments To Deficit Regions For 2000
(Thousands of Tons)

To From	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Total Shipments
New England										
Middle Atlantic										
East North Central										
West North Central			1021	458						1479
South Atlantic										
East South Central	27	1272	860		620					2779
West South Central	15	820	720		457					2012
Mountain			1460	600					836	2896
Pacific										
Amount of deficit	42	2092	4061	1058	1077				836	9166

SOME QUALIFYING REMARKS

The share of new output going to the West South Central region was increased to level somewhat above what the figures would have suggested because the authors felt the coal cost differential between the East South Central and West South Central may have been overstated.²³ Also, taking mileages between regions provided rather crude approximations. If the distances to Eastern markets were measured from aluminum plants in Louisiana rather than in Houston, Texas, the cost advantage of the East South Central over the West South Central for serving those markets would have evaporated for the 1985 analysis. The ideal location of the Gulf Coast with reference to receiving and sending shipments and its proximity to alumina capacity are also factors to its advantage. We know that at least one major aluminum producer already owns large holdings of cheap lignite in the West South Central region, so we would expect that the region will probably hold its own in winning new aluminum production capacity.¹⁸ This is especially true if the regional demand grows faster than we have anticipated, and there is a good possibility we have underestimated the market in that region.

If the large amount of existing hydropower in the Pacific Northwest keeps power rates relatively low in the future, more aluminum capacity could also be located there. In view of the current political situation, we have made our estimates of capacity expansion for that region fairly conservative, however.

Although inertia will tend to work against a radical shift in the aluminum industry in the relatively short period from now to 1985, the present distribution of the industry will have little effect on the distribution for the year 2000. Initially, the changing energy situation will have a significant impact on the location of the industry. The declining power requirement of the aluminum smelting process will tend to diminish the attraction of isolated cheap power locations over time, however. This

trend can be seen by comparing Tables 13 and 15. The Mountain region, especially, becomes less attractive, though it still remains important.

It should be remembered that a locational analysis of the aluminum industry is based largely on the national energy situation. Thus, technological breakthroughs in the power industry, new discoveries of domestic energy reserves, regional energy demand, political and environmental pressures affecting the power industry, and a host of other hard-to-predict variables all play important roles in deciding where the industry will locate. The above analysis provides a methodological background, but is only a first-run attempt at actually predicting the location of the industry. As more data are collected, they should be applied to the logical framework we have provided for an updated and more accurate prediction.

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