SUMMARY REPORT

POSSIBILITIES FOR UTILIZING ICELAND'S GEOTHERMAL AND POWER RESOURCES IN CHEMICAL INDUSTRIES

to

OFFICE OF TECHNICAL SERVICES,
U. S. DEPARTMENT OF COMMERCE

JUNE 30, 1953

BATTELLE MEMORIAL INSTITUTE

PRELIMINARY STUDY

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by

William E. Riley, Jr., Bruce W. Gonser, and Richard J. Lund

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June 30, 1953

SUMMARY

There is a definite need for new industries to be established in Iceland to furnish employment for the expanding population and to pay for the imports needed to support a constantly improving standard of living. There are definite limits to the agricultural resources and the growth of the fishing industry, which to date have been the main supports of the country.

Fortunately, the maritime position of Iceland, its climate, and the vigor of its population, all favor technological growth and the establishment of an export trade in new products. Since there is little to sell except electrical and thermal energy and the capabilities of its people, such an increase in export trade will have to depend largely on importing certain raw materials, and exporting finished or semifinished products. This report presents a general preliminary survey of the chemical industries that might flourish in Iceland. Previous suggestions have been considered and are discussed, as well as additions to the list. Metallurgical products, except magnesium and aluminum, were not considered, as there appeared to be too small an opportunity for the production of other metals and alloys, considering the absence of metallic mineral deposits in Iceland.

Since utilization of domestic minerals is so important in establishing a competitive trade position, it is of great importance to know what metallic and nonmetallic minerals might be available in the future. If a thorough survey has not been made, and material available for this report has indicated that information in this field is incomplete, a survey of the country by economic geologists is urged as a step toward future utilization of Iceland's resources to the best advantage.

In establishing a chemical industry, attention has been given particularly to possibilities in producing basic chemicals which can form the basis for expansion later. High in this list are sulfur, salt, chlorine, and phosphorus. Commercial fertilizer is also a logical product. Several conditions seem favorable for exportation of these products, and local consumption of fertilizers would be an added favorable factor. Of the metals, conditions seem favorable at present only for the production of aluminum.

Other than well-established markets, attention should be given to possibilities of developing markets that are comparatively new. These include production of alginates and various products from the sea other than fish.

INTRODUCTION

This preliminary study was undertaken at the request of the Technical Assistance Department of the Economic Cooperation Administration. The general purpose of the study is to suggest chemical industries that appear favorable for development in Iceland. Due to the limited domestic market in Iceland, greater attention was given to those industries that would produce exportable commodities.

Previous reports pertaining to Iceland's thermal and power resources have been reviewed in considering the broad aspects of utilizing these resources.(6)(24) Special consideration was given to those chemical processes that require an abundance of steam or electric power or both. Some industries other than chemical were considered on the basis of known available natural resources.

This report is intended only to make suggestions, not definite recommendations. A more detailed study of the suggested industries will be required before definite recommendations can be made.

Unless specifically stated, the exchange rate used in this report is 16.285 krónur to 1 United States dollar.

RESOURCES

General Statement

Iceland is located within a reasonable distance from the normal shipping lanes between North America and Europe. About 500 additional miles would be required for a stop at Reykjavik en route from Boston to Liverpool.

The climate of Iceland would have little, if any, adverse effect on industrial development. Harbors on the southern coast are open throughout the entire year and those in the north are closed temporarily only under unusual circumstances, as perhaps once in 20 years. There appears to be no more need for concern over earthquakes or volcanic activity in the vicinity of the more favored industrial sites than in California.

The quality of skilled labor in Iceland measures up to high standards. Of the limited population of 150,000 people, it is probable that 10,000 to 20,000 persons is the maximum that could be employed in new industries within the next few years. Perhaps only 2,000 to 3,000 workers would be quickly available in the very near future.

Natural Resources

This section of the report is devoted to a general discussion based on readily available literature and limited discussions with a few Icelandic engineers. It should not be considered as a detailed survey.

Electric Power

Hydroelectric. About 100,000 kilowatts of capacity is installed or being built in Iceland at the present time. The potential hydroelectric power is estimated at around 4,500,000 kilowatts. Since many of the rivers do not have a steady flow, this estimate is probably high for all-year operation. At least half of this potential is located in the southwest section of the country.

The rate charged for water power now is between 3 and 3.9 mills per kilowatt-hour.

Natural-Steam Electric. There is no steam-electric power in Iceland at this time. Utilization of natural steam for electric-power generation is now under development.

Geothermal Activity

Hot Water. Hot springs with a total discharge of about 25,000 gallons per minute are found in some 200 localities. Aside from the heating of Reykjavik, and several other small towns no major use is made of this natural hot water.

Steam. There are 10 steam fields known to exist in Iceland. Several of these areas are being studied for possible utilization. Assuming that these fields are the same general type as those in Italy, it may take at least tens of thousands of years to dissipate the heat now being released.

An experimental well has been drilled to 750 feet at Krisuvik. It has been tested at a rate of 30 tons of steam per hour at a temperature of 330 F and a back pressure of 85 psi. Deeper drilling is progressing in this same area, and higher temperatures are expected.

Mineral Resources

Perlite. There are at least three known deposits of perlite in Iceland. Two of these are of the expanding variety. The deposit just north of Seydisfjordur in the east is thought to be very extensive, but it has not yet been adequately explored.

Another in the north is not so favorably situated from the standpoint of ease in shipping. A nonexpanding perlite deposit at the extreme east end of Huglfjordur, just east of Akranes on the west coast, appears to be suitable for use in making cement.

Limonitic Clay. A bed of hydrated limonitic clay is located in the northwest near Flateyri. This clay is composed of approximately equal parts of iron, aluminum, and silica. The deposit is reported to be of large size. Underground mining methods would be required to exploit this deposit.

Halloysitic Clay. A layer of halloysitic clay is associated with the limonitic clay bed in the northwest. No information is available to us as to its extent or composition.

Shell Sand. Large deposits of shell sand, rich in calcium carbonate, are reported in the same area, near Flateyri.

Iceland Spar. Iceland spar (clear calcium carbonate) no longer is considered the valuable commodity that it once was. In addition, the reserves in Iceland have been seriously depleted.

Sulfur. Sulfur was mined at one time, but operations were discontinued. It has been reported that sulfur mining has been resumed in the northeast. No information is available as to the size of these recent operations. A sulfur deposit in the vicinity of Krisuvik contains small amounts of selenium and tellurium. *

Peat and Lignite. Peat and lignite are present in Iceland. Some reports indicate that these deposits are fairly extensive and are rather widely distributed, but they are said to be low grade. Peat is used for fuel in the rural districts.

Silica. A deposit of perhaps 100,000 to 200,000 tons of very fine white siliceous sinter deposited from hot springs exists at Reykjanes, south of Keflivik.

Pumice. A few small pumice deposits have been found in Iceland. Depending on the extent and purity, markets might be developed for pumice as a light-weight aggregate, insulation, and abrasive.

Building Stone. High-grade building stone of volcanic rock (indurated tuff) has been mentioned as existing on the east coast, but it has not been utilized.

Copper and Lead. Evidence of the existence of lead and copper minerals has been reported from the mountains at Lousheidi, near Austurhord, in the southeast part of the island.

Undiscovered Mineral Resources. Insufficient time was available in this study to review the literature to find how much has been written about Iceland's mineral resources. Data at hand were extremely limited, and it is reported by Lindal that information available on mineral resources actually is very scanty. It should be pointed out that a report appraising the potentials for using a country's geothermal and power resources should take into consideration the full resources at hand. This report, therefore, cannot be considered complete or final because of the paucity of data available on the nature and extent of Iceland's mineral resources.

Sea Water and Seaweed

Because of recent advances in technology, sea water and seaweed can be considered important potential sources of many valuable commodities.

* Friend, J. N., and Allchin, J. P., "The Selenium and Tellurium Contents of Sulfur From Krisuvik, Iceland", Mineral Mag. (London), 26 (172), March, 1941, pp 9-10.

INDUSTRIES BEST SUITED FOR ICELANDIC DEVELOPMENT

General Statement

The following industries are considered by Battelle to offer the best chance of commercial success in Iceland, based largely on Iceland's economic advantage in having available substantial amounts of potential cheap hydroelectric power and process steam. Such factors as minimum plant size, capital investment, export markets, and shipping problems have also been considered.

Even though markets for products of some of the industries suggested are not too well assured, they are included in the hope that further study will be made that will permit sound conclusions to be drawn.

Chlorine

Method of Production

The only feasible method of producing chlorine in Iceland is by electrolysis of salt brine. This process requires approximately 2,860 kilowatt-hours per ton of chlorine produced. A portion of Iceland's potential hydroelectric power could be utilized in this manner.

Raw Materials

Aside from the electrical requirements, the raw materials needed to produce 1 ton of chlorine are as follows:

(a)	Salt	- 3,660 lb
(b)	Sodium carbonate (58%)	- 57 lb
(c)	Sulfuric acid (66°Bé)	- 228 lb
(d)	Steam (evaporation of caustic)	-22,850 lb (if diaphragm cell is used)
(e)	Refrigeration	- 2,060 lb

Salt and sodium carbonate could be imported, but it should prove to be more economical to make these products locally.

Iceland's natural steam might perform a threefold function in this process. If present in sufficient quantities, sulfur for sulfuric acid and carbon dioxide for refrigeration could be separated from the steam. Several factors affecting the volume of the gases and the cost of separation would determine whether or not it would be economic to recover these materials. The temperature and pressure of the existing steam well (330 F at 85 psi) would be sufficient to concentrate the coproduct, sodium hydroxide.

Capital Investment Required for a Minimum-Sized Plant

In order to compete in the world market, a chlorine plant in Iceland should have a capacity of 100 to 150 tons per day, or 36,000 to 55,000 tons per year.

Chlorine facilities require a capital investment of between $240 and $280 per annual ton capacity. Investment costs vary, depending on location, capacity, and requirements of the customers.

The United States Army recently completed a chlorine plant at Muscle Shoals, Alabama. This plant cost $15 million and has a capacity of 150 tons of chlorine per day. Instead of the conventional diaphragm cell, the Army plant uses the DeNora mercury cell.

Coproduction of Sodium Hydroxide (Caustic Soda)

For every ton of electrolytic chlorine, about 1.1 tons of sodium hydroxide are produced. Present world markets for caustic soda have become somewhat soft because of the vast postwar expansion in chlorine production resulting from greatly enlarged demand. For example, the United States' output has more than doubled since 1946. From a long-range point of view, the disparity in demand growth between chlorine and caustic soda is likely to continue. This means that chlorine producers will be forced to find economical means of producing chlorine without caustic, of developing new large-scale uses for caustic, or of lowering the present price for caustic to increase the incentives for its use.

On the other hand, caustic soda is one of the basic chemicals used by industry. Thus, although there may be no present domestic market, the development of any industrial complex almost certainly would consume substantial quantities of caustic. For domestic use, it would not be necessary to solidify the caustic, thereby effecting a considerable saving in steam, as well as in cost per unit of causticity.

Another possibility would involve the passage of carbon dioxide through the caustic solution to form sodium carbonate. This might be an economical method of making the sodium carbonate needed for the production of electrolytic chlorine.

Production of By-Product Hydrogen

Hydrogen is produced as a by-product in the manufacture of electrolytic chlorine. Approximately 10,000 cubic feet (57 pounds) are produced with every ton of chlorine.

This hydrogen might be used at the ammonium nitrate plant recently installed in Iceland.

Uses of Chlorine

Chlorine is one of the basic chemicals of industry. Probably the greatest present use is in the production of organic chemicals. A portion of these are listed here to illustrate the variety of industries that demand chlorine.

1. Ethylene glycol
2. Monochlorobenzene
3. Ethylene dichloride
4. D. D. T.
5. Trichloroethylene
6. Perchloroethylene
7. Vinyl chloride
8. Tetraethyl lead
9. Freon
10. Plastics
11. Vitamins
12. Dyes
13. Drugs
14. Synthetic rubber

The paper, textile, and water-treating industries are also large users of chlorine.

Possible Chlorine Markets

The most probable outlet for chlorine produced in Iceland would be Europe. Since the end of World War II, European production of chemical products based on chlorine has been steadily increasing. The demand for chlorine has increased accordingly. A continuing increase in the production of petrochemicals in England should provide an excellent market for reasonably priced chlorine. France also appears to offer a good potential market. Although the demands of the United States are being met, the fact that chlorine demand is increasing more rapidly than the caustic demand should create good market possibilities.

Shipping Problem

Chlorine is a poisonous gas, so special returnable pressure containers must be provided for safe and economical shipment. However, the major problems involved in its movement have been solved.

Elemental Phosphorus

Method of Production

Production of elemental phosphorus by the electric-furnace method, utilizing low-cost hydroelectric power, appears to be a rather promising possibility for Iceland. This process requires 8,000 to 11,000 kilowatt-hours of electricity per ton of yellow phosphorus. A considerable part of Iceland's hydroelectric power could be utilized by this industry.

Power requirements constitute about 30 per cent of the total production costs of phosphorus.

Raw Materials

Iceland would have two possible sources of phosphate rock, North Africa and the United States (Florida). Of the two, Florida probably would be the better source, because the grade of the rock is higher than that of the African material, so shipping costs per unit of P_2O_5 would be lower. The P_2O_5 content of Florida material is also more uniform, thus requiring less variation in processing methods.

In 1950, Florida produced 8,000,000 tons of phosphate rock. The total United States production was 11,000,000 tons, 2,000,000 of which were exported.

Metallurgical coke, needed for this electric-furnace process, could be imported from various sources. The United States, West Germany, England, and possibly France are all potential suppliers.

Silica is required as a flux in electric-furnace phosphorus production. Various sources of this material exist in Iceland. Possibly the best source would be Iceland's perlite deposits.

Capital Investment Required for a Minimum-Sized Plant

Improvement of technology in the elemental-phosphorus industry has resulted in larger plants. To compete in the export market, a phosphorus plant probably should have a capacity of about 20,000 tons annually. Plants in the United States have capacities ranging from 3,000 to 65,000 tons per year.

The capital investment required for phosphorus facilities probably would be between $200 and $300 per annual ton of capacity. This would vary, depending on the number and size of furnaces used.

The 1950 cost of a 2-furnace plant in the United States was $3,371,000; the capacity of the plant was 15,000 tons of elemental phosphorus per year. Production costs per ton of phosphorus were around $153. In mid-1953, the market prices for yellow phosphorus in the United States varied from $340 per ton in tanks to $450 per ton in wedges or drums, fob the works. This wide spread between production cost and selling price would indicate a rapid pay-out time.

Uses of Elemental Phosphorus

Phosphorus is used in a wide variety of industries, and new uses are being found constantly. The chemical, fertilizer, pharmaceutical, and detergent industries are all heavy users of phosphorus. At present, the detergent industry is the most rapidly expanding consumer.

In the future, the relatively new phospho-organic chemical industry is expected to exceed even the detergent industry in the demand for phosphorus. Some of the products of this industry are:

1. Resins and plastics
2. Medicinals
3. Textiles and fibers
4. Pesticides
5. Plasticizers
6. Lubricants
7. Surface-active agents
8. Fire retardants

Phosphoric Acid

Elemental phosphorus can also be used as a starting material to produce phosphoric acid. Phosphoric acid is used as an intermediate in making many phosphate-base chemicals. In the United States, a substantial portion of the phosphoric acid is used in making triple-super-phosphate fertilizer.

However, electric-furnace phosphoric acid is purer than acid produced by the wet process. Depending on the situation, it might prove more economical to sell this acid for use in other industries and import the desired phosphate fertilizer.

Possible Phosphorus Markets

Due to recent expansion and construction, United States phosphorus producers are currently meeting the domestic demand. However, this situation could change easily if, in the future, more new uses of phosphorus are discovered.

Current industrial development is expected to increase the European demand for phosphorus. For the most part, Europe does not have additional blocks of cheap electric power essential for economical production of phosphorus. However, this may not be true of Norway, Switzerland, or some parts of Italy. Iceland is in a strategic position to act as a power station for England and Western Europe in the production of this commodity.

It may be found profitable to manufacture phosphorus end-products in Iceland for shipment to Europe and possibly the United States. A detailed evaluation of the economics and markets for such phosphorus end-products is beyond the scope of this investigation.

Shipping Problems

Elemental phosphorus is transported by rail in special tank cars. Steam connections are provided so that the phosphorus can be remelted at the point of destination.

Ocean shipment would constitute a different type of problem. During the first part of World War II, the United States shipped elemental phosphorus to France. Molten phosphorus was cast into wedge-shaped pigs which were placed in steel drums. The phosphorus was then covered with water and the containers sealed for shipment. This procedure could be used for small-scale shipment, but other methods should be developed for large-scale, over-water transport.

Commercial Fertilizers

General Statement

There appear to be promising possibilities for the economical operation of a fertilizer plant in Iceland. The particular type of fertilizer produced would depend on local conditions and foreign demand.

Nitrogenous Fertilizers

A small plant for the production of ammonium nitrate is presently under construction in Iceland. Initially, at least, Iceland could specialize in the production of ammonia fertilizers.

At present, the demand for nitrogenous fertilizer exceeds the supply in the world market. The United States Department of Agriculture estimates the use of nitrogen fertilizers in 1955 will be 70 per cent greater than in 1951.

Ammonium Nitrate. Ammonium nitrate is widely used as a fertilizer and as a raw material in the manufacture of explosives. It can be stored and is easily shipped. Although the plant now under construction in Iceland has an annual capacity of only 18,000 tons, it probably could be expanded to supply a healthy export trade.

Ammonium Sulfate. Ammonium sulfate is another commonly used nitrogen fertilizer. However, this product has been dumped in the United States recently by East Germany. This fact may be an indication of either a diminishing demand in Europe or an increase in output that has exceeded demand.

The hydrogen sulfide contained in the natural steam could be a source of sulfuric acid for ammonium sulfate production, as heretofore mentioned, and discussed in somewhat more detail in the Appendix.

Gypsum or anhydrite could be used in place of sulfuric acid as a sulfate source, but these products would have to be imported. There is serious doubt that they would be an economic source of the sulfate radical.

In the United States, over half of the ammonium sulfate produced is a by-product of coke production.

Liquid Ammonia. Processes for the direct application of liquid ammonia to the soil are being used in the United States, to a limited extent. However, the cost of high-pressure containers, plus the heavy cost of transporting them empty (on return), probably would preclude the exportation of liquid ammonia.

Urea. Urea is one of the most concentrated forms of nitrogenous fertilizer. If present in sufficient quantities, the carbon dioxide mixed with the natural steam could be separated and then combined with ammonia to produce this commodity.

Aside from use as a fertilizer, urea is used extensively in the production of plastics. The continued expansion of the plastics industry might result in a promising European market for additional supplies of urea.

Phosphates and Potassium

Normally, soil fertilization requires not only nitrogen, but also varying amounts of phosphorus and potassium. Nitrogen promotes faster plant growth and therefore increases the need for phosphates and potassium. As the use of nitrogen expands, the demand for phosphates and potash will grow accordingly.

Phosphates. If a phosphorus plant were constructed in Iceland, it could provide a source of phosphoric acid for use in a fertilizer industry. Phosphoric acid, when combined with ammonia, would produce the dual-purpose fertilizer, ammonium phosphate.

If desired, triple-super-phosphates could be produced by treating phosphate rock with phosphoric acid. If ordinary super-phosphate is produced, sulfuric acid would be used. The acid would have to be either imported or obtained from H_2S in the natural steam. Local conditions would determine which of these possibilities would be the most economical.

As mentioned before, electric-furnace phosphoric acid is very pure. It may prove more economical to use or sell this acid for purposes other than fertilizer.

Potassium. If economic methods are developed for the extraction of potassium from sea water or seaweed, this product could be utilized in a fertilizer industry.

The addition of potassium to a nitrogen-phosphate combination would result in a complete basic fertilizer.

Fertilizer Markets

It would appear that the long-term outlook for increased markets for fertilizers is favorable. United States markets undoubtedly will be supplied by local production, but the chances of exporting fertilizers to Western Europe appear more favorable. Recent trends indicate that stress is being placed on the production of more concentrated products.

The world demand for nitrogen is greater than the demand for phosphates or potash. Extensive phosphate and potash deposits exist in the United States, and German potash is used extensively in Europe. However, an abundance of raw materials alone will not meet future fertilizer demands. Greater production capacity and improved technology are necessary.

Europe at present uses low-grade quality and insufficient quantities of fertilizer. Further education of the farmers on the advantages of heavier use of fertilizers might well change this situation.

The existence of a local market is another favorable point for the production of fertilizer in Iceland. About 30 per cent of Iceland's population is engaged in agriculture. This agricultural industry would help to support at least a small portion of a fertilizer industry in times when foreign markets are slack.

So long as the world population continues to increase, greater demands will be made of the soil. The demand for fertilizer will increase accordingly.

Production From Sea Water and Seaweed

The oceans are considered to be the future source of many valuable products. Most processes for the extraction of minerals from sea water are still in the research and development stage. Certain of the industries considered to be favorable for future Icelandic development are mentioned in this section. Technical or economic factors probably would prevent their economical operation at the present time. However, future developments could alter this situation greatly.

Magnesium

Iceland is well suited for the production of metallic magnesium. The necessary resources, sea water, calcium carbonate, and electric power, are present in sufficient quantities. Methods for the economical production of magnesium have been in commercial use for many years.

The world demand for this commodity is small at present The demands of the United States and Europe are being met, for the most part, by domestic production. In January of 1953, the United States Government closed 5 of its 6 magnesium plants because of overproduction. Norway is planning to increase its production of metallic magnesium. This will add to the economic risk of any new producer's trying to compete in the European magnesium market. At present, Norway produces some 10,000 tons of magnesium oxide per year, which, aside from use in the production of metallic magnesium, is widely used as a refractory.*

Magnesium is considered to be a metal of the future. Much research must be done yet on the fabrication of this metal. As methods are found to prevent the excessive corrosion of this metal, expecially under a salty environment, expanded markets undoubtedly will develop.

Alginates

The production of alginates from seaweeds is discussed at some length in the Appendix.

* Chem. Eng. News, 31, No. 20, May 18, 1953, p 2107.

This industry is considered to have many future possibilities. Iceland is in a position to become a major supplier of this commodity, if and when its possibilities are developed. Research is continuing and may produce results that will expand its fields of application greatly.

Plankton

The extraction of plankton from sea water for use as an animal feed could become profitable. However, it is doubtful that this industry would be economical by itself. Plankton might be extracted as a by-product in some other sea-water industry.

The demand for animal feeds in Europe, especially England, is great. Consequently possibilities of plankton extraction should be kept in mind as a possible future development of value.

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APPENDIX

APPENDIX

A REVIEW OF PREVIOUS SUGGESTIONS FOR UTILIZING ICELAND'S NATURAL STEAM

A number of suggestions for commercial utilization of Iceland's natural steam were made in a report dated December 18, 1950, by the Geothermal Department of the State Electricity Authority.(6) This report included a summary of investigations by Haldor Topsoe, a Danish consulting engineer, a later survey by Baldur Lindal, a chemical engineer with the Geothermal Department, and a review by Gunnar Bodvarsson, Chief Engineer of the Geothermal Department. A few months ago, Mr. Lindal wrote a special report on possibilities in the production of alumina.(24)

Battelle's views on these suggestions follow as a brief commentary on each industry mentioned in these previous reports. Several industries mentioned here are discussed more fully in the main body of this report.

Ammonia

An ammonium nitrate plant is presently under construction in Iceland, and is scheduled for completion by the end of 1953. This plant will have an annual capacity of 18,000 tons, which will be sufficient to fill Iceland's ammonia-fertilizer needs. Hydrogen will be obtained by electrolysis of water, and nitrogen by air liquefaction. By electrolyzing water during off-peak periods, the cost of power for this purpose will be only 0.8 to 1.0 mill per kilowatt-hour.

This project appears to be economically sound. The production of ammonia is discussed at greater length in the main body of the report under "Commercial Fertilizers".

Salt (Sodium Chloride) and Industries Connected With Its Production

Iceland imports approximately 35,000 tons of salt yearly, most of which is being used in the fishing industry.

Although the chances of exporting salt are poor, certain economic advantages could be gained by domestic production. Since the fishing industry supports most of Iceland's present economy, being self-sufficient in a commodity upon which this industry depends may be advantageous. If necessary, a tariff could be placed on imported salt in order to strengthen home industry.

Probably the easiest and cheapest way of obtaining salt would be to evaporate sea water with natural steam. By this method, about 30 metric tons of steam are required to produce 1 metric ton of salt. Assuming the cost of steam to be $0.10 per metric ton, the fuel cost per ton of salt produced would be only $3.00. However, salt is a low-priced commodity, and it might prove more advantageous to use the quantities of steam available for the production of a more valuable product.

Another possible way of producing salt is to combine an ion-exchange process (currently under development by Ionics, Incorporated, of Cambridge, Massachusetts) and steam evaporation. Such an ion-exchange - steam-evaporation process is being developed now to produce fresh water from salt water. It may be economical to use this method for initial concentration of the salt in sea water before evaporating for commercial salt production.

In the Ionics, Incorporated, process, electrically charged membranes exchange charges with the salt contained in the sea water. Technical details, construction costs, and power requirements are not available, at present.

Salt for use in the fishing industry does not have to be of high purity, so fractional recrystallization, with its additional cost, would not be necessary.

Chlorine and Caustic

Topsoe mentioned several industries that use salt as a raw material. Probably the most important of these is the manufacture of chlorine and caustic by electrolysis. Such an activity might have interesting possibilities, and is discussed in the main body of this report.

Bromine

Bromine is a valuable commodity, but its principal market is limited to the production of ethylene bromide for use in the manufacture of tetraethyl lead. Since the production of this fluid is controlled by a few large producers, marketing of this product by Iceland might be difficult.

Potassium

The extraction of potassium from sea water has attractive features, but at present the design of an acceptable process requires much research and development. If perfected, such a process would fit very well into a commercial-fertilizer industry for Iceland.

Soda Ash (Washing Soda)

Soda ash is one of the most important alkalies used in industry, the glass industry probably being the greatest consumer. The international trade in this product is small at present. Since there is very little, if any, local demand, such a plant probably would not be justified in Iceland today. Future developments may change this picture, however.

If such a demand should develop, using the Solvay process may prove more economical than use of the electrolytic process. The Solvay process might make profitable use of the carbon dioxide mixed with the natural steam.

Ammonia-soda plants (Solvay) are usually very large. Very few plants in the United States have daily capacities of less than 500 tons.

Metallic Sodium

As in the case of bromine, the major use of sodium metal is in the production of tetraethyl lead.

The use of sodium as an electrical conductor and as a descaling agent in metallurgy may expand in the future. These applications may provide future markets, but are used to only a small extent at present.

Fertilizers

This topic is discussed in detail in the section on "Commercial Fertilizers" in the main body of the report.

Synthetic Products Via Calcium Carbide

The economic soundness of an industry in Iceland based on calcium carbide is doubtful. Coal and coke would have to be imported, and competition with chemical products based on acetylene produced in the United States or in Europe would be strong. In the United States, acetylene produced from natural gas is in strong competition with that produced from calcium carbide.

Production Based on Herring Oil

Work is being done on fish oil processing in Iceland, but the factors involved in expanding this field are too little known for critical comment at this time.

Production in Connection With the Petroleum Industry

World markets for petroleum products are strongly competitive. At present, extensive petroleum-refining facilities exist in both the United States and Western Europe. Iceland would have to import nearly all the raw materials necessary for such an activity.

Industry Based on Peat

Much more information than is at hand concerning the location, extent, and quality of the peat deposits would be necessary before definite conclusions could be drawn concerning the potentials of an industry based on peat. However, there are a few important possibilities. Peat can be a valuable source of hydrogen, carbon monoxide, and carbon dioxide.

Technical and economic research may show that certain peat deposits are a cheaper source of hydrogen than is the electrolysis of water. With the aid of natural steam, it may be possible to dry and process the peat in the vicinity of the deposit.

For heating purposes, it is probably cheaper and more efficient to use geothermal heat than to burn peat, where both are available.

Pharmaceutical Industry

The production of well-established pharmaceuticals would be limited to a small domestic consumption. Export possibilities are poor at present. The Swiss and English are looking for markets and the United States has extensive facilities and a thriving export trade.

Most of the successful pharmaceutical companies depend upon a diversity of products and an active research organization to keep supplying new or improved products. As a new product becomes widely accepted, mass production brings the manufacturing cost down, but active competition quickly brings the profit margin down, too, unless worldwide patent protection is obtained. The cost of steam and electricity is normally such a small fraction of the selling price, that Iceland would seem to offer no particular advantage over countries more favorably situated with respect to a heavy consuming populace. If, however, a new and valuable pharmaceutical could be discovered by Icelandic scientists, the picture would be different, since competition could be controlled by patents. Even under such conditions, however, the advantage would be only temporary.

Caustic Soda, Trichloroethylene, and Vinyl Chloride

Caustic Soda and Carbon Tetrachloride

Caustic Soda and Ammonium Chloride

Caustic Soda and Bromine

The economic success of these industries would depend largely on the local demand for caustic soda. At present, such a demand does not exist, and export markets are presently poor. The United States and European caustic supplies are considered ample to meet the demand for some time to come. Recently, many consumers have erected facilities to supply their own demands.

If, in the future, an alumina plant were to be erected in Iceland (see later in this Appendix), it would provide an outlet for caustic.

Trichloroethylene, vinyl chloride, carbon tetrachloride, and ammonium chloride could be exported. However, the profits made on these products alone would not maintain these industries. The bromine market has been mentioned earlier in this Appendix.

Sodium Chlorate

The principal use of sodium chlorate is as a weed killer. Small amounts of this product could be consumed locally, but export prospects are poor. In the United States, even locally produced sodium chlorate is considered to be too costly for extensive use.

In order to afford economy of operation, any electrochemical process must be operated at a steady load throughout the year. Because of the highly seasonal nature of its use, considerable warehouse space would be required for sodium chlorate. Many of the present manufacturers produce other electrochemical products, such as chlorine and caustic soda, to alleviate the seasonal manufacturing factor.

Ammonium Chloride, Sodium Carbonate, and Sodium Hydroxide

As mentioned before, the export market potential for sodium carbonate (soda ash) and sodium hydroxide is poor.

The major use of ammonium chloride is as a welding and soldering flux. Other uses include applications in galvanizing, in dyes, and in the textile industry. There is probably a limited world market for ammonium chloride, but such an industry could not be maintained on this basis alone.

Refining of Bauxite

See "Production of Alumina" at the end of this Appendix.

Heavy Water

The details concerning the production and uses of heavy water are highly secret. However, two facts can be stated. First, the capital investment required to produce this commodity is very large. Secondly, if heavy water could be produced at one-half the present cost, there would undoubtedly be a market for it.

Iceland's various water sources should be checked for deuterium concentration. Water from the natural hot springs might have a higher-than-average concentration of this valuable product. Also, the electrolytic cells in which hydrogen will be produced for the ammonia plant are a potential source of heavy water, since there is a good possibility of concentrating deuterium in electrolysis.

Production Based on Algae

The existing markets for alginates are small but are expected to expand in the future. At present, the largest use of sodium alginate is as a stabilizer in ice cream. The textile industry uses small amounts of this commodity, and work is being done on the development of synthetic fiber from alginates. Alginate research is currently being conducted by the Scottish Seaweed Research Institute at Inverest, Scotland.

Drying is an important cost factor in any seaweed industry. Iceland's natural steam might be used for this purpose.

Economical operation of an alginate industry would depend on a constant supply of seaweeds. Methods for the location of kelp beds by aerial photography are being developed. Economical methods of harvesting are necessary before an alginate industry can operate at a profit. Smoothness and the absence of large boulders on the ocean floor on which the kelp grows favor successful use of economical mechanical equipment for harvesting.

Sodium Hydroxide Via Electrolysis

As stated before, the profitable operation of any caustic plant would depend almost entirely on local demands, which are virtually nonexistent in Iceland. Sodium hydroxide is a basic chemical, and the future construction of chemical industries could give rise to a demand for this product. Therefore, economical methods for caustic production should be kept in mind to meet any future needs.

Salt Fish Drying

Fish Products

Hay Processing

Refrigeration of Foodstuffs

The economics of these industries, as was the case with herring oil, would depend entirely on local conditions. Evaluation would involve a closer study of such conditions than is justified by the scope of this report.

Industrial Utilization of Gases in Natural Steam

The various gases contained in the natural steam may be important to future chemical industries. They are possible sources of sulfur, hydrogen, and carbon dioxide.

It is possible that enough sulfur could be obtained from the hydrogen sulfide to supply sufficient sulfuric acid for certain chemical processes. However, since sulfur recovered from H_2S is extremely pure, and there is an immediate market in Europe, it would seem preferable at this time to build a plant for sulfur recovery. There is ample experience in building and operating such plants in the United States; hence, engineering and cost data are available. In the next 25 years, the sulfur demands of Europe and the United States are expected to increase about 110 per cent.

Later, as the need for sulfuric acid in Iceland grows, it may be feasible to recover H_2S from natural steam at another location and use it directly in making sulfuric acid. It is believed to be technically feasible to make sulfuric acid from SO_2 produced by direct burning of H_2S in comparatively simple equipment, although, to our knowledge, there is no existing plant that does this at present.

The hydrogen mixed with the natural steam could be extracted, but electrolysis of water or gasification of peat are probably more important sources in this respect.

Enough carbon dioxide might be extracted to supply future industrial demands for a refrigerant. Also, carbon dioxide would be required if the Solvay process were used to meet any sodium carbonate demands.

More technical and economic research will be needed before industrial applications of these gases can be evaluated properly.

Production of Alumina

Fuel Requirements

Digestion. The temperatures required for the digestion of bauxite depend on whether the trihydrate or the monohydrate ore is used. Ore from North and South America is mainly trihydrate, while the monohydrate predominates in European bauxites. Jamaican bauxite is also composed mainly of trihydrate, but it contains more monohydrate than the usual North American ores.

Trihydrate bauxite requires a steam temperature of about 340 F and monohydrate a temperature of 430 F or greater for effective digestion.

The temperature and pressure of the existing steam well (330 F at 85 psi) are not great enough for either ore. However, deeper drillings undoubtedly will result in higher temperatures and pressures.

Quantity of Steam. For the economical production of alumina for export, a plant in Iceland should have a capacity of not less than 1000 tons per day. About 15,000 pounds of steam are required to produce 1 ton of aluminum hydrate from trihydrate bauxite. This means that approximately 7,500 tons of steam per day would be needed.

This rate of steam production is not available in Iceland at present. However, Lindal (personal communication) believes that such production is feasible in the future.

Steam Costs. In the United States, steam for the digestion of trihydrate bauxite amounts to only 1 or 2 per cent of the total production costs (including costs of raw materials, of course). The European process, using monohydrate ore, probably would require up to 3 times this amount of steam. The cost of steam in Europe is higher than in the United States because of the lack of low-cost fuel.

However, not enough facts are known to predict a competitive margin between Icelandic and European production costs. A very thorough investigation of the economics would be required before this could be done.

Calcining. After aluminum hydroxide is precipitated, it must be calcined to aluminum oxide. This process uses about one-half the total fuel requirements and needs temperatures up to 2192 F.

An alumina plant in Iceland would have to import fuel oil for this purpose. Coal cannot be used because of the high silica content of the ash.

Possible Detrimental Effects of Hydrogen Sulfide

It is possible that the hydrogen sulfide mixed with the natural steam would have a detrimental effect on alumina. It may cause an increase in caustic consumption due to the formation of sodium sulfide.

Capital Investment Required for an Alumina Plant

Recent figures indicate the capital investment required for an alumina plant to be around $100+ per annual ton of capacity. This would vary, depending on the size and location of the plant. Thus, for a 1,000-ton-per-day plant, the cost would amount to roughly $36 million.

Alumina Supply and Demand

It is probable that existing facilities and planned expansion can meet existing and presently planned alumina demands, both in the United States and in Europe.

The Aluminum Company of Canada probably would be Iceland's strongest competitor for the European market. France and Italy would also be competitive, even though their production costs may be higher. Most of the existing plants have been built under conditions that gave rapid amortization and construction costs that were much lower than would be possible in constructing a new plant. This makes the competitive position unfavorable for Iceland, even though steam costs may be much lower there.

Future Trends

Further expansion of aluminum production, world-wide, might allow for output of alumina combined with aluminum reduction in Iceland, assuming favorable economics resulting from her low-cost steam and potential hydroelectric power. However, planned increases in output of alumina in Canada and Jamaica by the Aluminum Company of Canada, and in Africa by the British, raise serious questions as to the immediacy of such a development.

The Production of Alumina From Clays

An electrolytic process for the production of alumina from low-grade clays has been patented in Europe. It is claimed that this process produces alumina at a 15 per cent cost saving over the Boyer process. Likewise, considerable attention is being given in other countries to developing means for recovery of alumina from sources other than bauxite.*

If any of these processes are successful, it may be possible to utilize some of the clay deposits in Iceland that have a composition favorable for such a process. Thus, the alumina-production picture would be much more favorable for Iceland if a local source of raw material were available, and particularly if an electrolytic process were involved. This points to the need for more information on aluminum-containing mineral deposits in Iceland, and to being kept informed on progress being made elsewhere in the treatment of such deposits for alumina recovery.

* Chem. Eng. News, 31, No. 21, May 25, 1953, p 2159.

Production of Aluminum

The location of aluminum plants depends largely on the cost of electrical power. About 10 kilowatt-hours of electricity are required to produce 1 pound of aluminum from alumina. At present, an aluminum plant in Iceland would have to import alumina. Competition from Canadian and certain European aluminum producers would be strong, but future growth of the industry seems assured and conditions in Iceland are favorable.

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