OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

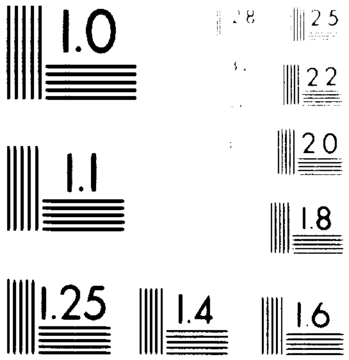
CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

1 OF 2



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

24x
F

ENGINEERING OFFICE OF BALDUR LÍNDAL
BRAUTARHOLTI 20, REYKJAVÍK

REPORT ON RECOMMENDATIONS CONCERNING RESEARCH ON CHEMICAL PRODUCTION FROM SEAWATER

Work undertaken for
THE NATIONAL RESEARCH COUNCIL

By :
Vilhjálmur Lúdvíksson
and
Baldur Líndal

Translated for the United Nations Industrial Development Organization

By :
Runólfur Thordarson

REYKJAVÍK - AUGUST 1966

ENGINEERING OFFICE OF BALDUR LÍNDAL
BRAUTARHOLTI 20, REYKJAVÍK

02591

REPORT ON RECOMMENDATIONS CONCERNING RESEARCH ON CHEMICAL PRODUCTION FROM SEAWATER

34+70 p.

Work undertaken for
THE NATIONAL RESEARCH COUNCIL

By:
Vilhjálmur Lúdvíksson
and
Baldur Líndal

Translated for the United Nations Industrial Development Organization

By:
Runólfur Thordarson

REYKJAVÍK - AUGUST 1966

INDEX

INDEX (cont.)

LIST OF TABLES

SUMMARY

The objective of this report is to specify new subjects of research, which concern the utilization of chemicals from seawater, with special consideration of conditions in this country.

Previous studies have indicated the need for a careful study of a combined production of many chemicals from seawater.

This report is based on a rather thorough literature study, carried out at the beginning of this study, of the production of chemicals from seawater. Possibilities of producing 40 chemicals obtainable from seawater were studied and it was found that, on the basis of technology, raw material and markets, it might be possible to produce 25 of those, where magnesium oxide, magnesium metal, salt and potassium chloride would be of greatest importance. Other chemicals, such as sodium hydroxide, bromine, sodium chlorate, hypochlorate, sodium metal and gypsum might also be produced at a later time.

Some possible methods of coordinating such production and the utilization of the natural resources, which are available, such as electric power, steam, salty geothermal water and seawater are indicated.

In the conclusions it is indicated that conditions in this country for chemical production from seawater seem to be favorable in main respects and later possible size investment and production value of such an industry is shown. It is found that an industry which produces 16 thousand tons of magnesium metal per year and 60 thousand tons of salt, besides various by-products, might cost approximately 1000 million Icel. kr. and the production be worth 600 million kr. per year.

Certain arrangement of preliminary studies of chemical production from seawater is proposed, giving special consideration to the possibility of discontinuing the work with the least possible financial loss if studies show the production not to be economical. It is felt that the preliminary study would

last two years and not cost over 1% of the investment in the proposed enterprise, but that the preliminary estimate of construction and operation would take other two or three years and cost approximately 3% of the investment in the proposed undertakings.

Also the possibility of establishing this industry in steps over a longer time is indicated, but considering also the necessity of not separating individual production sectors, so that the economy of the production coordination would be lost. In the concluding chapter it is pointed out that the chemical production under discussion is rather simple from a technical point of view, but important from the economic point of view and likely to give good results.

1 INTRODUCTION

1-1 OBJECTIVES

The objectives of this study are to indicate new fields of research concerning the utilization of chemicals in seawater around this country. The study is broad. The production in this country of as many chemicals and chemical compositions as possibly may be obtained from seawater are studied. Technology, raw materials and market conditions are considered and chemicals, which are not found to be feasible, in that respect, are rejected.

Based on these studies definite production possibilities are indicated and the research which must be carried out in order to learn more about the economy of the various possibilities is specified.

These studies are based only on conditions in this country and the utilization of electric power and geothermal energy in connection with the proposed chemical production is considered especially. Also, a hot spring with changed seawater or brine found on Reykjanes is taken into account as it may be of importance in this connection. Previous studies in this country of the subject are considered.

1-2 PREAMBLE

During the years 1949-1959 studies of production of chemicals from seawater were carried out by the State Electricity Authority (I 1, I 7). These studies were primarily based on the utilization of geothermal heat for the production of salt. The energy requirements and location of such a factory were studied rather thoroughly (I 2). The salt content in seawater at locations, which were found most likely, was analysed for several years and it was then found that the content of salt is quite variable at some locations, but steady at others. Also the demand for salt in Iceland and import in previous years was looked into. Based on those studies a cost estimate was made for a 40.000 and 60.000 tons salt production factory, located at Krísuvík (I 5, I 6). It was concluded from those studies that direct economical gain from that production was slight, although it might be positive from a national economic point of view. In this field, considerable technical progress has taken place since those studies were made, especially in the construction of evaporators for sea water and for that reason, among other things, review of previous conclusions is necessary.

Based on the studies by the State Electricity Authority it was also concluded that further research in this field should be based on a coordinated production of more chemicals from sea water (I 7). The reason for that conclusion was that it was found that one chemical production branch would support another economically because of joint production factors, direction and other benefits, which in that way would be possible.

2 METHOD OF STUDY

In order to obtain the best possible general view of the subject, a rather thorough list of publications concerning chemical production from seawater and related matters was made at the outset. This is found in appendix XI. References in this report are indicated by capital letters and numbers in parenthesis refer to that list.

As conditions for such a literature study are not good in this country, use was made of foreign literature studies (A 1, A 2), which extend up to the year 1963. For the period after 1963 a review of technical literature, which is known to be available in this country and which might have published articles on this subject, had to suffice. Those publications are listed in appendix XII along with the subscriber. Innovations in the chemical production from seawater were kept tract of among other things with the help of a newsletter from the Office of Saline Water, which directs research in the field of fresh water production from seawater in the United States. Some of those studies have great importance for the general production of chemicals from seawater.

Although this literary study is not complete and does not cover several publications, which should be included, it is not likely that important basic items have been missed. As yet it has not been found possible to obtain except a small part of the publications referred to. That work will be continued with the help of parties abroad.

Information about world production, international trade and prices have mostly been obtained from American (A 3, A 5) and British (A 4) publications. Trade reports were found to be of great help for the study of the market and prices in this country. Their new arrangement and increased itemizing after 1963 has made it much easier to obtain information.

3 RESULTS

3-1 CONSTITUENTS IN SEAWATER

Salinity of seawater is composed of many constituents. Nearly half of all the elements are found in seawater, although most of those are there in small quantities. Table 3-1 shows the content in seawater of the various elements. These constituents might be grouped in three main categories by their quantity in seawater. In the first group are those that are present in a concentration of more than 100 mg/kg (major constituents). In the next group (minor constituents) are those that are present in amounts of 1-100 mg/kg, and in the third group trace constituents, which amount to less than 1 mg/kg.

3-2 THE VALUE OF MATERIALS FROM THE SEA

All materials which have been economically produced from seawater, are in the first two groups, although experiments have been made and plans are to be found for the utilization of the trace constituents, such as silver, gold, uranium and lithium.

In table 3-2 the value of some materials which possibly might be produced from seawater, is indicated. This is based on their quantity in 100 tons of seawater and that the constituent is all obtained in the form indicated. Other materials might possibly also be produced from seawater, but their value in the same amount of seawater is less than those listed.

It must be stressed that the value of the constituents listed in the table is based on their presence in elementary or first generation compounds. By further processing, more valuable compounds could be obtained from the sea. By producing magnesium metal instead of the oxides of magnesium a value of kr. 3.300 might be obtained instead of kr. 720 from the same amount of seawater. The same holds true for the production of sodium metal, sodium hydroxide, chlorine, chlorates or sodium peroxide from salt.

3-3 CONSTITUENTS IN A SALTY HOT WATER SPRING ON REYKJANES

For some time a hot spring with transformed seawater or brine has been known to exist on Reykjanes. By drilling in that area in 1956 it was found possible to increase the upflow considerably. The result of that investigation indicates that the quantity of salty water could be increased considerably by further drilling. In this hot water the proportion of the various constituents has been disarranged considerably compared to regular seawater. In table 3-3 the most important constituents which are found in the hot water are listed and their quantities, along with comparable figures for seawater for comparison. From this table it can be seen that the liquid in the drill hole is considerably salter than seawater and that some constituents such as potassium, calcium, iodine and lithium are found there in considerably greater quantities than in seawater. Especially, is it important that the quantity of potassium is five times that found in regular seawater. Various production processes of potassium compounds which are possible, are based on the quantity of potassium being three times greater than in seawater. This is therefore highly beneficial in that respect. Other constituents, such as magnesium and sulphate are found in much smaller quantities than in seawater.

It is possible that this disarrangement of the quantitative proportions of the various constituents could lead to other benefits than production of potassium compounds, such as for example the precipitation of sulphate from seawater by calcium from the calcium-rich drill hole water. This is a matter to be studied, however, and other possibilities might be present.

TABLE 3-1. SEA WATER, CONSTITUENTS

	Element	Symbol	Concentration mg/kg
I	MAJOR CONSTITUENTS		
	CHLORINE	Cl	18.980
	SODIUM	Na	10.561
	MAGNESIUM	Mg	1.272
	SULFUR	S	884
	CALCIUM	Ca	400
	POTASSIUM	K	380
II	MINOR CONSTITUENTS		
	BROMINE	Br	65
	CARBON	C	28
	STRONTIUM	Sr	13
	BORON	B	4,6
	ALUMINIUM	Al	1,8
	FLUORINE	F	1,4
	SILICON	Si	1,2
III	TRACE CONSTITUENTS		
	NITROGEN	N	0,7
	LITHIUM	Li	0,1
	PHOSPHORUS	P	0,075
	IRON	Fe	0,06
	IODINE	I	0,05
	BARIUM	Ba	0,05
	RUBIDIUM	Rb	0,02
	ARSENIC	As	0,015
	COPPER	Cu	0,005
	ZINK	Zn	0,005
	MANGANESE	Mn	0,005
	LEAD	Pb	0,005
	SELENIUM	Se	0,003
	TIN	Sn	0,003

cont.

TABLE 3-1, SEA WATER, CONSTITUENTS (cont.)

Element	Symbol	Concentration,mg/kg
CESIUM	Cs	0,002
URANIUM	U	0,002
MOLYBDENUM	Mo	0,0005
NICKEL	Ni	0,0005
GALLIUM	Ga	0,0005
THORIUM	Th	0,0005
CERIUM	Ce	0,0003
SCANDIUM	Sc	0,0003
VANADIUM	V	0,0003
LANTHANUM	La	0,0003
YTTRIUM	Yt	0,0003
MERCURY	Hg	0,0003
SILVER	Ag	0,0003
BISMUTH	Bi	0,0002
COBALT	Co	0,0001
GOLD	Ak	0,000001
RADIUM	Ra	0,0000000001

Information from books by C.B. Ellis (A 6)
and Armstrong and Miall (A 7).

TABLE 3-2. VALUE OF MATERIALS IN 100 TONS OF SEA WATER

Element	Quantity in mg/kg	Value kr/100 tons seawater	Unit price	Sold as
SODIUM	10.561	2.260	840	SALT
MAGNESIUM	1.272	720	3.400	MAGNESIUM OXIDE
SULFUR	884	450	1.340	SODIUM SULFATE
POTASSIUM	380	145	2.000	POTASSIUM CHLORIDF
BROMINE	64	131	20.500	LIQUID BROMINE
CALCIUM	400	56	1.000	CALCIUM OXIDE
BORON	4,6	8	2.070	BORAX
STRONTIUM	13	7	2.700	STRONTIUM SULFATE

TABLE 3-3. CONSTITUENTS IN SEAWATER AND SALTY HOT SPRING ON REYKJANES

Constituent	Quantity in seawater Mg/Kg	Quantity in drill hole Mg/Kg	Ratio
CHLORIDE	19.000	27.400	1,44
SODIUM	10.000	13.800	1,38
SULFATE	2.650	128	0,048
MAGNESIUM	1.270	45	0,035
CALCIUM	400	2.200	5,5
POTASSIUM	380	1.920	5,1
BROMINE	65	98	1,5
BORON	4,6	13	2,8
FLUORINE	1,4	0,7	0,5
LITHIUM	0,1	7,4	74
IODINE	0,05	0,5	10

3-4 ELEMENTS AND CHEMICAL COMPOUNDS FROM SEA WATER

In order to view the possibilities, which are present, we may list all the chemical compounds which may be produced from sea water or in connection with chemical production from sea water and may be of financial importance. Then each compound may be looked at separately from the points of view, which determine the possibilities of their production in this country. Those points are primarily three:

1. Technology
2. Raw materials
3. Markets

From a technical point of view one may investigate whether it is possible to produce an element or a chemical compound from sea water. In many cases such processes are known although they have not been fully tried and require alterations for Icelandic conditions. From the point of view of raw materials the constituents of sea water and water from the drill hole and alterations thereof, are to be considered. In this connection it is also of importance, which additional materials and production aspects are needed for the production, and whether those may be obtained inexpensively in this country or from abroad. Market possibilities for the compound in this country and abroad are studied, or whether a market may develop in he near future. In some cases the compound is a factor in the production of other compounds, without it being saleable itself. Thus, one may study the possibilities in general without going into details or estimating direct financial gains and the study is then narrowed considerably to a smaller group of compounds. In order to estimate further their production possibilities more extensive research is necessary and in many cases cost estimates.

TABLE 3-4. MATERIALS WHICH MIGHT BE PRODUCED FROM SEAWATER OR BRINE AND POSSIBILITIES OF UTILIZATION

Material	Formula	Production premises		
		Technical	Raw materials	Markets
Sodium metal	Na	+	+	+
Salt	$NaCl$	+	+	+
Sodium bicarbonate	$NaHCO_3$	+	+	−
Sodium carbonate	Na_2CO_3	+	+	±
Sodium hypochlorite	$NaClO$	+	+	±
Sodium chlorate	$NaClO_3$	+	+	+
Sodium hydroxide	$NaOH$	+	+	±
Sodium sulfate	Na_2SO_4	+	+	−
Borax	$Na_2B_4O_7$	−	−	+
Sodium thiosulfate	$Na_2S_2O_3$	+	±	−
Sodium peroxide	Na_2O_2	+	+	+
Potassium metal	K	+	+	−
Potassium chloride	KCl	+	+	+
Potassium hydroxide	KOH	+	+	−
Potassium carbonate	K_2CO_3	+	+	+
Potassium chlorate	$KClO_3$	+	+	+
Potassium perchlorate	$KClO_4$	+	+	+
Potassium sulfate	K_2SO_4	+	+	+
Potassium nitrate	KNO_3	+	+	+
Magnesium metal	Mg	+	+	+
Magnesium oxide	MgO	+	+	+
Magnesium chloride	$MgCl_2$	+	+	+
Magnesium hydroxide	$Mg(OH)_2$	+	+	+
Magnesium sulfate	$MgSO_4$	+	−	−
Magnesium bromide	$MgBr_2$	+	+	−
Magnesium carbonate	$MgCO_3$	+	+	+
Calcium	Ca	+	+	−
Calcium chloride	$CaCl_2$	+	+	+
Gypsum	$CaSO_4$	+	+	+
Calcium carbonate	$CaCO_3$	+	+	−
Calcium oxide	CaO	+	+	+
Chlorine	Cl_2	+	+	+
Bromine	Br_2	+	+	+

TABLE 3-4. MATERIALS WHICH MIGHT BE PRODUCED FROM SEAWATER OR BRINE AND POSSIBILITIES OF UTILIZATION (cont.)

Material	Formula	Production premises		
		Technical	Raw materials	Markets
Hydrochloric acid	HCl	+	+	+
Lithium	Li	-	-	+
Boron	B	-	-	+
Iodine	I_2	-	-	+
Fluorine	F	-	-	+
Carbondioxide	CO_2	+	+	±
Strontium	Sr	-	-	±

In table 3-4 the elements and compounds covered in this preliminary study are listed with grades given to the materials based on the three factors previously mentioned. The grade is + (plus) if the production possibilities are positive, based on a particular point of view, - (minus) if it is negative, and ± if it is doubtful. Materials with one or more minuses, in this evaluation, are dropped and not considered further at this stage. The other chemicals, which can be considered doubtful or positive, are studied somewhat further and discussed separately.

It would take too long to explain each individual grade. It is also possible with a minor study to test the validity of each of the grades, if it is found doubtful at a later time. Certainly conditions can change, for example it is not unlikely that a method will be discovered for the production of lithium, boron, iodine, or even fluorine from such thin solutions as sea water or water from the drill hole, but one should certainly keep ones eyes open for those possibilities in the future.

4 CONCLUSIONS

4-1 Production possibilities

From table 3-4 it is seen that of the 40 materials considered, there are 25 which at first sight seems possible to produce in this country. For convenience those chemicals are listed in table 4-1. Of those chemicals there are only four: Salt, magnesium metal, magnesium oxide and bromine, which are commonly produced from sea water, but besides that magnesium hydroxide and magnesium chloride are important steps in the production of magnesium metal.

Although sodium compounds are in general not produced from sea water salt, there is technically no objection to the production of sodium metal, chloride, chlorate, hydroxide or peroxide and such production may be beneficial in many ways as the sea water salt can be produced purer than rocksalt, which in general is used.

Besides those there are other materials such as potassium chloride, gypsum and others, which must be studied because of special conditions in this country.

Still other chemicals, such as calcium chloride, might be obtained as byproducts if desired. In general, these chemicals are not recovered however during such production, as they may be obtained at a lower cost by other methods, but in this country they might most likely be competitive with imported material.

4-2 Organization of chemical production

Although the possibilities of chemical productions are several as stated above, it is not likely to be found economical to produce but a portion of those mentioned. The production processes will then govern what chemicals are obtained. It is therefore important to select those materials and processes which give the greatest capital gain.

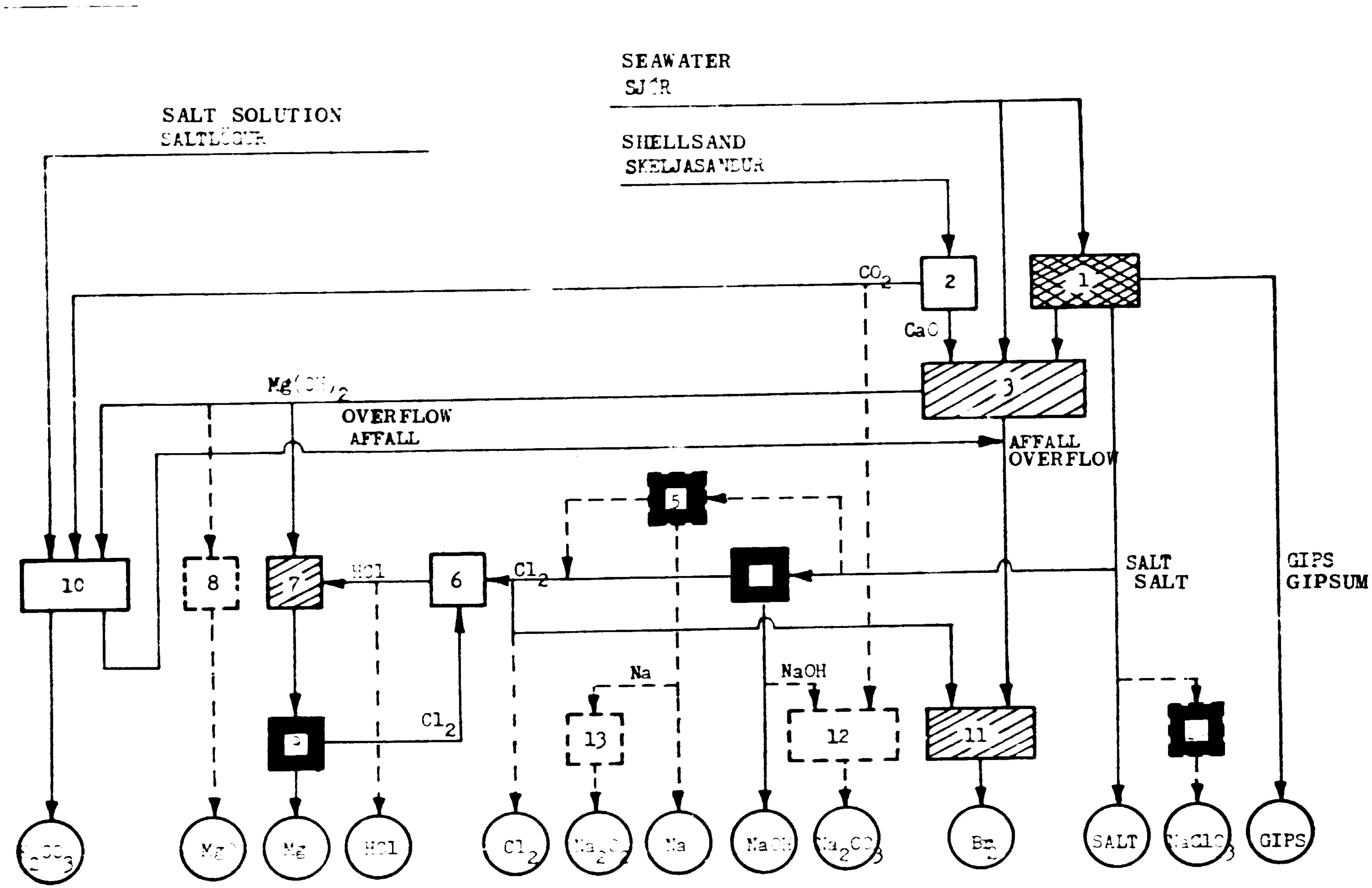
The materials, which might be produced can be divided in three main groups: Firstly basic materials or main compounds which are the prime sales products and on which the production is based. In this group are for example magnesium oxide, magnesium metal, salt and potassium chloride. In another group are secondary materials,that is materials which are necessary as a production step in the production of the basic materials. In this group are chlorine,calcium oxide, hydrochloric acid, magnesium chloride and magnesium hydroxide and possibly sodium hydroxide. In general these materials are not intended for sale as such, although their sale is possible if conditions allow. For example it is not unlikely that chlorine and hydrochloric acid might be saleable if a considerable domestic chemical industry were developed.

In the third group are those materials which are obtained as byproducts in the production of the above mentioned materials, or might be produced from those materials because of special conditions. In this group are gypsum, calcium chloride, all chlorates, hypochlorites and perchlorates, sodium metal, sodium peroxide, bromine and carbon dioxide. This last group can be of considerable importance for the economy of the production and helps spread the production cost.

This grouping is not very definite and some of the materials could belong to more than one group. Thus sodium hydroxide might both be produced for use in the chemical production as well as for sale on a domestic market. It is also possible that materials such as chlorates and peroxide would be fundamental for the production and would therefore have to be grouped as basic chemicals.

TABLE 4-1. MATERIALS WHICH MIGHT BE PRODUCED IN THIS COUNTRY

Material	Formula	Remarks
SALT	$NaCl$	Produced from seawater
MAGNESIUM METAL	Mg	Produced from seawater
MAGNESIUM OXIDE	MgO	Produced from seawater
BROMINE	Br_2	Produced from seawater
NATRIUM METAL	Na	Produced from sodium chloride
SODIUM CARBONATE	Na_2CO_3	Produced from sodium hydroxide
SODIUM HYDROXIDE	$NaOH$	Produced from sodium hydroxide
SODIUM HYPOCHLORITE	$NaClO$	Produced from sodium hydroxide
SODIUM CHLORATE	$NaClO_3$	Produced from sodium hydroxide
SODIUM PEROXIDE	Na_2O_2	Produced from sodium metal
MAGNESIUM HYDROXIDE	$Mg(OH)_2$	Intermediate product during Mg production
MAGNESIUM CHLORIDE	$MgCl_2$	Intermediate product during Mg production
HYDROCHLORIC ACID	HCl	Intermediate product during Mg production
CHLORINE	Cl_2	Produced from sodium hydroxide
CALCIUM OXIDE	CaO	Produced by heating of limestone
CARBON DIOXIDE	CO_2	Produced by heating of limestone
POTASSIUM CHLORIDE	KCl	Produced from drill hole water
POTASSIUM CARBONATE	K_2CO_3	Produced from drill hole water
POTASSIUM CHLORATE	$KClO_3$	Produced from potassium chloride
POTASSIUM PERCHLORATE	$KClO_4$	Produced from potassium chloride
POTASSIUM SULFATE	K_2SO_4	Produced from drill hole water
POTASSIUM NITRATE	KNO_3	Produced from drill hole water
MAGNESIUM CARBONATE	$MgCO_3$	Produced from magnesium hydroxide
CALCIUM CHLORIDE	$CaCl_2$	Produced from seawater
GYPSUM	$CaSO_4$	Produced from seawater

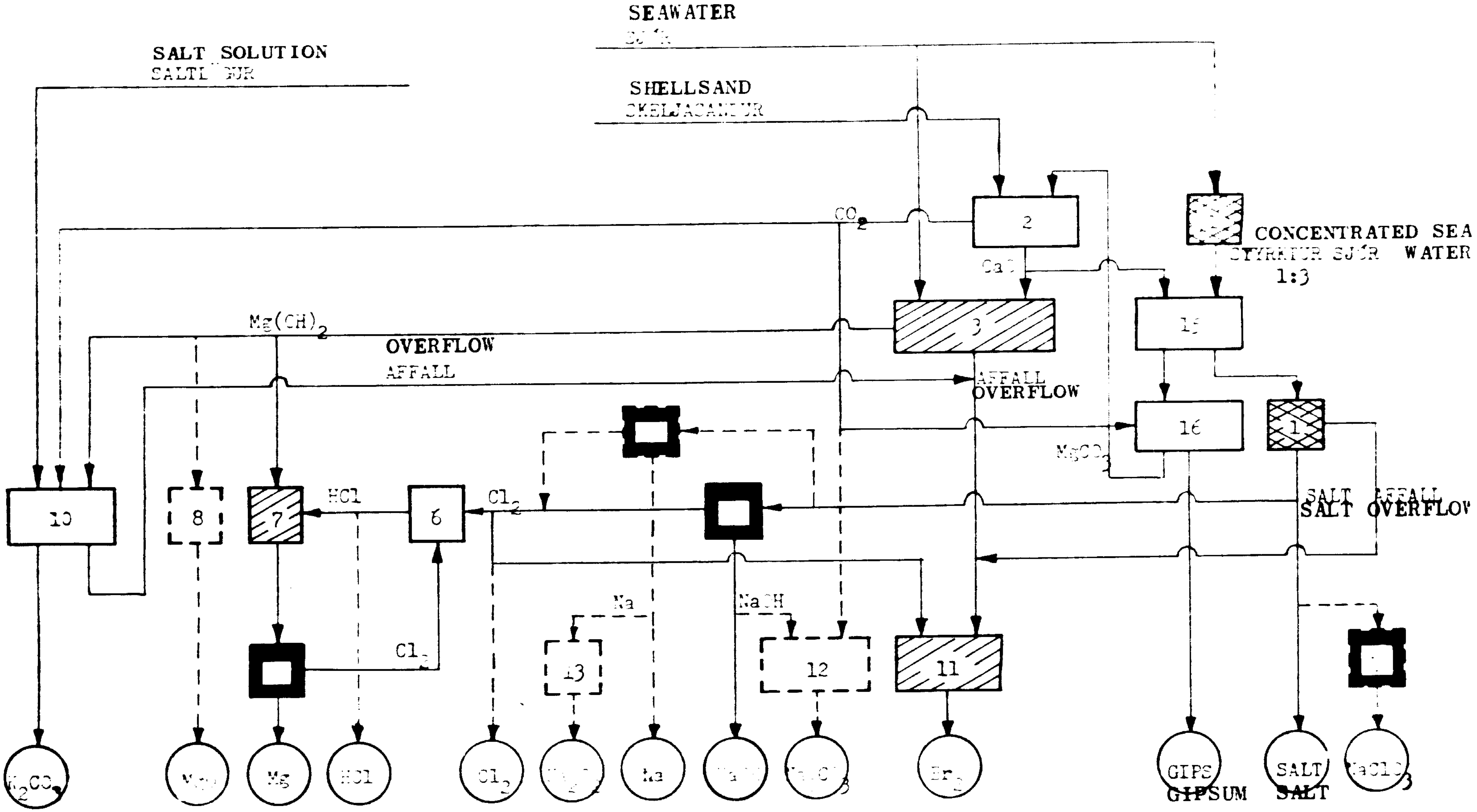


MYND 4-1 HUGSANLEGT SKIPULAG SAMHÆFÐRAR SJÓEFNAVINNSLU - HUGMYND 1
A POSSIBLE ORGANIZATION OF COORDINATED PRODUCTION FROM SEAWATER - IDEA 1

■ RAFORKUÞÖRF
ELECTRIC ENERGY REQUIREMENT

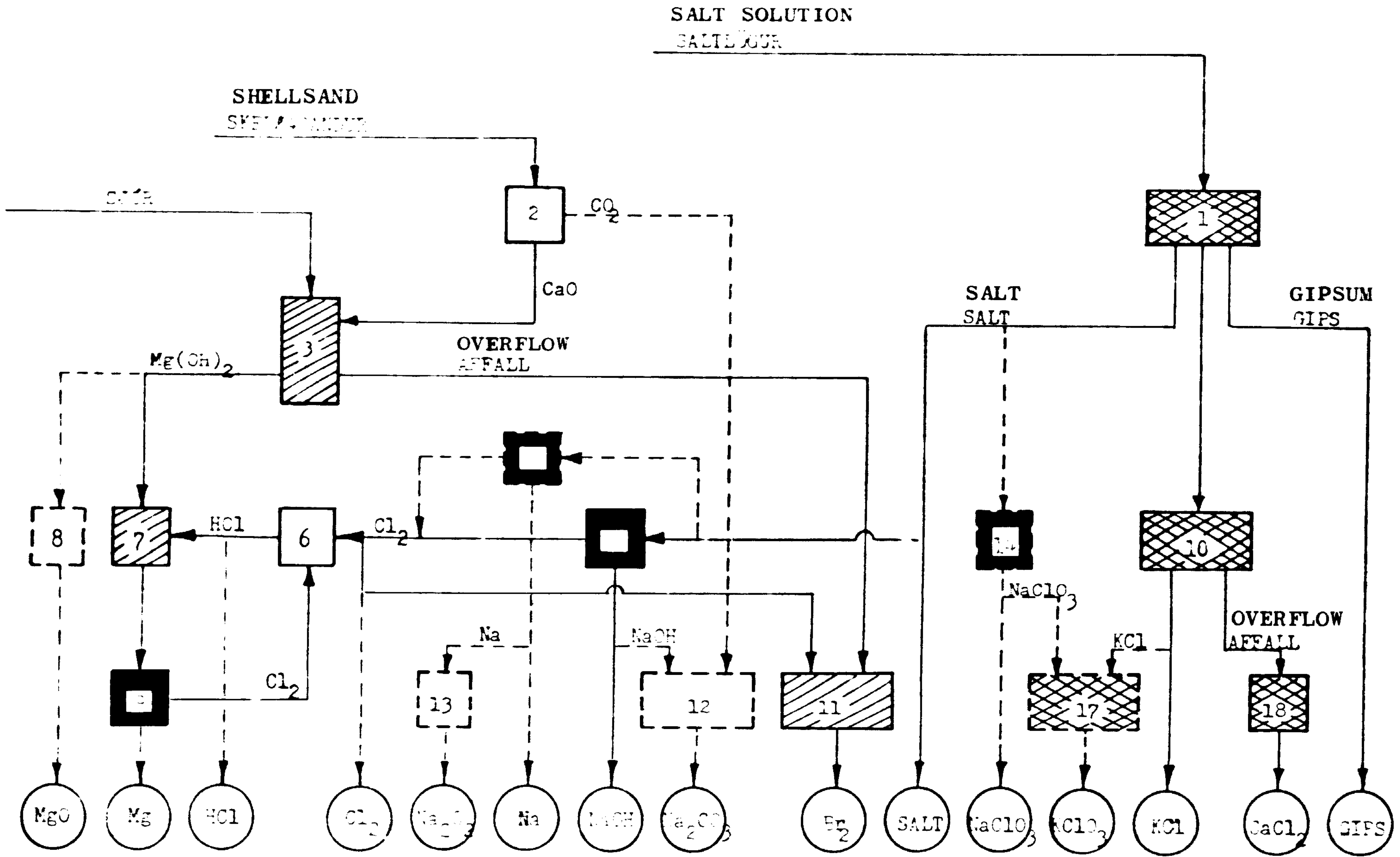
▩ GUFUÞÖRF
STEAM REQUIREMENT

▨ HUGSANLEG GUFUÞÖRF
PROBABLE STEAM REQUIREMENT



MYND 4-2 HUGSANLEGT SKIPULAG SAMEINAÐRAR SJÁVAREFNAVINNSLU - HUGMYND 2
A POSSIBLE ORGANIZATION OF COORDINATED PRODUCTION FROM SEAWATER - IDEA 2

■ RAFORKUÞÖRF ELECTRIC ENERGY REQUIREMENT ▩ GUFUÞÖRF STEAM REQUIREMENT ▨ HUGSANLEG GUFUÞÖRF PROBABLE STEAM REQUIREMENT



A POSSIBLE ORGANIZATION OF COORDINATED PRODUCTION FROM SEAWATER - IDEA 3

MYND 4-3 HUGSANLEGT SKIPULAG SAMHÆFÐRAR SJÓEFNAVINNSLU - HUGMYND 3

■ RAFORKUÞÖRF ELECTRIC ENERGY REQUIREMENT

▩ GUFUÞÖRF STEAM REQUIREMENT

▨ HUGSANLEG GUFUÞÖRF PROBABLE STEAM REQUIREMENT

4-3 PRODUCTION PROCESSES

In order to indicate how a coordinated chemical production from seawater can operate and the relation of one compound to another, flow diagrams 4-1 to 4-3 are enclosed. The solid lines show possible production processes in the main factory, that is in that part of the process, where the main compounds or elements are produced as previously explained. These materials are potassium chloride, magnesium and salt. Production of secondary compounds, which are obtained more or less automatically, such as caustic soda, gypsum and bromine, are also shown by solid lines. Production of those secondary compounds, which require special attention, are shown by broken lines. Other production possibilities than those indicated in the main production are also shown by broken lines. Thus soda (Na_2CO_3) can be produced from caustic soda and carbondioxide, which are available, sodium chlorate may be produced from salt, etc. Instead of the caustic soda production, which is shown in step 4 as a by-product from chlorine production, sodium metal may be produced by process 5, as shown, and from the sodium metal sodium peroxide (Na_2O_2) can be produced. Which one of those processes would be selected depends on which by-products are in greatest demand and most profitable. It is important that this matter be carefully studied.

The difference between the three ideas is based on a different coordination of the salt production (step 1) and magnesium hydroxide precipitation (step 3). On picture 4-1 the overflow liquor from the salt production is used directly to strengthen seawater in the hydroxide precipitation.
In picture 4-2 the magnesium hydroxide and gypsum are precipitated before salt is crystallized. Then the magnesium hydroxide is separated from the gypsum by carbonization and thus magnesium carbonate is obtained, but that is later burned with shell sand and then a precipitate is obtained, which is quite similar to burned dolomite, but that again makes magnesium hydroxide precipitation easier, as will be explained later. On picture 4-3 the salt is produced from

TABLE 4-2. A LIST OF PRODUCTION STEPS SHOWN IN PICTURES 4-1 TO 4-3

STEPS	EXPLANATIONS
1.	Evaporation and crystallization of salt.
2.	Calcining of shell sand.
3.	Precipitation of $Mg(OH)_2$ by slaked lime.
4.	Chlorine and caustic soda production.
5.	Chlorine and sodium production.
6.	Hydrochloric acid production.
7.	$MgCl_2$ by acidulation of $Mg(OH)_2$.
8.	Burning of periclase from $Mg(OH)_2$.
9.	Magnesium metal production by electrolysis.
10.	Potassium chloride production.
11.	Bromine production by chlorination of overflow liquor.
12.	Soda production by carbonization of caustic soda.
13.	Sodium peroxide by burning of sodium metal.
14.	Sodium chlorate production by electrolysis.
15.	Precipitation of $Mg(OH)_2$ and gypsum from concentrated seawater.
16.	Separation of gypsum by carbonization of $Mg(OH)_2$.
17.	Potassium chlorate production.
18.	Calcium chloride production by evaporation of brine.

geothermal water along with potassium chloride and calcium chloride by fractional crystallization. Here the geothermal water is evaporated completely and there is no possibility of using the leftover for strengthening the seawater in the production of magnesium hydroxide or for the production of bromine.

Many other possibilities are available. It is important that as many processes as possible be studied and the ones selected which are found to be most economical and utilize the natural resources best. The various possibilities are based both on different production processes for the various compounds, the coordination of the production processes and also on the compounds to be produced.

Production of the individual compounds listed in table 4-1 is thoroughly explained in appendixes, where the technology and marketing of each compound is discussed. Intermediate compounds, such as magnesium hydroxide, magnesium chloride, magnesium carbonate, hydrochloric acid and carbon dioxide are not discussed, however. In the foreseeable future there does not seem to be any considerable market for those materials except in the chemical production itself. This can of course change, especially in the case of hydrochloric acid, which could become a sales product, if a considerable chemical industry were established in this country.

4-4 UTILIZATION OF CONDITIONS

The conditions of greates importance for the economy of chemical production from seawater are:

1. The country's location
2. Natural resources
3. Social conditions

Those conditions may be divided into more categories, for example as follows:

1. The country's location
   - (i) distance from markets
   - (ii) distance from raw materials
   - (iii) distance from competitors
   - (iv) situation with respect to trade alliances.
2. Natural resources
   - (i) the seawater
   - (ii) salty water in geothermal areas
   - (iii) hydroelectric power
   - (iv) geothermal steam
   - (v) shell sand
3. Social conditions
   - (i) small population
   - (ii) the nature of the country's industries
   - (iii) the country's economy

The relative effect of transportation cost on production cost and competitive conditions is in general dependent on the value of the product, or the material, which is being transported. Thus, valuable goods may be transported long distances without the transportation cost having any appreciable effect, but it is not economical to transport inexpensive goods long distances, unless necessary.

For those reasons, the country's distance from markets has no appreciable effect in the case of highly developed chemicals, such as magnesium metal or sodium, and for the same reason the fisheries have never had any appreciable difficulties due to distances from markets, as fish products are relatively expensive goods.

On the other hand, the production of salt, gypsum and potassium chloride in this country would to an great extend be based on the fact that the cost of those inexpensive chemicals is raised considerably when imported by transportation to this country and the conditions of competing with foreign competitors are improved.

As raw materials for a chemical production from seawater are all obtained in the country, distances from the raw material sources only effects the choice of location of the factory in this country.

Of greater importance than the geographical location of the country is its relation to the various trade alliances and trade conditions in the possible trade areas. This must be studied carefully in connection with market research and its effect evaluated.

The country's natural resources are rather undiversified. Yet, their combination is such that chemical production from seawater may have good possibilities. Seawater is of course available in more places than here and its constituents not much different from that found at other locations. It is in most cases cleaner around this country, however, and less contaminated by waste than in general at the coasts of the continents. Its salt content is also rather stable outside of the areas affected by the rivers. On Reykjanes there is a geothermal area with brine, which possibly could at the same time be a source of potassium for fertilizer production and steam for heating, evaporation and drying in a chemical production process as the area is located near the sea.

Inexpensive hydropower has for a long time been considered a basic element for the future of chemical production and industry in Iceland. It so happens that in connection with chemical production from seawater, it is possible to coordinate three production processes, which are based on electrolysis, that is production of magnesium metal, chlorine production (along with caustic soda and sodium metal) and chlorate production. Electrolysis is the only competitive process, which is known for the production of those chemicals, and should therefore be promising from that point of view.

The second most important raw material, which is needed, besides seawater, is limestone or calcium carbonate. This is obtained mostly in two forms: as shellsand (mostly calcium carbonate) or dolomite (a mixture of 10-40% magnesium carbonate in calcium carbonate). Dow Chemicals, Inc. in the United States, which is the largest producer of magnesium metal in the world, uses only shell sand, but the British and Norwegians dolomite. The magnesium content in dolomite leads to less seawater being used and makes precipitation and filtration easier for various reasons, for example because of a smaller water content and better crystallization. The shell sand in Faxa Bay contains 2.7% MgO, which is considerably less than in dolomite, although that fact might be of benefit and must be studied. In the overflow liquor from salt production there is considerable magnesium and that could be used to concentrate the solution for the magnesium precipitation. This magnesium content is comparable to 11-12% magnesium carbonate content in shell sand and may prove just as economical as the use of dolomite in other places.

Social conditions are primarily of importance in connection with the fact that the small population leads to small demands for most chemical goods and accordingly the small chemical industry demands only small quantities of such basic chemicals as chlorine, caustic soda, hydrochloric acid, soda, etc. Yet, there are a few concerns which can utilize the production of a seawater chemical factory. The fishing industry must be mentioned first of all in this connection, but it uses salt for fish processing and salting of herring, amounting to 50-60 thousand tons yearly. Other users are f.ex. the sement-factory, which uses approximately 5.000 tons of gypsum yearly, the agriculture, which uses approximately 6.000 tons of potassium chloride yearly, the diatomite factory, which will use 1-2.000 tons of soda, and besides those there is demand for other chemicals to a lesser degree, such as calcium chloride for dust binding of roads, etc.

Various social views also affect the feasibility of chemical production from seawater, without considering directly the financial economy of the industry. The great and diversified needs of imports might make it desirable to produce in this country what is possible. Also, there is always the need for new export industries for obtaining foreign currency and for creating diversification and stability. The utilization of hydropower is a very important task in the next 10-20 years and one may expect chemical production from seawater to take an active part in that development.

As may be seen from what has been said, conditions other than the small inland market, are in general positive, and it seems to be a good possibility that those may be used to make chemical production from seawater economical. Where chemicals are produced from seawater in other places the production is never as diversified as contemplated here. In general magnesium metal, magnesium oxide and bromine are the only chemical products and no possibilities are of utilizing the by-products due to local conditions. Thus, greater production economy must be possible in this country. The inexpensive geothermal steam and electric power also seem of great importance in improving the competitiveness in foreign markets, and it is of great importance to study how these may best be utilized.

4-5 SIZE, LOCATION, CAPITAL INVESTMENT, ETC.

The size and capital investment in a factory for production of chemicals from seawater, is primarily determined by quantities of main materials that are to be produced. For several technical reasons it may for example be possible to base the magnesium production on 16 thousand tons of metal per year, or 30.000 tons of magnesium oxide. Domestic demand for salt would allow approximately 60.000 tons per year salt factory and the demand for potassium chloride was approximately 6.000 tons last year. In accordance with those figures it is possible to produce 1.000 tons of bromine per year and approximately 8.000 tons of sodium metal. Possible production of chlorate could be 10.000 tons per year.

In table 4-4 there are listed possible capacity capital investment, energy requirements and product value of several seawater processing units. One sees from there that the total capital investment is over 1000 million kronur and the total production value over 600 millions, based on the production of magnesium metal, not magnesium oxide. It must be remembered, that those figures are only indicating orders of magnitude and do not take into account production processes in detail. For example it is not at all clear how the production of potassium would be best arranged and therefore no figures are indicated for that production.

Electric energy and/or geothermal heat are of importance in most of these processes as the figures in the table indicate. Those are factors, which along others, are of importance in connection with the choice of location for the factory. Studies of location are of great importance and are discussed especially in the chapter on organization of research.

TABLE 4-3. POSSIBLE CAPACITY, CAPITAL INVESTMENT, ENERGY REQUIREMENTS, AND PRODUCT VALUE OF SEAWATER PROCESSING UNITS.

Process	Capacity tons/yr	Capital investment, million kr.	Electric energy requirements KWH/ton	Requirements of geothermal steam tons/ton	Product value	
					Kr/ton	Yearly product. M kr
Magnesium hydroxide + burning of limestone	30.000	150	little	0.4 +		
Magnesium metal from $Mg(OH)_2$ + corresponding chlorine production	16.000	400	20.000		26.000	415
Salt production, incl. bagging	60.000	130	little	12	900	54
Chlorine production	12.500		3.000			
Bromine production	1.000	30	little	none	20.000	20
Magnesium (periclase) from $Mg(OH)_2$	30.000	70	little		3.400	100
Sodium metal from salt	8.000	200	10.500	5.2	16.000	128
Sodiumchlorate from salt	10.000	150	6.000	5.5	6.500	65
Potassium salts (K_2O)	5-20.000				3.500	17-70

5 PROPOSED RESEARCH

5-1 INTRODUCTION

As mentioned in the beginning of this report, its objective is to suggest new fields of research concerning the utilisation of constituents in seawater around this country. In the preceding chapters an attempt has been made to narrow the field as much as practical without the danger of throwing away possibilities which might be of economic importance. At this state we can only get far enough to conclude, that obviously extensive research work has to be done and it will take a long time.

In the following discussion all research concerning geothermal heat and electric energy is excluded, although it is assumed that the use of both is a factor in this study. Also, research work concerning the increased upflow of salty water on Reykjanes is excluded.

Before definite research proposals are discussed, a few concepts which will be used should be explained, and the organization of research and selection of priorities.

5-2 DEFINITION OF CONCEPTS

For the purpose of explaining the concepts which are used here, and concern the development of studies, prior uses of such concepts as used in Iceland in similar cases is explained below.

<u>Preliminary research</u> covers studies, which on a broad base concern raw materials, technology and markets. Conclusions are presented as <u>preliminary estimates</u> of capital investment and operation, and as proposals of definite avenues to follow. This part of the work has been in the hands of people who direct and conduct research.

Feasibility study is a more detailed engineering development of the main conclusions of the preliminary research. This estimate can be a basis for resolutions in financial matters and can lead to conclusions concerning development. This work has been done by engineering consultants in direct consultation with special representatives of the Government or parties that conduct research.

A final estimate covers final engineering design, on which drawings, financing and organization of operation can be based. This is sponsored by the parties, which are to care for the operation of the enterprise.

Although only the first step or preliminary research refers directly to research, it is nevertheless an important item in all these steps. Proposals, presented later in this chapter, are, however, primarily based on the requirements of preliminary research and feasibility study.

5-3 ORGANIZATION OF THE RESEARCH

Due to the broad and expensive character of the research suggested here, it is important to list the tasks realistically by priorities so that each step in the research leads to definite conclusions, which primarily determine the development possibilities and the economy of the enterprise. Then it is soon determined whether the undertaking is economical and large amounts of money not spent on research, which is of no use, if the idea is dropped. It is also important to be able to discontinue the work at all stages of the research with the least possible financial loss.

In the following research proposals those view points have been determining as far as possible, but as the research itself will lead to new priority ratings, one must always have those facts in mind and reorganize the work accordingly.

Basically, in the first priority group is research concerning the possibilitities of production and requirements along with preliminary cost estimates. Such estimates must be reviewed steadily at all stages of research. The second most important item is market research, and thirdly raw materials research, along with studies of location. Preliminary estimates and feasibility studies usually show what further research is necessary and how it should be conducted.

5-4 PRELIMINARY RESEARCH

a) Preliminary estimates: At the outset a quite thorough study must be made of the needs of the proposed production. Quite accurate information must be obtained about equipment, water requirements, labour, energy and raw materials for the various processes, which are to be considered. On that basis preliminary estimates must be made of the capital investment and operating cost of the basic production units.

Special attention should be paid to factors concerning the production of:

1. Magnesium hydroxide
2. Magnesium oxide
3. Magnesium metal
4. Salt (a review of former estimates)
5. Bromine
6. Sodium metal and sodium peroxide
7. Potassium compounds
8. Sodium chlorate

A comparison of production processes must be made when more than one process is possible. Also a comparison of conditions enjoyed by present producers and the conditions in this country.

These preliminary estimates have two purposes. Firstly to determine more precisely the possibilities which are available, and their economy, before proceeding further. Secondly, it determines necessary research projects and in what order they shall be executed and how interpreted. Preliminary estimates are thus a necessary tool at this preliminary stage to make it possible to determine whether work should be continued on a particular project at each stage and thus save a lot of money, if the estimates indicate the project to be uneconomical at an early stage. For these reasons the estimates must always be reviewed in order to give a good view of the whole work.

b) Market research: In the beginning a quite thorough market study must be carried out concerning all the main materials proposed to produce in order to obtain information as to the size of the market, its growth, a possible share of the market, which domestic production might gain, also information on market prices and market behaviour, competitors' production, form of the product, etc. Also tarifm must be carefully studied in the possible market areas, and marketing possibilities must be investigated by meetings with important parties abroad. Market research abroad should especially be concerned with the following production items:

1. Magnesium oxide
2. Magnesium metal
3. Bromine
4. Sodium chlorate
5. Sodium peroxide
6. Sodium metal
7. Potassium carbonate

Domestic market studies should only concern salt to begin with and the needm of the various users of salt studied thoroughly. One must separate the uses of salt in fish processing, salting of herring and food production and account especially for demands on quantitity and salt properties made in those fields. It must also be investigated what the various users pay for the salt.

c) Raw material: The main raw materials used in the production of chemicals from seawater are seawater and shell sand. The saltiness is of great importance concerning the seawater, but mining conditions and chemical composition in the case of shell sand. The following proposals are made:

1. Salt content studies should be started again at locations which seem most likely to be of economic importance in connection with this matter. Samples should be taken continuously for two years at the most important places. The saltiness of seawater at the Reykjanes peninsula shall be one of the fields studied.

At the geothermal area on Reykjanes, an upflow of hot transformed seawater is found. A part of this field of study is to keep track of the amount of chemical constituents found in this salty spring water.

2. Shell sand mines known in this country should be studied in order to obtain information on the quantity of shell sand, mining conditions and properties of the raw material. It should be pointed out that extensive research of this nature took place in connection with the foundation of the State Cement Factory and the conclusions of those studies are without doubt available. On the other hand, it is assumed that more extensive studies are now necessary and that samples should be obtained from more than one place for examination. Plans should be made for the mining of shell sand at a definite place or places, as well as estimates of transportation costs to factory.

d) Location of a processing plant for seawater: The research work will be greatly facilitated by determining early the location of the proposed plant. Main points for engineering consideration are:

1. Transportation of raw materials and water
2. Transmission of heat and electric energy
3. Transportation from the plant
4. Contamination
5. Personnel and conditions for the construction of living quarters
6. Factors in the production requiring comparable conditions
7. Availability of various services for the plant

Determination of location must be coordinated, however, with research on raw materials and other important studies previously mentioned. Attention is brought to the method of studying single factors individually and finding which locations are excluded thereby.

e) <u>Process engineering research</u>: As soon as the above mentioned research work warrants, it is necessary to study thoroughly the quality of the available raw materials which are available in this country. In a broad way, they are already known to be sufficiently good, but their quality in finer details is of course not known and therefore not clear if or which special measures must be taken which could improve the conditions.

For this purpose experiments should be planned, with the aim of producing a few kilograms of the basic compounds. At this stage it is clear that at least the following experiments should be made:

1. Burning of shell sand. Determine the activity of the lime.
2. Slaking of lime from (1) in fresh water and seawater. Investigate separation of sand.
3. Study precipitation of $Mg(OH)_2$ from seawater with slaked lime from (2). Study influence of temperature.
4. Study settling and washing of $Mg(OH)_2$ from (3) at different temperatures and pH (investigate influence of NaOH).

5. Determine rate of filtration of $Mg(OH)_2$ from (4) at different temperatures and pH.
6. Calcine $Mg(OH)_2$ to produce magnesium oxide.
7. Acidulation of $Mg(OH)_2$ and bench scale production of magnesium chloride suitable for production of magnesium metal.
8. Comparison of results of studies 1 to 7 with same studies conducted with dolomite instead of shell sand.
9. Crystallization of salt from three-fold concentrated seawater.
10. Studies of precipitation of sulfate and $Mg(OH)_2$ from mother liquor from (9).
11. Studies of using $Mg(OH)_2$ from (10) as seed for the crystallization in (3).
12. Studies of using mother liquor from (10) to concentrate seawater in (3).
13. Studies of potassium compounds production from concentrated and transformed seawater with the aid of $Mg(OH)_2$ and CO_2.

It should be stressed that these studies should all be conducted in this country among other things to gain experience in this field.

This preliminary research work, which now has been explained, will lead to revised preliminary estimates, which one would expect to show whether chemical production from seawater is an economical undertaking and as well as the most economical size of the plant and its general arrangement. The next step in the development, if continued, will be a preliminary capital estimate of the plant and its operating cost.

5-5 FEASIBILITY STUDY

The feasibility study can be in many parts and steps, which develop automatically. In general the proposed production will be divided into definite fields, primary production and secondary production and the details of each field studied thoroughly. It is likely that the division of the feasibility study will primarily be based on normal stage development of the chemical production as an enterprise. At this stage definite machinery and equipment to be used in the production will be studied and experiments made in cooperation with those that would supply the machinery. Then raw material, markets, technology and economy will be studied carefully, and certain basic decisions concerning location, production methods and production forms made. When the preliminary estimates are on a firm ground more or less, it is time to establish a company around the planned undertakings and operation, and start looking into the sale of the product.

5-6 ESTIMATED EXPENSE OF THE PRELIMINARY RESEARCH

The importance of the preliminary research for an economic evaluation of the production possibilities, makes it obvious that this work will cost considerable money. As an indication it may be mentioned that the technical feasibility study is estimated to cost approximately 1% of the capital investment or approximately 10 million kronur in this case. Besides this, basic research on raw materials is necessary, which would also cost much money.

The following estimate of the cost of the preliminary research is based on only the main stages of the chemical process being considered, as explained above, and that various other items belonging to the preliminary research be considered when they come up. The following estimate does therefore only cover the first stage of the preliminary research.

TABLE 5-1. APPROXIMATE COST ESTIMATE FOR THE FIRST STAGE OF A PRELIMINARY RESEARCH

	Thousand kronur
Preliminary estimates	1.200
Market research	600
Raw materials research	600
Location	150
Process engineering research	1.200
Miscellaneous	400
TOTAL thousand kronur	4.150

The expenses involved in other parts of the preliminary research should not exceed 6 million kronur.

The cost of the feasibility study depends on the production stages being considered and how much is covered. It is reasonable to estimate 3% of the capital investment for such work.

5-7 TIME PLAN

At this stage it is not possible to give an accurate time plan for individual steps in the above mentioned work. On the other hand, it may be possible to state approximately the time required for the various stages of the development work.

To start with it may be estimated, that the preliminary research, described above, would take two years. But before that time has passed it is possible to start work on the feasibility study, which may be assumed to take two to three years. Thus, it may be estimated that the cost of these parts of the investigation would be spread over

4-5 years and it may also be assumed that after approximately two years definite conclusions will be available concerning the feasibility of chemical production from seawater.

5-8 CONCLUSIONS

From the description above, many will possibly find chemical production from seawater a quite extensive undertaking. It is also clear that such an industrial complex would not be completely erected overnight. One of the most import fields to be studied in this connection is, therefore, how such an enterprise can be erected in steps, both as concerns individual processes and also production quantities of each step.

In the beginning it is for example possible to produce only magnesium oxide and salt as main compounds. Thus only processes 1, 2, 3 and 8 on figure 4-1 need to be developed in the beginning. Later on, production of magnesium metal could start and could be increased gradually as the market situation demands. The production of potassium carbonate could also begin along with magnesium oxide and salt production or later as found practical. Production of other chemicals could then be initiated as markets and financial means allow.

When the production is developed in such stages, one must be careful not to loose sight of the overall organization, because the final economy is to an great extend based on the complete enterprise. Thus, the whole production program must be planned in the beginning, although it is developed in steps. Also the close relationship of the various processes must be kept in mind, such as when materials from the salt production are used in the magnesium production. Besides this, pumping and cleaning of raw materials is also common to the processes. The use of geothermal steam and electric energy is closely interrelated in the whole production program and makes possible a good utilization of these energy sources and the equipment required in that connection. Thus the same transmission lines and pipes, transformers, etc., can be used and also heat left over from one process may be used in another process. From this it is clear that it does not seem possible to separate the production too much or to locate the various plants in the production program at many different places. Besides increasing expenses in construction and equipment, it would make impossible various economic measures, which would be possible within a closely interrelated plant area.

It is also clear from what has been said that a chemical production from seawater involves coordination in the use of important sources of raw materials in the country and the main energy sources, hydropower and geothermal heat. The products could be expensive goods whereby value of those natural resources should be extracted at a great profit.

From the appendixes it is clear that the materials, which have been discussed here and thought possible to produce, are in general steady in price and use and many of them can become a basis for an extensive chemical industry in the country. Is some cases the growth of the market is strong. In appendix II it will for example be seen that the magnesium market is growing fast, faster than the market for aluminum. Besides this, international trade in these chemicals is in general at a high value.

On the other hand, it might not be as clear to the reader that the chemical processes under discussion are comparatively easy from a technical point of view compared to the process industries in general. The process steps involve comparatively simple chemical changes and in many cases the various production steps are thoroughly tried, under conditions similar to those existing in this country. Thus it may be mentioned that magnesium production is much easier from a technical point of view than production of aluminum.

From all this it may be clear that this is an area which seems to be well suited for an Icelandic chemical industry in its infancy. It requires of course much research work before decisions can be taken, but that research can be done by Icelandic personnel to a great extend, and thus become the basis for increased technical knowledge in Iceland in a field of economic importance and thus likely to lead to good results.

APPENDIX I. MAGNESIUM OXIDE

I-1 PRODUCTION FORM AND ORIGIN

Magnesium oxide is produced by burning magnesium hydroxide, which is precipitated from seawater or brine, and from various solids, which are rich in magnesium carbonate, such as magnesite, dolomite, olivine and others.

The products are in many quality groups and types and the grouping depends on the chemical composition and purity and the crystal shapes of the product. The main contamination in magnesium oxide are magnesium carbonate, iron oxide, aluminum oxide and lime.

The main categories of magnesium oxide are two, caustic and deadburned. Caustic magnesium oxide is obtained by burning at 700-1000°C, so that the carbonate content as CO_2 is approximately 2-7%. Caustic magnesium oxide must be very active and the burning requires great care. The material is sold as powder, similar to cement.

Deadburned magnesium oxide is obtained by burning at 1450-1500°C and then all the carbonate is removed. The material becomes dense and rather like slag and is hardly active at all. The common deadburned magnesium oxide contains 65-85% MgO, but socalled periclase, which has the same crystal structure contains over 90% MgO and is obtained by burning at 1760°C. Production of magnesium oxide from seawater is usually aimed at producing periclase because demands for purity can then easily be met.

1-2 PRODUCTION PROCESS

The main step in the production of magnesium oxide is heating of magnesium carbonate or magnesium hydroxide (which for example may be obtained by precipitation from seawater).

The heating is carried out in rotary kilns heated with gas or oil at 700-1760°C depending on the use of the material. The oil consumption when periclase is produced is approximately 200 kg per ton.

I-3 USE

Caustic magnesium oxide is primarily used in quick hardening cement (oxychloride or sorel cement). It is also used in insulation materials and in the production of other chemicals, such as uranium, rubber, etc.

I-4 MARKET AND PRODUCTION

The largest producers of burned magnesium oxide in the world are: Austria, Greece, United States, Jugoslavia and possibly England, although figures are not available from there (table I-1). These countries are also the only exporters of any importance. International trade amounts to approximately 600-700 thousand tons per year (see table I-3) and that is approximately half of the world production, which thus is placed on the international market. The largest importers are England, Germany, Hungary and Holland, along with the United States, which is both an exporter and importer of magnesium oxide.

It is remarkable that the United States imports primarily from Austria, Greece and Jugoslavia and that import is primarily deadburned magnesium oxide or periclase. Import from these countries to the United States amounted to 86 thousand tons in 1963 and not quite 60 thousand tons in 1964.

The Greek import to Holland is approximately 30 thousand tons per year (1963-64) and to Germany Greece sold 31 thousand tons in 1964.

1-6 PRICE BEHAVIOUR

The average price of burned magnesium oxide (both caustic and deadburned) is $44 per ton. A similar price is quoted in India. In the United States the price differs with the types. Deadburned magnesium oxide is sold for $51.50 per ton, but as caustic and ground powder it is sold for 91-95 dollars per ton. The price of periclase is similar or approximately $86 per ton.

Magnesium oxide, which is used in the rubber and pharmaceutic industries is much more expensive or from $620 up to $1100 per ton depending on purity and packing. Of course, the market for such materials is limited and difficult to enter.

TABLE I-1. PRODUCTION OF MAGNESIUM OXIDE 1958-1964

Producing country	1958	1959	1960	1961	1962	1963	1964
AUSTRIA							
caustic	98.700	162.000	119.000	128.000	131.000	130.000	135.000
deadburned	414.000	377.000	192.000	534.000	476.500	406.000	520.000
Powder (caustic)	39.000	40.000	45.000	52.000	.48.000	38.000	56.000
GREECE							
caustic	24.000	24.000	41.000	47.000	30.000	50.000	missing
deadburned	8.000	22.000	26.000	24.000	30.000	42.000	"
UNITED STATES							
caustic	40.000	49.000	54.000	72.000	78.000	121.000	146.000
deadburned	371.000	401.000	452.000	535.000	515.000	636.000	760.000
JUGOSLAVIA							
deadburned	52.000	58.000	63.000	56.000	62.000	85.000	missing
TOTAL	1.046.700	1.133.000	1.297.000	1.448.000	1.370.500	1.508.000	1.616.000

From Statistical Summary of the Mineral Industry, London 1965, and Minerals Yearbook 1964, U.S. Dept. of the Interior, 1965.

Remark: Information is not available from England on the production of magnesium oxide, but over 3 million tons of dolomite are used in the country yearly, most likely mostly for the production of magnesium oxide. Accordingly the table is not complete with respect to the total production in the world.

TABLE I-2. INTERNATIONAL TRADE

EXPORT OF MAGNESIUM OXIDE 1958-1964

Exporting country	1958	1959	1960	1961	1962	1963	1964
AUSTRIA							
caustic	81.000	88.000	95.000	95.000	96.000	94.000	100.000
deadburned	131.000	170.000	213.000	235.000	186.000	164.000	237.000
JUGOSLAVIA							
deadburned	52.600	58.000	63.000	56.000	62.000	85.000	missing
UNITED STATES							
deadburned	48.000	78.000	83.000	110.000	65.000	70.000	71.000
GREECE							
caustic and deadburned	33.500	52.300	65.300	76.500	81.000	92.000	95.000
TOTAL	345,600	446,300	519,300	573,500	490,000	505,000	503.000

From Statistical Summary of the Mineral Industry, London 1965 and Minerals Yearbook 1964, U.S. Dept. of the Interior 1965.

TABLE I-3. INTERNATIONAL TRADE

IMPORT OF MAGNESIUM OXIDE 1958-1964

Import country	1958	1959	1960	1961	1962	1963	1964
ENGLAND burned and unburned	30.000	30.000	95.000	152.000	47.000	38.000	86.000
CANADA caustic and deadburned	14.000	18.000	25.000	23.000	25.000	17.000	28.000
BELGIUM - LUXEMBURG caustic and deadburned	2.000	4.500	3.000	4.500	3.500	3.000	3.600
FRANCE caustic and deadburned	25.000	18.000	20.000	23.000	23.000	22.000	34.000
GERMANY caustic and	89.000	101.000	109.000	109.000	111.000	103.000	114.000
deadburned	70.000	56.000	83.000	96.000	100.000	96.000	178.000
HUNGARY deadburned	46.000	43.000	50,000	59.000	69.000	65.000	59.000
ITALY deadburned	14.000	17.000	28.000	42.000	33.000	27.000	30.000
HOLLAND caustic and deadburned	14.000	16.000	23.000	32.000	35.000	38.000	49.000
POLLAND caustic and deadburned	51.000	63.000	60.000	79.000	missing	134.000	122.000
SWEDEN burned and unburned	1.500	1.400	2.500	5.500	4.500	7.000	9.200
UNITED STATES caustic	2.100	5.000	4.000	4.000	7.000	9.000	8.000
deadburned	71.000	135.000	103.000	47.000	88.000	78.000	54.000
JAPAN deadburned	66.000	111.000	96.000	91.000	68.000	21.000	19.500
TOTAL	494.600	608.900	703.500	769.000	614.000	650.000	794.200

Information from U.S. Minerals Yearbook 1964, U.S. Dept. of the Interior 1965 and Statistical Summary of the Mineral Industry, London, 1965.

APPENDIX II. MAGNESIUM METAL

II-1 PRODUCTION FORM

Magnesium is produced as a 99,9% pure metal and sold in 18 lb ingots. It is almost exclusively produced from seawater or brine.

II-2 PRODUCTION PROCESSES

Magnesium metal is in general produced as follows:

a) Magnesium is precipitated as magnesium hydroxide ($Mg(OH)_2$) by slaked lime ($Ca(OH)_2$), which is obtained from burning shell sand or dolomite.

b) After filtration $Mg(OH)_2$ it is transformed into a magnesium chloride solution by a 10% solution of hydrochloric acid.

c) The magnesium chloride solution is then concentrated by evaporation, magnesium chloride crystallized from it and dried in a rotary dryer.

d) Flaked magnesium chloride is placed in electrolytic cells, where the metal is formed 99,9% pure at the cathode, but chlorine gas at the anode. The chlorine gas is used for the production of hydrochloric acid.

The main facts about the production are:

a) Electric energy requirement is 17,6 kwh/kg metal (direct current for electrolysis)

b) Voltage is 6,2 volts per cell

c) Consumption of carbonelectrode is 0,1 kg/kg of metal

d) The life of the cells: 500 days for the fire clay cells
1000 days for the steel cells

e) The cells are heated by electric energy or fuel.

f) Difficulties: Boron and iron in the electrolyte cause difficulties for the operation.

It may be mentioned that the magnesium content of the lime, which is used for the hydroxide precipitation, is of great importance as it forms ~~a~~ nuclei, on which the magnesium hydroxide can precipitate.

II-3 USE

Magnesium is the metal with the lowest specific weight of those used in any appreciable amount. Its specific weight is 1,8, but for comparison the specific weight of aluminum is 2,5. By strength and weight it is less expensive to use magnesium for many purposes than any other metal. Besides, it is easier to work magnesium than aluminum and therein lie considerable savings. The metal is rather soft pure and not very strong, but in a mixture, for example with aluminum, it can form a very strong material, usable in structural beams, etc. Magnesium is among other things used in the following products and industries:

a) Automobile and aviation industry
b) In alloys (with aluminum) for structural beams
c) For metal casting of small items (letters, typewriters, etc.)
d) For cleaning and production of iron and scarce metals, for example titanium
e) In flash bulbs for photography and in fireworks products.

II-4 PRODUCTION BEHAVIOUR

Production and use of magnesium became first appreciable during World War II, when approximately 100 thousand tons were used yearly in airplanes and fire bombs. After the war the production dropped to 10 thousand tons, but increased again to over 100 thousand tons during the Korean war. After the United States had built up a large storage in 1957, prices and production decreased sharply. Since then its use has increased steadily and at a greater rate than the increase in the use of aluminum, that is 10-14% yearly compared to 7,5% for aluminum. The world production in 1964 was somewhat over 150 thousand tons (see table II-1 (M21)).

In the United States a great increase in the uses and production of magnesium is expected and various companies have made known their plans for construction of new factories or additions, which altogether could increase the production there over 100 thousand tons (see table II-4), so that the production capacity would then be 210-220 thousand tons.

In Western-Europe, Norway is by far the largest producer of magnesium and the Norwegians sell nearly all their production (22.700 tons in 1964) to Germany. The Norwegians intend to increase their production of magnesium by 100% in the next 10 years. Other countries in Europe outside the Soviet Union produce neglicable amount of magnesium, except England and Italy, which have produced each over 5000 tons per year for some years.

II-6 INTERNATIONAL TRADE

In table II-2 and II-3 one sees that international trade in 1964 amounted to 50 thousand tons. Norway and the United States are the largest exporters and both sell nearly all their export to Germany. Canada sells approximately 6.000 tons yearly mostly to England, it seems, but the English export on the other hand finished magnesium goods and alloys corresponding to 3000 tons of magnesium.

From the tables it is seen, that the largest markets for exported magnesium are in Europe and that most of industrial countries in that area except Germany use small amounts of magnesium as yet. In the German market the Volkswagen factories are of greatest importance, which indicates what influence ~~of~~ the automobile industry could have if it started using magnesium metal in increasing amounts. The Opel factories in Germany and Vauxhall in England are reported (M20) to have such plans in connection with new transmission casings. This would open up a market for at least 5000 tons yearly, but production of gears such as Volkswagen does would create a market of approximately 600.000 yearly in the U.S. automobile industry alone. Accordingly the total world market could become approximately 1,5 million tons at the end of the next decade.

Although those figures are not to base estimates on, they indicate nevertheless the possibilities in the magnesium future.

II-6 PRICES AND PRICE BEHAVIOUR

After the United States Government stopped stocking the metal and the market came normal again around 1956, the price of magnesium became steadier in the United States and has been approximately 36 c/lb in smaller lots, but down to 30 c/lb in larger quantities. On the European market the price is somewhat lower and the Volkswagen factories are believed to pay approximately 26 c/lb, or $573 per ton, compared to $660 per ton on the U.S. market.

It is believed that the price may dropp somewhat and Chemical Week (M20) believes that a price of 28 c/lb will be the approximate market price in the United States after 1970.

TABLE II-1. WORLD PRODUCTION OF MAGNESIUM 1959-1975

Production country	1959	1960	1961	1962	1963	1964	1965	1970	1975
CANADA	5.530	6.600	3.930	8.000	7.900	8.180			
CHINA (estimated)	1.000	1.000	1.000	1.000	1.000	1.000			
FRANCE	1.760	2.120	2.070	2.120	1.820	990			
W-GERMANY	500	300	400	500	500	500			
ITALY	4.520	5.450	5.600	5.600	5.500	5.500			
JAPAN	1.560	2.140	2.250	2.080	2.440	2.900			
NORWAY	9.600	10.300	14.500	14.550	20.300	22.700			
SOVIET UNION	20.300	25.300	31.500	31.500	31.500	31.700			
ENGLAND	2.150	3.740	5.280	5.080	4.770	5.000			
UNITED STATES	38.100	36.300	37.000	62.600	68.700	72.000	80.000	117.000	165.000+ 300.000x
TOTAL	85.080	87.230	100.530	135.030	144.520	150.470			

+ Estimated (Chemical Week Nov. 27th, 1965)

x If the automobile industry starts using magnesium

xx Information from U.S. Mineral Yearbook 1964 and Statistical Summary of the Mineral Industry, London 1966.

TABLE II-2. INTERNATIONAL TRADE

EXPORT OF MAGNESIUM METAL 1958-1964

Export countries	1958	1959	1960	1961	1962	1963	1964
ENGLAND (alloys)	3.520	2.680	2.180	1.540	2.060	3.010	2.360
CANADA				5.470	5.960	6.000	
FRANCE	62	52	60	95	63	94	150
GERMANY	160	215	710	612	235	433	915
ITALY (alloys)	3.310	4.460	4.370	4.490	4.540	4.170	5.700
HOLLAND			32	180	250	370	243
NORWAY		11.150	13.000	12.400	14.800	19.100	23.200
SOVIET UNION	1.600	1.000	1.300	1.800	1.900	2.100	2.850
UNITED STATES (alloys)	188	1.450	4.050	5.600	5.830	14.000	14.500
JAPAN	780	53	1		52	20	23
TOTAL	13.262	21.110	25.703	32.427	35.690	49.297	49.941

From Statistical Summary of the Mineral Industry, London 1966

TABLE II-3. INTERNATIONAL TRADE

IMPORT OF MAGNESIUM METAL 1958-1964

Import countries	1958	1959	1960	1961	1962	1963	1964
ENGLAND	2.080	3.560	3.970	5.580	5.610	4.680	3.820
AUSTRALIA	93	100	93	150	130	207	497
AUSTRIA		275	380	380	325	460	513
BELGIUM-LUXEMBURG	520	330	440	380	520	490	725
FRANCE	760	135	475	465	1.200	1.880	2.660
GERMANY	14.000	18.000	26.900	26.400	30.000	31.000	34.500
HOLLAND	180	180	190	160	315	390	492
FINLAND	90	90	100	220		430	280
SWEDEN	325	450	410	420	490	500	590
SWITZERLAND			420	470	700	585	755
JUGOSLAVIA	235	185	300	585	155	270	495
MEXICO	325	350	355	325	360	595	483
UNITED STATES	490	540	365	910	2.130	1.800	790
BRASIL	70	45	50	95	610	1.800	1,500
TOTAL	19.168	24.340	34.458	36.540	42.545	45.087	48.200

From Statistical Summary of the Mineral Industry, London 1966

TABLE II-4

ESTIMATED PRODUCTION CAPACITY IN THE UNITED STATES UP TO 1970

Corporation	Size	Start of production	Location
ALABAMA MET. CORP (ALUMET)	7000 t/year	1965	SELMA, ALA.
MELCO DIV. OF CHAS. PFIZER & CO.	5000 t/year	1965	CANAAN, CONN.
DOW CHEM. CORP.	100,000 t/year incl. old	1966	FREEPORT and VELASCO, TEX.
NATIONAL-LEAD, HOOKER CHEMICAL, M-K CO.	30,000 t/year	1968-69	UTAH-PACIF. N.W.
HARVEY ALUMINIUM	20,000 t/year		UTAH-PACIF. N.W.
KAISER AL. & CHEM. CORP.	20- 30,000 t/year	after 1970	UTAH-PACIF. N.W.
DOW CHEMICAL CORP.	25,000 t/year	" 1970	UTAH-PCAIF. N.W.

TOTAL 210-220,000 thousand

APPENDIX III. SALT

III-1 PRODUCTION FORM

Salt production in this country would only be intended for domestic use. Four types of salt are being used in this country.

1. Food salt or table salt is used to a small degree. It consists mostly of small crystals and is packed in consumer packings of 5 kg or less.
2. Feed salt is imported in some quantities, in several different compositions for the various domestic animals, containing trace elements.
3. Medium coarse salt for salting of herring and use in the food industries is imported in considerable quantity. It should be as clean as possible and especially not contain copper, calcium and magnesium to any degree.
4. Coarse salt is used in this country in great quantities for fish processing. Purity must be comparable to salt from Spain, where the sodium chloride content is from 93,5 to 96%, and the crystal size such that approximately 60-70% of the salt is greater than 2000 microns and a considerable spread in the crystal size is necessary. Strict conditions prevail regarding the copper content of the salt, as copper can cause yellow spots in the fish. The copper content must not exceed 0,2 parts per million and preferably nothing.

It is considered desirable that the coarse salt be with minor quantities of secondary materials. Thus experiments in this country indicate that a calcium content up to 1% and magnesium content up to 0,5% give a nicer color to stock fish (it becomes whiter). On the other hand, wet salted fish is better processed by the use of pure salt.

III-2 PRODUCTION PROCESSES

Of the various processes used for the production of salt, only low pressure evaporation of seawater or brine will be considered here. By that method two types of evaporators or evaporating systems are used.

1. Multiple effect evaporators
2. Flash evaporators

The first mentioned have been used in evaporation for many years and some types are highly developed. The latter type is rather new, but has certain advantages above the other, for instance as regards scaling problems.

A previous estimate of salt production has been made based on the use of multiple effect evaporators, but the advantages of flash evaporators have not been studied in detail yet. Extensive research work has been carried out in connection with evaporation of seawater for the Office of Saline Water in the United States Department of Interior and those should be carefully studied.

Crystallization of salt from a saturated liquid is a well known unit operation and no special innovations seem to have developed in the field in recent years.

III-3 USE

Use of salt in this country has been discussed previously (I 1, I 6). Table III-1 shows the import of coarse and medium coarse salt for the years 1930 to 1965. It is seen that the use of salt has been steadier in the last decade than during a similar period before. From 1953 it has not been below 40.000 tons per year and in most years above 50.000 tons per year. The average consumption for the years 1950-1965 is 50.617 and for the years 1955-1965 it is 52.940 tons. It must be remembered that salt production in this country would primarily compete with salt imported from Spain and Italy, which amounts to, according to Trade Statistics for the year 1963-1965, approximately 88-90% of the above mentioned amount. The rest is salt, obtained by Icelandic fishing vessels in foreign harbors and taken directly to the fishing grounds, as well as salt for salting of herring from Norway, Sweden and Germany. Excluding this last amount it is safe to figure on at least 45.000 tons per year, which could be sold from a factory in this country. If a magnesium factory were to be erected, along with a salt factory, one might assume that chlorine gas required in the magnesium production would be obtained by electrolysis of molten salt. For the production of one ton of magnesium metal one can figure on half a ton of chlorine gas being needed. If a magnesium factory producing 16.000 tons per year were established, approximately 13.500 tons of salt would be needed for the corresponding production of chlorine. Thus, the total demand for salt would be approximately 60.000 tons per year. Production of chlorine for other uses for example production of bromine and other domestic chemical industries would increase this figure considerably. These possibilities must always be kept in mind.

III-4 PRICE BEHAVIOUR

The price of sun-dried salt from Spain and Italy is 175-181 kr/ton (fob). In this country average cif. price of all imported salt was 619 kr/ton in the years 1963-1965.

Sun-dried salt cost 568 kronur per ton on the average during the same period. Medium coarse salt imported from Northern-Europe is considerably more expensive, costing approximately 900-1000 kr. per ton.

TABLE III-1. IMPORTS OF SALT 1930-1965

Year	Imported salt tons	Year	Imported salt tons
1930	86,970	1948	21,067
1931	65.319	1949	21.314
1932	87.551	1950	56,503
1933	113.096	1951	27.503
1934	70.433	1952	35.489
1935	62.588	1953	52.184
1936	49.660	1954	55.875
1937	43.517	1955	55.992
1938	52,204	1956	70.166
1939	61.114	1957	53.429
1940	17.692	1958	46.060
1941	16.612	1959	40.589
1942	13.141	1960	52.662
1943	7,072	1961	48,551
1944	10.379	1962	57.768
1945	5.896	1963	54,092
1946	20.198	1964	52,257
1947	43.307	1965	50.782

TABLE III-8

IMPORTS AND PRICES OF SALT 1963-1965

Country	1963			1964			1965		
	Quantity ton	FOB kr/ton	CIF kr/ton	Quantity ton	FOB kr/ton	CIF kr/ton	Quantity ton	FOB kr/ton	CIF kr/ton
DENMARK	35	2.460	3.090	79	2.150	3.180			
NORWAY	3.815	743	760	3.711	873	879			
SWEDEN	-	-	-	266	715	715			
GREAT BRITAIN	237	1.385	1.775	310	1.055	1.545			
HOLLAND	120	960	1.350	135	866	1.525			
ITALY	7.873	175	508	5.085	173	533			
SPAIN	38.690	172	526	40.727	183	577	41.500	181	590
W-GERMANY	3.382	632	961	1.938	638	872			
E-GERMANY	10	1.200	1.500	5	1.200	1.600			
TOTAL IMPORT	54.093	250	582	52.257	261	618	50.782	267	652

APPENDIX IV. CHLORINE, SODIUM AND SODIUM COMPOUNDS

IV-0 In the production of magnesium metal, one step consists of the production of magnesium chloride ($MgCl_2$) from magnesium hydroxide ($Mg(OH)_2$) and hydrochloric acid (HCl). For the production of hydrochloric acid, chlorine and water are needed. The chlorine will most likely be produced at the location as the most common production method is electrolysis of salt (NaCl) or brine. In connection with the chlorine production it is possible to produce several other chemicals, such as:

NaOH	(Caustic soda)
Na	(Sodium metal)
Na_2CO_3	(Soda)
Na_2O_2	(Sodium peroxide)
NaClO	(Sodium hypochlorite)

One of the main difficulties in the chlorine industry is to get rid of the alkali by-product. The demands for chlorine and caustic soda do not by any means follow each other, and there is overproduction of caustic soda.

Two methods of electrolysis are possible. One is based on saturated brine, obtaining caustic soda as a by-product. The other method uses molten salt for the electrolysis, obtaining sodium metal as a by-product. The choice of a production method must to a certain degree depend on the saleability of the by-product. Each of these processes and corresponding products are therefore studied in somewhat more detail.

IV-1 CHLORINE

IV-1a PRODUCTION FORM AND ORIGIN

Chlorine is a poisonous yellow gas, which is mostly produced by electrolysis of salt. Chlorine gas can easily be condensed to a liquid by the application of a pressure of somewhat less than 6 atmospheres.

IV-1b PRODUCTION PROCESSES

There are two methods of electrolysis, as mentioned above:

1. Electrolysis of brine

$$2NaCl + 2H_2O \rightarrow Cl_2 + 2NaOH + H_2$$

There are two main types of electrolysis cells available:

a) Diaphragm cells
b) Mercury cells

Their difference is that in the former type a diaphragm separates the chlorine gas from the caustic soda produced, but in the latter cell mercury is present which combines with the sodium and separates it thus from the chlorine. The sodium is later separated from the mercury using water, and forming caustic soda and hydrogen as in the diaphragm cells. The main advantage of the mercury cells is that a purer product is obtained which can be used in the industry without further cleaning. The mercury cells are on the other hand more expensive than diaphragm cells and use more electric energy.

For the production of one ton of chlorine, 1,1 tons of caustic soda and 25,5 kg of hydrogen the following is needed, based on using diaphragm cells:

Salt	1,6	ton
Soda (Na_2CO_3 58%)	25,5	kg
Sulfuric acid (66° bé)	100	kg
Steam	10	tons (variable)
Electricity	2500-3000	kWh. (variable)
Cooling	0,9	tons
Labour	18	hours
Graphite	5	kg
Voltage per cell	4-4,5	volts

2. Electrolysis of molten salt

$$2\ NaCl \rightarrow 2Na + Cl_2$$

Cells available for use in this process are much fewer than in the former process using brine. The cells will be discussed in more detail in connection with the production of sodium metal.

From the electrolysis cells the chlorine gas is lead to a cleaning tower where entrained lye and salt are separated from it. If the chlorine is to be transported from a factory, it must be liquified by compression and cooling and put on tanks or steel barrels.

IV-1c USE

Chlorine is extensively used in various chemical industries. A list of a few of the main categories will suffice:

Production of dissolving liquids
Plastic and weaving materials
Pesticides
Paper industry
Cooling media and fuels
Disinfectants and health protection materials

In connection with a coordinated chemical production from seawater, a chlorine factory would primarily be established in connection with production of magnesium and bromine, where approximately half a ton of chlorine is needed for each ton of metal and three and a half tons of chlorine for each ton of bromine produced. Based on 16.000 tons of magnesium per year, 60.000 tons of salt and a corresponding amount of bromine, or approximately 1000 tons, 11.000-12.000 tons of chlorine per year would be needed or somewhat less than 35 tons per day.

Other domestic uses of chlorine would be extremely small, only approximately 40-50 tons per year, and therefore any production above the demand stated above would have to be exported. There are, however, various difficulties connected with the transport and handling of chlorine and strong rules govern its ocean transport and it is by no means certain whether transportation of large quantities would be economical.

IV-1d PRICE

The price of chlorine for the production contemplated here would of course have to be considerably lower than of imported chlorine, but should be easily obtainable as the gas would not have to be liquified or placed in tanks or barrels nor transported over long distances.

In the United States the price of chlorine in tanks is approximately $70 per ton or kr. 3000.- per ton.

The price of chlorine differs considerably among export countries and from one year to another. The following table shows imports and prices of chlorine by export countries in the last three years. As shown, last years fob. price of chlorine was kr. 6.250 per ton in England, but 30.200 kr/ton in the United States. The reason for this difference is not clear, but is most likely due to differences in purity and packing.

TABLE VI-1. IMPORTS AND PRICES OF CHLORINE 1963-1965

	Quantity tons	FOB-price kr/ton	CIF-price kr/ton
1963			
DENMARK	24,4	9.425	11.550
GR. BRITAIN	34,4	4,000	5.120
UNITED STATES	8,6	17.600	19.150
Total	67,4	7.700	8.900
1964			
DENMARK	35,0	7.175	8.430
UNITED STATES	12,3	31.500	38.200
Total	47,3	13.500	15.250
1965			
DENMARK	33,2	10.700	12.450
GR. BRITAIN	10,8	6.250	7.500
UNITED STATES	12,3	30,200	33.700
Total	46,4	15.800	17.950

IV-2 SODIUM METAL

IV-2a PRODUCTION FORM AND ORIGIN

Sodium is a silver white and very active metal. It is produced from salt by electrolysis of molten salt.

IV-2b PRODUCTION PROCESS

In the electrolysis of molten salt, a mixture of 33.2% salt and 66.8% calcium chloride is placed in the cells and heated above the melting point. The mixture melts at 600°C, but the melting point of pure salt is, on the other hand, 804°C. When the cells are energized by direct current, sodium metal is found at the cathode. By cooling the calcium chloride precipitates again and a 99.9% pure sodium metal is obtained.

The most common cells in use are based on a British invention (N20) and named after Downs, but differ somewhat in size and other details.

For the production of one ton of sodium metal and 1,5 ton of chlorine, the following is needed:

Electric energy 11.500 Kw h/ton of metal (including heat for melting the salt)
Voltage 5,7 - 6,0 volts
Calcium chloride 40 kg
Temperature 600°C
Life of anode 300-350 days.

It is to be noticed that the salt is melted by the conducting current through the cells and thus does not need outside heating.

A new type of cells for chlorine and sodium production has recently been tried, and seem to have great advantages (N14). These cells use molten lead instead of mercury and the sodium metal is later evaporated from the lead solution instead of being obtained by hydrolysis. The cells, which are named after Szechtman and are produced by Chlormetals Inc., can also be used for the production of other alkali metals, for example magnesium and potassium and could be of great advantage. The salt must be completely waterfree when electrolyzed, and the electrodes then last for a long time. Those cells have a comparatively larger production capacity than the Downs cells and require less space. The further development of these cells should be followed because of the importance it may have for us.

IV-2c USE

Sodium is used as a catalyst in the production of tetraethyl lead for use in gasoline. Also, it is used in considerable quantities in the production of soap and for the production of sodium bromide and sodium peroxide. Sodium has also been tried as a conducting material for high tension lines and was found to be good for that purpose, but appreciable amounts are as yet not used for this purpose.

IV-2d MARKET AND PRICE

The market for sodium metal has not grown fast during the last years. Yet the production in the United States increased by 11% in 1964 or up to 126.500 tons, compared to 115.000 tons in 1963. According to Chemical Week (N17), experiments are now being made with the use of sodium in electric conductors with good results. The magazine believes that this could lead to considerable increase in the use of sodium and states that a yearly increase of 15.000 tons would be a careful estimate.

It should be mentioned that from sodium metal most of the sodium compounds in use could be obtained and its production is therefore not only dependent on the sale of the metal itself.

The price of sodium has been steady and is now 17 cents per pound sold in large lots or 375 dollars per ton.

IV-3 CAUSTIC SODA

IV-3a PRODUCTION FORM AND METHODS

Sodium hydroxide or caustic soda is produced as a by-product during the production chlorine gas from brine. The method of electrolysis has been discussed earlier in connection with the production of chlorine (IV-1). It may be added, that the lye, which is obtained that way, is concentrated by evaporation, the salt separated by crystallization and the concentrated lye further evaporated or cooled in such a way that caustic soda is precipitated. The material is then flaked or coarsly ground, obtaining particles containing 73 to 99% NaOH, depending on the intended use.

IV-3b USE

Caustic soda is a basic chemical in various chemical industries, besides being used as a production aid without participating directly in the chemical reactions, as for example for changing the acidity of water, for cleaning, etc. A few industries using much of caustic soda are:

Rayon weaving
Oil refining
Paper industry
Weaving industry
Soap production
Metal production
Rubber production, etc.

IV-3c MARKET

Although caustic soda is in great demand, the demand for chlorine is greater and increases at a greater rate. There is, therefore, overproduction of caustic soda in most countries, and not much hope for export.

A few means are available to make use of the caustic soda, however. Firstly, it may be used for precipitation of magnesium hydroxide in magnesium production. The quantity, which could be used that way, is difficult to estimate, as experiments must be made. Caustic soda could presumably replace slaked lime to a certain extent for this purpose. There is also a small domestic market for caustic soda. Imports amount to somewhat more than 400 tons yearly, but the form is not known or its uses. It is not certain that it would be economical to produce a usable product for such a small market. Lastly, caustic soda could presumably be used as a raw material for soda production in this country.

IV-3d PRICE

The price of the caustic soda, which has been imported has on the average been approximately kr. 3.800 per ton fob. and approximately kr. 4.700 per ton cif. The price in the United States of a 76% caustic soda is $114.5 per ton or kr. 4.920 per ton.

IV-4 SODIUM PEROXIDE

Sodium peroxide is a light yellow hygroscopic powder which absorbes water from the atomsphere and becomes snow white. It is a good bleaching agent and used to bleach silk, wool, cotton and for various industrial purposes.

It is produced by burning sodium metal in a special oven at 300°C. Dry air is blown over the metal in the ovan and the purity of the material becomes approximately 95%. The product is packed and sold in steel or nickel barrels.

Production of sodium peroxide in this country would primarily be for export. Figures on use and international trade could not be obtained for this material. Nothing can be reported concerning that at this stage.

The price of sodium peroxide in the United States is listed at 20.5 - 21.5 c/lb or dollars 450-475 per ton.

IV-6 SODIUM HYPOCHLORITE

By mixing chlorine gas and caustic soda, sodium hypochlorite is obtained by the reaction $Cl_2+2NaOH \rightarrow NaCl+H_2O+NaOCl$. After concentration by evaporation the solution is cooled and the hypochlorite precipitates.

Sodium hypochlorite is used extensively as a desinfectant and for sanitary purposes, for example in swimming pools, water wells, sewage disposal units, also in the processing of milk and various food industries. It is also used as a bleaching agent in washing, in the linen and cotton industry, the paper industry and many others.

As the production is rather simple, the material could easily be produced on a small scale from left over chlorine and caustic soda from the magnesium production, but sales possibilities are uncertain and would have to be looked carefully into.

APPENDIX V. POTASSIUM CHLORIDE

V-1 PRODUCTION FORM AND ORIGIN

Potassium chloride is made from mined salt or brine. It is sold as fine crystals or powder, nearly colorless. In this country potassium chloride is used as a fertiliser on grassland and other cultivated land. Its grain size and sales form would have to be based on the means used in this country for the spreading of fertilizers. It is assumed that the K_2O content of the fertilizer is 50-60% and its price is based on that percentage. Imported potassium chloride contains 50% K_2O and is in the form of fine crystals.

V-2 PRODUCTION PROCESSES

The most common production process used is fractional crystallization of potassium chloride from sodium or magnesium chloride. The method is based on the differences in the solubility of these salts at different temperatures. Thus the solubility of the potassium chloride decreases rapidly with lower temperatures, but the solubility of sodium chloride increases at the same time. It has recently been shown (K14) that by dissolving ammonia in the brine the solubility of the sodium chloride is increased, but the solubility of the potassium chloride is decreased and the crystallization thus made considerably easier.

Otherwise the fractional crystallisation of the materials is a well known process and used all over the world.

V-3 USE

Market for potassium chloride is primarily based on its use as a fertilizer. Production of glass and soap are also to a certain degree based on the use of potassium chloride. In this country its production would primarily be based on its use as fertilizer.

V-4 MARKET

In recent years considerable amounts of potassium chloride have been imported as shown in Table V-1. During the last five years, approximately 5 thousand tons per year have been imported on the average and the imports have increased somewhat.

Potassium chloride is among the most important of international trade materials, its trade amounting to at least 2-3 million tons per year (see tables V-2 and V-3).

In Europe the largest export countries are Belgium, Luxemburg, France, Spain, Germany (East and West) and the Soviet Union. The Scandinavian countries, Polland and England import a total of two million tons yearly. Norway alone imports over one hundred thousand tons a year (1963). If it proved possible to produce an appreciable quantity of potassium chloride, there would be a large market to compete for.

V-5 PRICE BEHAVIOUR

The CIF price of imported potassium chloride has varied from 1510 up to 2075 kronur per ton in the last five years, with an average price of 1805 kr. per ton during that period. At the same time the FOB price in East-Germany has been 1210 and up to 1615 kr/ton and the average price 1400 kr/ton, according to Icelandic Trade Statistics.

TABLE V-1

IMPORTS AND PRICES OF POTASSIUM CHLORIDE DURING THE YEARS 1959-1965

Year	Imports tons	FOB price kr/ton	CIF price kr/ton
1959	1152.9 x	503	873
1960	3811.3 x	1170	1710
1961	3046.9 x	1512	2075
1962	5250.0 x	1370	1745
1963	4751.5	1210	1510
1964	5560.8	1340	1760
1965	6000.0	1615	1945

From Trade Statistics 1959-1965

x Including other potassium salts

TABLE V-3. INTERNATIONAL TRADE

EXPORTS OF POTASSIUM CHLORIDE

Export country	1958	1959	1960	1961	1962	1963	1964
BELGIUM-LUXEMBURG	714.323	701.031	736.860	795.950	770.045	768.648	701.649
FRANCE	795.688	800.778	1.094.430	1.228.067	1.028.713	1.082.522	1.187.890
W-GERMANY (fertilizer salts)	1.233.852	1.370.091	1.538.379	1.650.061	1.343.640	1.507.028	1.542.227
E-GERMANY (fertilizer salts K_2O)	970.000	1.025.000	1.075.000	1.030.000	1.129.000	1.142.664	1.199.000
SPAIN	260.495	298.861	354.176	288.349	225.113	253.374	305.150
UNITED STATES	414.969	471.348	698.323	644.614	717.856	593.113	821.407
SOVIET UNION (fertilizer salts)	388.400	431.800	619.000	749.000	863.800	976.530	742.300
TOTAL	4.777.727	5.098.909	6.173.168	6.535.841	6.078.167	6.323.879	6.499.623

From Statistical Summary of the Mineral Industry, London 1966.

TABLE V-3. INTERNATIONAL TRADE

IMPORTS OF POTASSIUM CHLORIDE

Import country	1958	1959	1960	1961	1962	1963	1964
GR. BRITAIN	581.713	610.400	711.972	683.156	666.464	680.088	660.597
CANADA (Unpurified)	117.236	85.089	130.969	151.587	132.119	66.137	59.855
CEYLON	35.080	42.596	39.054	47.483	38.516	60.560	47.879
INDIA	25.088	52.544	22.535	43.815	76.661	69.684	75.315
AUSTRALIA	48.756	38.044	31.573	45.109	65.214	47.472	84.864
NEW-ZEALAND	52.088	73.016	82.383	120.366	66.945	100.400	128.714
IRELAND	93.133	108.743	107.401	117.434	142.725	158.217	154.772
AUSTRIA	128	8.982	6.088	6.871	28.017	39.313	59.607
DENMARK	294.454	303.945	326.710	371.940	281.323	279.760	278.982
FINLAND (fertilizer salts)	76.454	102.769	170.500	125.175	127.210	128.797	133.249
HOLLAND	47.385	53.158	67.947	89.881	104.518	112.758	123.585
BELGIUM		1.153.374	1.165.642	1.269.205	1.158.088	1.108.101	1.257.902
NORWAY	54.822	77.770	75.760	76.164	81.004	100.407	111.246
POLAND (fertilizer salts)	663.900	769.900	808.900	791.200	missing	735.694	missing
PORTUGAL	11.763	13.888	9.818	14.068	13.890	21.348	21.975
SWEDEN	137.164	127.671	152.547	137.821	144.294	134.852	144.780
SWITZERLAND	15.936	21.230					
JUGOSLAVIA	72.050	10.224	27.749	35.226	13.367	19.080	17.000
UNITED STATES	266.379	290.433	298.433	296.343	407.650	788.153	1.067.604
BRASIL	90.320	89.048	166.491	109.374	104.082	144.184	108.759
JAPAN	578.215	671.237	903.292	917.080	691.305	984.106	976.434
TOTAL x	3.211.858	4.712.452	5.146.774	5.460.187	4.373.402	5.749.179	5.513.119

From Statistical Summary of the Mineral Industry, London 1965.

x Many other countries import fertilizer salts without itemization. Thus, these figures are not complete.

APPENDIX VI. POTASSIUM SALTS OTHER THAN CHLORIDE

VI-0 INTRODUCTION

Potassium compounds may be obtained from concentrated seawater or brine by other methods than evaporation and crystallization of potassium chloride. Several slightly soluble salts of potassium are known, which have been or could be used as a basis of a potassium production by precipitation. These methods have that in common, however, to be more or less in a experimental stage and would require quite extensive research work in this country before production could be based on them. Yet, the methods that seem promising should be looked at more closely and also the products obtained.

VI-1 PRECIPITATION OF POTASSIUM MAGNESIUM PHOSPHATE

Potassium may be precipitated from seawater as a magnesium potassium phosphate. This is a highly productive method if the seawater is concentrated five times. Up to 99% of the potassium in seawater can be caught this way, and the product is usable as a fertilizer.

The method is based on having concentrated seawater which is rich in magnesium. On the other hand, the hot spring water, which potassium production in this country would most likely be based on, has a low magnesium content and for that reason it is not likely that the precipitation would be successful. It may be mentioned that approximately 5.000 tons of phosphoreous fertilizer calculated as P_2O_5 are imported yearly to this country. If the potassium production were based on that amount of phosphoreous, only about 1400 tons of potassium per year would be needed, which is a much too small quantity for economic production.

VI-2 POTASSIUM SULFATE PRECIPITATION

Potassium sulfate forms a slightly soluble complex with calcium sulfate (gypsum). This fact could be utilized to obtain the potassium calcium sulfate complex in addition to magnesium, by the addition of sufficient quantity of slaked lime. Calcium chloride could also be added to the seawater causing a precipitation of calcium and potassium sulfate, but no magnesium. It has also proven advantageous to add gypsum to the brine causing a potassium salt to precipitate directly, if enough sulfate ions are present.

It must be remembered that the hot spring water, which the potassium production would most likely be based, has a low content of sulphate ions and it is not certain that the potassium salt would precipitate without the addition of such ions as for example sodium sulfate along with the gypsum (this would be a research project in this country).

After precipitation the potassium sulfate is separated from the calcium sulfate by dissolution in water and then crystallized from a nearly saturated solution.

Potassium sulfate is used as a fertilizer and imports to the country, amounting to approximately 2.500 tons per year. It may be pointed out that potassium sulfate and potassium chloride may usually be used interchangeably as fertilizer and one material could be used exclusively depending on conditions. The price of potassium sulfate from Belgium in 1964 was 2.530 kr/ton FOB and 3.050 kr/ton CIF.

VI-3 POTASSIUM CARBONATE PRECIPITATION

Potassium carbonate has been produced from potassium chloride solution by precipitating it as a double salt, potassium magnesium carbonate and then separating the potassium carbonate by hydrolysis. The magnesium carbonate is used again.

Experiments have indicated (K12) that it is best to use alkaline magnesium carbonate or socalled magnesia alba, which results in excellent efficiency of the potassium salt production and much better results than by the sulfate precipitation described above.

Magnesia alba can easily be produced from magnesium hydroxide obtainable from a magnesium factory and carbonisation by carbondioxide obtained by burning of lime, All the materials needed would be therefore most likely obtainable at the same place.

Potassium carbonate could be used as fertilizer, but is usually too expensive for such use. It might, however, become competitive in this country as a fertilizer, but possibilities for export are also present as potassium carbonate produced as above is more valuable than potassium salts from mines.

VI-4 DPA-PRECIPITATION, POTASSIUM NITRATE

It has been known for a long time that potassium forms very poorly dissolvable salts when combined with certain chelating agents such as DPA (dipicrylamine). Such materials have such a strong affinity for potassium that other chemicals as sodium and calcium do not precipitate at the same time, even if they are present in much higher concentrations. The precipitation takes place in an alkaline solution, but by acidifying the precipitate the potassium is separated and forms a salt with the acid used and the precipitating agent, in this case DPA, is recovered in its original form.

By using nitric acid for recovering the potassium precipitate, potassium nitrate is obtained, which is a fertilizer in high demand.

The limitations of this method are that the precipitating agent is very poisonous and the process would require close control. The DPA is also expensive and would have to be imported.

Attempts are being made to decrease the make-up requirements of the precipitating agent and that work should be carefully followed. It is also a limitation that the nitric acid would have to be brought to the plant, but it could possibly be obtained from the Fertilizer Plant, Inc., and a cooperation with that concern should be possible for this production.

APPENDIX VII. CHLORATES AND PERCHLORATES

VII-0 INTRODUCTION

Chlorates and perchlorates are a group of chemicals which can easily be produced in connection with the production of other chemicals from seawater. The main raw materials are solutions of sodium and potassium chloride, but the production method is based on electrolysis. The product is sodium or potassium chlorate or perchlorate and hydrogen is obtained as a by-product. As this is an energy consuming industry and considerable market seems to be available in nearby countries, it seems proper to discuss further some of the main points in the production and use of these chemicals.

VII-1 SODIUM CHLORATE

The most important chemical in this group and a basic chemical in the production of othere is sodium chlorate ($NaClO_3$). It is produced by the electrolysis of a saturated salt solution and the chemical reactions are rather complicated. The overall reaction is:

$$NaCl+3H_2O+(6Farad)\longrightarrow NaClO_3(aq)+3H2(g).$$

The solution ie acidified, calcium and magnesium removed and sodium dicromate (2 grams per liter) added in order to prevent side reactions and corrosion of the equipment. During the electrolysis chlorine and caustic soda are formed at the electrodes, but as no diaphragm separates the chlorine from the lye, hypochlorite is formed and later chlorate. The solution is thenconcentrated by evaporation to a concentration of 700 g/liter of sodium chlorate. Then it is filtered and cooled, causing the sodium chlorate to crystallize.

For one pound of chlorate the following is needed:

Salt	565	kg
Hydrochloric acid	13,5	kg
Sodium dicromate	0,5	kg
Barium chloride	6,5	kg
Carbonelectrodes	6-10	kg
Electricity for electrolysis	5.500-6.500	kw.

Steam	5,5	tons
Pumps and motors	85	hp.
Water ($25^\circ C$)	230.000	liters
Labour	8	hours
Temperature	$35-45^\circ C$	

The product is in the form of fine crystals, very hygroscopic and requires careful handling due to fire danger.

Sodium chlorate is widely used as a week disposal agent, but is also increasingly used in the production of chlorine dioxide ClO_2, which is bleaching agent extensively used in the paper industry. It may be mentioned that the Swedish and Finnish paper industry now uses sodium chlorate to a large degree and that its use is rapidly increasing.

In the United States it is estimated that the production for the year 1966 will be 160.000 tons (N16) and that 24-26% of that production is used in the paper industry, but 19-21% for weed disposal.

Improvements in the design of the electrolytic cells (N16) has decreased the consumption of the carbon electrodes and made utilization of hydrogen obtained in the electrolysis easier. The price of sodium chlorate in the United States has been approximately 6-9 c/lb or $130-200 per ton.

VII-2 SODIUM PERCHLORATE

By mixing a 60-70% solution of sodium chlorate with a strong solution of sodium chromate (5 grams/liter) and by applying a higher voltage than in the production of chlorate (6-7 volts instead of 2,8 - 3,6 volts) sodium perchlorate $NaClO_4$ may be obtained. The production method is basically the same as before. Considerably less energy is needed, however, or approximately 1,5 - 1,9 kwh/lb or 3.300-4.300 kwh/ton.

There is not much use for sodium perchlorate as such and it is in general only a step in the production of ammonium or potassium perchlorates, which are used in fireworks and explosives.

VII-8 POTASSIUM CHLORATE AND POTASSIUM PERCHLORATE

Potassium chlorate may be produced in the same way as sodium chlorate by electrolysis of a saturated potassium chloride solution. On the other hand, it is more easily produced by mixing potassium chloride and sodium chlorate in solution getting the reaction:

$$NaClO_3 + KCl \rightarrow KClO_3 + NaCl$$

Potassium chlorate is a slightly soluble compound and precipitates immediately as fine crystals and can easily be separated, cleaned and dried by common methods.

The main use of potassium chlorate is in match manufacture and as an ingredient of explosives. The production of potassium chlorate is considerably smaller than of sodium chlorate and the price somewhat higher or 12-14 c/lb (260-310 dollars per ton). Potassium perchlorate is produced by similar means from sodium perchlorate and potassium chloride. As previously mentioned, it is used in the manufacture of fireworks and its price is approximately 18.5 c/lb or 407 dollars per ton.

APPENDIX VIII. BROMINE

VIII-1 PRODUCTION FORM AND ORIGIN

Bromine is only produced from seawater or brine and sold as a heavy dark brown liquid. It is also sold as an ingredient in alkali compounds or organic compounds, for example as ethylene dibromide.

VIII-2 PRODUCTION METHOD

In recent times bromine has been primarily produced from seawater in the following way:

a) The seawater is acidified with sulfuric acid.

b) It is then chlorinated by chlorine gas or chlorine water.

c) Bromine is liberated by this treatment and blown out of the solution with a stream of air.

d) Bromine is mixed with sulfur dioxide (SO_2) and then sent through an absorption system where a water solution of bromic and sulfuric acids is formed.

e) By chlorinating this solution bromine gas is obtained which is condensed and collected for the use in the production of ethylene dibromide.

The method gives a 90% efficiency of bromine recovery and for the production of 1 ton of bromine the following are needed among other things:

Seawater	17.000 tons
Chlorine	3,5 tons
Sulfuric acid	2,06 tons
SO_2	412 kg

VIII-3 USE

By far the greatest part of bromine produced in the world is used in the production of ethylene dibromide, which is used as an antiknocking agent in gasoline engines. A smaller amount is used in salts of the alkali metals in the pharmaceutical and photographic industry, for the production of fire extinguishing materials, insecticides, dyes and other chemical processing.

VIII-4 MARKET AND PRODUCTION

The world production 1963 was somewhat more than 100.000 tons, of which the United States produced 90%. Approximately 8-10.000 tons were sold in the international market and the United States produce approximately half of that amount. The largest importers are the countries in Western-Europe, excluding France, which exports considerable amounts. Also, recently a large market has opened up in Africa (Malawi, Zambia, South-Rhodesia, Nigeria and the South-African Republic). According to the Minerals Yearbook 1964, the United States exported more than 1600 tons to those countries in 1964. It may be mentioned that concurrently a magnesium production of 16.000 tons, and a salt production of 60.000 tons, 800-1000 tons of bromine could be produced yearly.

VIII-5 PRICE BEHAVIOUR

The price of bromine in the United States has been rather steady, approximately 21,5 to 22,5 cents per pound for the impure material, or approximately 20.800 kr. per ton.

TABLE VIII-1. WORLD PRODUCTION OF BROMINE 1958-1964

Production country	1958 tons	1959 tons	1960 tons	1961 tons	1962 tons	1963 tons	1964 tons
FRANCE	1.610	1.710	2.010	1.830	missing	missing	missing
ITALY	560	715	1.285	1.515	"	"	"
UNITED STATES	80.000	88.600	79.500	82.000	86.600	92.100	103.000
ISRAEL	765	1.815	2.400	4.400	missing	missing	missing
JAPAN	1.465	1.575	1.950	2.770	2.885	2.780	2.880
TOTAL x	84.400	94.415	87.145	92.515	89.485	94.880	105.880

x A few countries such as Great Britain, Spain and Germany produce small amounts of bromine.

From Statistical Summary of the Mineral Industry, London 1966.

TABLE VIII-8. INTERNATIONAL TRADE

IMPORTS OF BROMINE 1958-1963

Import country	1958	1959	1960	1961	1962	1963	1964
GREAT BRITAIN							
bromide	305,0				missing	missing	
CANADA							
bromine	7,9	30,1	31,9	28,1	16,0	17,8	missing
bromide	36,1	29,9	30,5	48,2	35,3	45,4	"
INDIA	0,4	0,2	73,5	137,0	207,0	180,0	120,0
bromine							
BELGIUM-LUXEMBURG							
bromine	9,2	13,7	8,3	7,0	14,8	12,5	16,5
bromide	152,0	192,0	183,0	112,0	148,0	111,0	148,0
DENMARK							
bromine	missing	90,0	1,8	14,3	5,0	5,0	3,0
bromide	53,5	45,0	50,2	18,1	50,8	46,0	47,0
GERMANY							
bromide	68,0	40,8	11,4	10,4	missing	108,0	181,5
ITALY							
bromine	50,3	114,1	315,0	463,0	206,0	50,8	53,5
bromide	2,0	11,4	15,3	10,3	33,8	115,0	70,0
HOLLAND							
bromide	152,0	192,0	183,0	112,0	148,0	111,0	148,0
bromine						525,0	412,0
UNITED STATES							
bromine compounds	5,4	11,9	157,5	133,0	209,0	139,5	
ARGENTINE							
bromine compounds	113,0	68,5	87,5	93,5	129,0		
BRASIL							
bromine	0,5	3,0	1,1	0,7	1,1	0,1	
bromide	60,5	141,5	353,0	305,0	303,0	260,0	

Many other countries import small amounts of bromine or bromide. The bromides are mostly alkali bromides.

From Statistical Summary of the Mineral Industry, London 1965.

TABLE VIII- 3. INTERNATIONAL TRADE

EXPORTS OF BROMINE 1958-1963

EXPORT COUNTRY	1958	1959	1960	1961	1962	1963	1964
GREAT BRITAIN							
bromide	171,0	218,0	317,0	296,0	missing	missing	missing
BELGIUM-LUXEMBURG							
bromine	2,0						15,0
bromide	2,0	0,7	8,0	0,0	0,0	0,0	7,4
FRANCE							
bromine	157,5	403,0	592,0	409,0	382,0	764,0	960,0
bromide	660,0	863,0	1.040,0	627,5	825,0	786,0	945,0
GERMANY							
bromide	72,3	69,0	88,4	76,6	missing	59,4	80,5
ITALY							
bromine	-	-	27,1	-	0,2	-	97,8
bromide	1,5	1,7	0,2	1,1	5,9	7,2	
HOLLAND	362,0	402,0	missing	missing	missing	467,0	475,0
UNITED STATES							
bromine and bromine compounds	4.550,0	4.165,0	4.650,0	5.050,0	4.000,0	4.920,0	7.720,0
ISRAEL							
bromine	766,0	1.000,0	1.180,0	1.060,0	1.148,0	945,0	missing
JAPAN							
bromine	1,4	-	0,25	10,0	missing	missing	"
bromine compounds	20,0	15,0	14,2	12,6	94,5	126,0	177,0

The bromides are mostly alkalibromides.

From Statistical Summary of the Mineral Industry, London 1965.

APPENDIX IX, GYPSUM

IX-1 PRODUCTION FORM

Many kinds of gypsum are produced, for different uses. These types differ by the following:

a) Purity (sodium and magnesium salts are the main impurities)

b) Water content (unprocessed gypsum contains two molecules of water for each molecule of $CaSO_4$)

c) Added chemicals, which change its characteristics.

In this country the demand is greatest for unprocessed gypsum or gypsum, which contains crystal water.

IX-2 PRODUCTION PROCESSES

Gypsum is primarily mined and large mines of gypsum exist in many places. Sometimes it is obtained as a by-product in the production of other materials. In connection with a chemical production from seawater, gypsum might be obtained in three ways:

1) After $Mg(OH)_2$ has been precipitated by adding burned lime to the seawater, more lime or calcium chloride may be added to the leftover solution precipitating the gypsum.

2) Gypsum may also be precipitated by adding a large amount of calcium chloride ($CaCl_2$) solution to concentrated seawater, causing the calcium to precipitate with the sulfate ions in the seawater and form gypsum; this would be done before the magnesium hydroxide ($Mg(OH)_2$) is precipitated.

3) The third possibility is in the production of salt where gypsum is precipitated before the salt begins to crystallize.

IX-3 USE

Gypsum is primarily used to increase the setting time of Portland cement, but also as a plaster in the building industry. Furthermore, considerable quantities are used as fertilizer on cultivated land. In this country a cement factory is just about the only user of gypsum.

IX-4 MARKET

In connection with a factory producing magnesium or salt in this country, the production of gypsum would only be based on the domestic market. The State Cement Works imports considerable quantities every year and a small amount is used in the building industry. The enclosed table shows imports and prices of gypsum from 1959. The average yearly import of unprocessed gypsum to the cement factory has amounted to approximately 4.800 tons during the years 1959-1965 (see table IX-1).

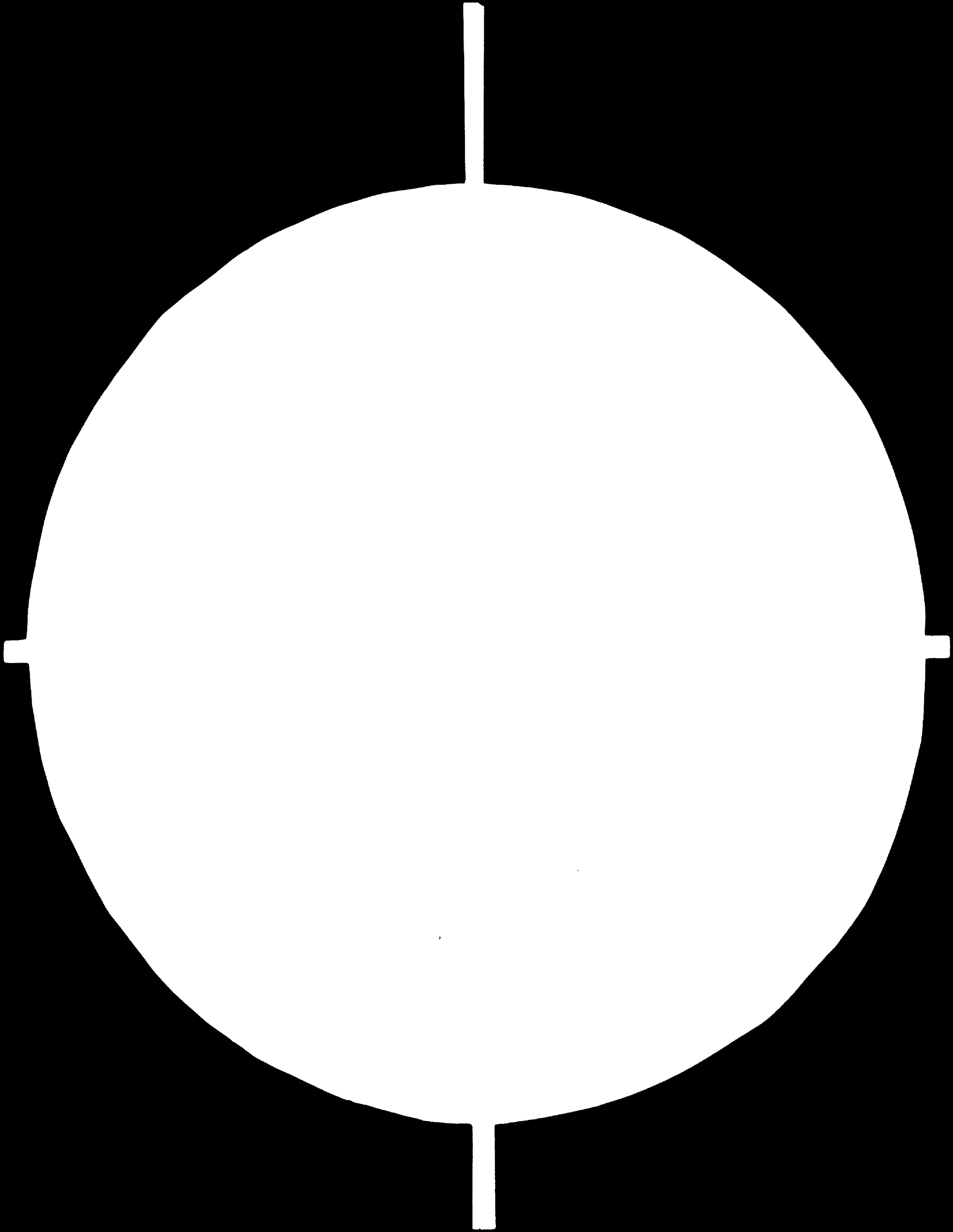
IX-5 PRICE BEHAVIOUR

Tremendous quantities of gypsum are produced in many places in the world and the price is low; being considerably lower than for salt, for example. There are only small variations in use and production and the price is therefore steady. During the last five years the FOB price has been from 126,50 up to 129,50 kronur per ton and in this country its price has been from 450 to 480 kr. per ton.

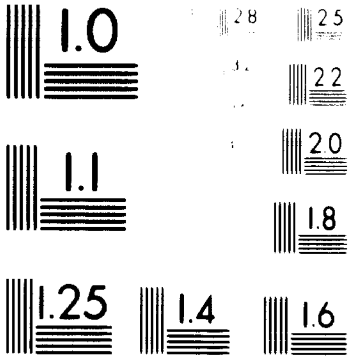
C-550

→

84.11.02
AD.86.07
ILL 5.5+10



2 OF 2



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

24x
F

TABLE IX-1. IMPORT OF GYPSUM TO ICELAND 1959-1965

Year	Imported tons	FOB-price kr/ton	CIF-price kr/ton
1959	5.575.3	54.6	210.0
1960	3.520.8	112.5	298.0
1961	5.252.2	128.5	450.0
1962	887.1	129.5	470.0
1963	4.573.0	126.5	480.0
1964	9.758.5	126.5	450.0
1965	4.150.0	126.5	450.0

From Trade Statistics 1959-1965.

APPENDIX X. CALCIUM CHLORIDE

X-1 PRODUCTION FORM

Calcium chloride is sold as a white, flaked or bagged chemical, which is approximately 77-80% pure. It is obtained as a by-product in the Solvay-soda process or from brine. The least possible magnesium impurities are desirable.

X-2 PRODUCTION PROCESS

The basic process in the production of calcium chloride is the evaporation of calcium rich brine. Usually the process is as follows. The magnesium hydroxide is precipitated first from the liquid by slaked lime. The liquid is then evaporated until sodium chloride precipitates. When the specific weight of the liquid has reached

42°Bé, just about all the salt has been precipitated. After filtration and purification, the solution is evaporated further in an open pan and when its solids content is approximately 75% it is cooled and solidified on a rotating cylinder, the flakes scraped off and ground.

In connection with production of chemicals from seawater in this country, it is possible to produce calcium chloride by two methods. The one is by evaporation of left over liquid from precipitation of magnesium hydroxide; salt would presumably be produced at the same time. The other method is by processing the calcium rich hot spring water on Reykjanes. Thus, by fractional crystallization of concentrated hot spring water, salt, potassium chloride and calcium chloride could be produced.

X-3 USE AND MARKET

Calcium chloride is extensively used for binding of dust and preventing ice formation on roads and that is the most likely use in this country. At the present time approximately 400 tons of the material are imported yearly and its use in the country still is at an experimental stage. If its use became appreciable, the market could increase greatly. It is figured that 4 tons are needed to bind the dust on each kilometer of dirt road. Calcium chloride is also used as a strengthening material in concrete and in cooling liquids, but such uses are on a small scale, however.

X-4 PRICE

The price of calcium chloride is rather steady at approximately 31 dollars per ton (1335 kr.) on the U.S. market. In Europe the price is slightly higher or approximately 1450 kr/ton and the price in this country of imported material is 2200 kr/ton. As steam is the largest factor in the production cost, it seems quite possible that the material could be produced economically here if it could be done in a coordinated chemical factory and if the market allowed.

APPENDIX XI. LIST OF REFERENCES ON CHEMICAL PROCESSING OF SEAWATER

XI-1 SODIUM COMPOUNDS

No.	Reference	Concerns
N 1	Dale W. Kaufmann; ACS Monograph 145 Sodium Chloride, Reinhold N.Y. (1960	Salt in general, properties, uses and production
N 2	Aikawa, M., KATO, Y.: Japan Patents 132, 465 to 132, 467 (1939)	Prod. of salt by evaporation of seawater, Na_2SO_4 precipitation
N 3	Nakao, et.al.: Japan Pat.2267 (1952)	Electrolysis of seawater for NaClO production
N 4	Kume, T.: Records Oceanog. Works Japan <u>12</u> 57 (1957	Electrolysis of seawater for NaOH prod. (Hg electrodes)
N 5	Wiseman, J.V.: U.S. Patent 2, 784, 056 (1957)	Prod. of $NaHCO_3$ and Na_2CO_3 from CO_2 and NaCl
N 6	Nakahara, S. et.al.; Japan Pat. 175, 044 (1958)	Na and Cl_2 by electrolysis
N 7	Takahara M. et.al.; Japan Pat. 5814 (1954)	Na and Cl_2 by electrolysis
N 8	Sconce, J.S.: ACS Monograph No. 154, Chlorine, Reinhold N.Y. (1962)	Prod. of Cl_2 and Na or NaOH by electrolysis
N 9	Yamamura, T., Nomiyama, Y.: Japan Patent 181, 089 (1949)	Magnesium bicarbonate gives $NaHCO_3$ by ionexchange
N 10	Tanaka, K. et.al.: Tokyo Kogyo Shikensho. Hokaku <u>51</u> 437 (1956)	Description of a plant for the prod. of NaOH and Cl_2 from sea
N 11	Nishida, K.: Kogyo Kagaku Zasshi <u>61</u>, 623 (1958)	Description of equipment for prod. of NaOH and Cl_2
N 12	Salutsky, M.L.-, W.R. Grace Co.: Research on Mineral By-products from Saline Water. OSW Res. & Dev. Prog. Report No. 137, (1965)	Na_2SO_4 from seawater; not much information
N 13	Gardiner, W.C.: Chem. Eng. Prog. <u>59</u> No. 4 [illegible] - 80 (1963)	New cell for $NaOH+Cl_2$ production
N 14	Sommers, H.A.: Chem. Eng. Prog. <u>61</u> No. 3 94 - 109 (1965)	Summary of Cl_2-alkali industry
N 15	Weisman, W.I.: Chem. Eng. Prog. <u>60</u> No. 11 (1961)	Na_2SO_4 from brine; summary
N 16	Chem. Week., May 28, 1966	$NaClO_3$, a new process and increased market in paper ind.
N 17	Chem. Week. Febr. 19 1966	Use of Na in batteries.

XI-1 SODIUM COMPOUNDS

No.	Reference	Concerns
N 18	Chem. Week, Jan. 15, 1966	Increase in use of NaOH 5% yearly
N 19	Chem. Week, June 9, 1966	Expansion and new development in Cl_2-alkali industry
N 20	Downs, J.C.: British Patent 238, 956 (1924)	Cells for Na production

XI-2 POTASSIUM COMPOUNDS

No.	Reference	Concerns
K 1	Otaya, M., Shibata, T., Myojo, M., Annual Rep., Shiongi Res. Lab. No. 2 116 (1952)	Crystallization and solution of carnallite
K 2	Gadre, G.T., Rab. A.V., Bhavnagary, H.M.: Sci. India Res. 17a 141 (1958)	Precipitation of potassium salt from a carnallite solution
K 3	Kjelland, J. et.al. German Patents 691,368(1940) 404,545; 715,199; 715, 200(1941); 726,545(1942); Norway Patents 77, 06[illegible] (1950); 77, 756(1950); 77,756(1950); U.S. Patent 2, 659, 656(1953)	Dipicrylamine precipitation " " "
K 4	Norsk Hydro; Brit.Pat. 605,694(1948)	"
K 5	O.S.W. Ann. Rept. 23 (1963)	"
K 6	Pluim, J., Sipres, H., Van Steedew, B.G.: U.S. Patent 2, 733, 986 (1956)	Crystallizer for DPA process
K 7	Kirk, R.E.: Othmer, D.F.: Encycl. Chem. Tech. Vol. 12 154-81. Interscience (1954-61)	Other precipitation methods and properties of precipitating agents
K 8	Murtell, A., Calvin, M.: Chemistry of Metal Chelate Compounds, Prentice Hall (1952)	"
K 9	Reid, J.C. Calvin, J. Am. Chem. Soc. 72 2988, 1950	"
K 10	Williams, R.J.: J. Chem.Soc.(1952)3770	"
K 11	Mellor, D.P., Maurey, L.: Nature 159 370 (1947) 161 436 (1948)	"
K 12	Januzzi, S.: Italian Patent 527, 422 (1955)	Na Bi SiO_3 precipitation
K 13	Sugi, J., Ohno, J.: Japan Patent 4514 (1951)	$CaClO_3$ precipitation and electrowinning
K 14	Gaska, R.A., Goodenough, R.D.: Chem. Eng.Prog. 61 No. 1 139-144 (1965)	NH_3 as a solvent for KCl and NaCl
K 15	Butt, J.B., Tallmadge, J.A., Sarage, M.R.: Chem.Eng. Progr. 60 No. 11 (1961)	Potassium recovery from seawater by DPA precipitation

XI-2 POTASSIUM COMPOUNDS

No.	Reference	Concerns
K 16	Salutsky, M.L. - W.R. Grace Co.: O.S.W. Res.Dev.Prog.Rept. No. 138 (1965)	Precipitation with a phosphate, $CaSO_4$, $MgCO_3$ and K_2SiF_6
K 17	Spealman, M.L.: Chem.Eng. 72 No. 23 198-200 (1965)	Production of Cl_2 and KNO_3
K 18	Garett, D.E.: Chem. Eng. Prog. 59 No. 10 59-64 (1963	Crystallization of potash
K 19	Chemical Week, July 24 (1965)	New KNO_3 process

XI- 3 MAGNESIUM COMPOUNDS

No.	Reference	Concerns
M 1	Dunset.,M.G., Salutski,M.L.: Ind.Eng. Chem. 56 No. 3, 56 (June 1963)	Precipitation with NH_3 and H_3PO_4 results in $MgNH_3PO_4$ complex
M 2	Shreve,R.N.: Chemical Process Ind. 2nd ed. p 224, McGraw-Hill (1955)	Dow Magnesium Process (good information)
M 3	Chem. Met. Eng. 48 No.11 130 (1941)	Flowsheet and description; precipitation with shells
M 4	Chem. Met. Eng. 54 No. 8 132 (1947)	"
M 5	Murphy,W.: Chem. Ind. 49 618 (1942)	Dow Magnesium Process
M 6	Schambra, W.P.: Trans. A.I. Ch.E. 41 35 (1945)	"
M 7	Manning,P.D.V.: Chem. Met. Eng. 45 478 (1938)	Magnesium Process
M 8	Gilpin,W.C., Heasman,N.: Refroctories J. 28 302 (1952)	Precipitation of dolomite and calcination of $Mg(OH)_2$
M 9	Spiro, N.S., T.R. Akad, Nauk, Ukr. SSR 38 70 (1940)	Problems in Mg precipitation
M 10	Spiro, N.S.; Tr. Vses. Nauchn. Issled, Inst. Galurgii 36 281 (1959)	"
M 11	Chesny, H.H.: Ind.Eng.Chem. 28, 383 (1936)	$Mg(OH)_2$ calcination
M 12	Forbath,T.P.: Chem. Eng. 65 No. 6 112 (1958)	"
M 13	Antonea,C.M.: Bol.Inform. Petrol. 25 No. 285, 11 (1948)	Summary of Mg and Br_2 production
M 14	Chemical Week, June 12 (1965)	Production behaviour of Mg metal until 1975
M 15	Salutsky, M.L.- W.R. Grace Co.: OSW Res. Dev. Prog. Rept.No.137(1965)	Precipitation of K-Mg complex with a phosphate
M 16	Havighorst, C.R.: Chem.Eng. 72 No. 16 84-86 (1965)	Kaiser MgO process; flowsheet
M 17	Weinberger,A.J., Delapp, D.F.: Chem. Eng. Prog. 60 No. 11 56-60 (1964)	Economic prospects of Mg-salt production from seawater
M 18	Chemical Week, Feb. 26 (1966)	Mg-Li and salt production in Utah.
M 19	" " Feb. 5 (1966)	Mg production in Utah and Oregon
M 20	" " Nov. 27 (1965)	Prospects of Mg markets and production
M 21	" " June 12 (1965)	"

XI-4 CALCIUM COMPOUNDS

No.	Reference	Concerns
Ca 1	Staab, W.A.: The Compass 24 5 (1946)	$CaCl_2$ from seawater by crystallization together with NaCl
Ca 2	Trauffer, W.E.: Pit and Quarry 30, 13 (1938)	$CaCl_2$ precipitation in connection with $Mg(OH)_2$
Ca 3	Span. Patent 220, 890 (1955) To Union Salinera S.A.	Multi-step evaporation for $CaSO_4$ production
Ca 4	Office of Saline Water, Res. Dev.	$Mg-NH_3-Ca_2PO_4$ precipitation

XI-5 CHLORINE

NO.	Reference	Concerns
Cl 1	Sconce, J.S.: ACS Monograph No. 154 Reinhold N.Y. (1962)	Chlorine in general
Cl 2	Nakahara, S, Sueta, H., Yamamura T.: Japan, Patent 175, 044 (1958)	Electrolysis and ionexchange in seawater for Cl_2 prod.
Cl 3	Takahara M, Adki, H.: Japan Patent 5814 (1954)	pH control with NaOH together with electrolysis
Cl 4	Kirk, R.E., Othmer, D.F.: Encyclopedia of Chemical Technology, Interscience, New York (1954-61)	Chlorine from brine in general
Cl 5	Shreve, R.N.: The Chemical Process Industries, 2nd ed. McGraw-Hill, N.Y. (1955)	"
Cl 6	Spealman, M.L.: Chem. Eng. 72 No. 23 198-200 (1965)	Process for production of Cl_2 and KNO_3
Cl 7	Gardiner, W.C.: Chem. Eng. Prog. 59 No. 4, 77-80 (1963)	A new cell for Cl_2 prod.
Cl 8	Sommers, H.A. Chem. Eng. Prog. 61 No. 3 94-109 (1965)	Summary on Cl_2-alkali industry
Cl 9	Chemical Week, Jan. 15, 1966	Increase in Cl_2 demand 7-10% yearly. 10 mill. tons (1970) (list of users)
Cl 10	" " July 31, 1965	Cl_2 and NaOH demand
Cl 11	" " June 4, 1966	Growth in Cl_2-NaOH industry

XI- 6 BROMINE

No.	Reference	Concerns
Br 1	Shreve, R.N.: Process Ind.; McGraw-Hill New York, (1955)	Production processes of Bromine
Br 2	Stewart, L.C.: Ind. Eng. Chem. 26 361 (1934)	Bromine production
Br 3	Grebe, J.J., Boundy, R.H.J., Chamberlain, L.C.; U.S. Patent 1, 917, 762 (1933)	Bromine with Cl_2 oxidation; absorption with SO_2+H_2O
Br 4	Robertson, G.R.: Ind. Eng. Chem. 34 133 (1943)	Bromine driven out with steam
Br 5	Greabe, J.J. et al: U.S. Pat. 1, 917, 762 U.S. Pat. 1, 885, 255 Can. Pat. 334, 742	Absorption of Br_2 on activated carbon
Br 6	German, F.F.: Khim, Prom. (1956) p. 171 CA 50. 160. 53 f	Use of chlorinewater instead of Cl_2 to prevent Mg precip.
Br 7	Chamagne, G.: Genie Civil 120 221 (1943)	Dow Bromine process
Br 8	Stewart, L.D.: Trans. Can. Inst. Mining Met. 41 443 (1938)	" " "
Br 9	Ind. Eng. Chem. Sup. 27A (1947)	" " "
Br 10	Hart, P.: Chem. Eng. 54, 102 (1947)	Problems solved
Br 11	Stewart, L.C.: Chem. Ind. 41 15(1937)	Br_2 production
Br 12	Seaton, M.Y.: Trans. Am. Inst. Mining Met. Eng. 18 11 (1942)	Br_2 production
Br 13	Chemical Week, Jan. 29 (1966)	Increase of Bromine market

XI-7 IODINE

No.	Reference	Concerns
I 1	Dyson, G.M.: Chem. Age. 22 362 (1930)	Iodine from sea-weed
I 2	Sawyer, F.G., Ohman, F.G., Lush, F.R.: Ind. Eng. Chem. 41 1547 (1949)	Iodine production from brine
I 3	Russian and Japanese Patent. See Butt and Talmandge Rev.	

XI-8 BORON

No.	Reference	Concerns
B 1	Nanamura, S., Suzuki, K.: Japan Patent 174, 696 (1947)	Solvent extraction with alcohol
B 2	Tadenuma, H.: Japan Patent 6661 (1955)	Boron removal
B 3	Lyman, R.W., Preuss, A.F.: U.S. Patent 2, 813, 838 (1957)	" "
B 4	Murphy, N.F., Tinsley, R.S., Meenaghan, G.F.: Bull. Virginia Poly. Inst. Eng. Expt. Sta. 115 Feb. (1957)	Electrolysis of boron salts
B 5	Bixler, G.H., Sawyer, D.L.: 322-333 Ind. Eng. Chem. 49 No.3 (1957)	Boron compounds from brine (Searles Lake)
B 6	Havighorst, C.R.: Chem. Eng. 70 No. 23 228-232 (1963)	Borate separation at Searles Lake
B 7	Gustafsson, H., Kominek, U.S. Patent 6661 (1955)	Boron removal

XI-G MIXED SALTS

No.	Reference	Concerns
S 1	Galimbert, L.: French Pat. 739, 394 (1932)	Evaporation
S 2	Un.Sal. d'Esp. S.A. Span: Patent 22, 089 (1955) or 220, 899	Triple-evaporation and production of chlorine
S 3	Clarke, R.E.: U.S. Patent 2, 793, 099 (1957)	Multi-effect evaporation
S 4	Transworth, W.M., Martin, C.H.: U.S. Patent 2, 191 561 (1940)	" "
S 5	Sekiguchi, S.: Japan Pat. 7175(1954)	Flash evaporation
S 6	Lee, J.A.: Food Eng. 27 90 (1955)	Salt precipitation and calcination
S 7	Gadre, G.T.: J.Sci. Ind. Res. 13B 46 (1954), 12B 171 (1953)	Dissolution of phosphate rock in seawater
S 8	Ishizaka, S., Iwata, S.: Japan Patent 1861 and 3769 (1958)	Production of ammonium potassium and sodium fertilizer
S 9	O.S.W. Rept. Spec. Rept. PB.181406	" "
S 10	Tanaka, Et.Al. Tokyo Kogyo Shikensho Hokaku 31 437 (1936)	Description of a pilot plant for production of NaOH and Cl_2 from seawater
S 11	Garret, D.E.: Chem.Eng.Prog. 59 No. 10 59-64 (1963)	Crystallization of potash and salts from seawater

XI-10 UNIT OPERATIONS

No.	Reference	Concerns
U 1	Kirk, R.E., Othmer, D.F.: Encyclopedia of Chemical Technology, Interscience, N.Y.	General description of unit operations and processes
U 2	Perry, J.H. ed.: Chemical Engineers Handbook 4 ed.: McGraw-Hill, New York (1964)	Unit operations in general
U 3	Treybal, R.E.: Mass Transfer Operations Mc-Graw-Hill (1955)	" "
U 4	Gillman, J.L. Jr.: Chem. Eng. Progr. 53 68 (1957)	Summary on salt production
U 5	Gardner, W.A.: Mar.Engng. 62 No. 4, 78 - 80 (1957)	Flash evaporators
U 6	Frankel, A.: Inst. Mech. Eng. Proc. 174 No. 7 312-324 (1960)	" "
U 7	Smith, W.: Chem. Proc. Eng. 42 391-394 (1941)	Flash evaporation plants
U 8	Steiner, W.: Chem. Proc. Eng. 42 395-401	Basic principles of flash evaporation
U 9	Meibovic, K.N.; Chem. Eng. Prog. 54 No. 3, 71-74 (1958)	Multi-effect evaporation calculations
U 10	Clark, R.L., Bromley L.A.: Chem. Eng. Prog. 57 No. 1 64-70 (1961)	Multiple effect rotating evaporators
U 11	Cuccione, E.: Chem. Eng. 69 No. 24 102 (1962)	Flowsheet of multi-effect flash evaporators
U 12	Saline Water Conv. Plant. No. 1 Freeport Texas, Third Ann. Rept. Sal. Water Conv. Prog. Rept. No. 123 (1964)	Information on LTV water plant
U 13	Clerk, J.: Chem. Eng. 72 No. 1 100 (1965)	Comparison of water, air and seawater cooling
U 14	Gardiner, W.C.: Chem. Eng. Prog. 59 No. 4 77-80 (1963)	A new Hg cell for Cl_2-NaOH production
U 15	Heinemann, G.: Chem. Eng. 70 No. 12, 188-190 (1963)	Use of seawater as a cooling medium
U 16	Baker, R.A. Jr.: Chem. Eng. Prog. 59 80-83 (1963)	Flash evaporator for evaporation of seawater
U 17	Standford, F.C. Jr.: Chem. Eng. 70 No. 35 158-176 (1963)	Summary on evaporation

XI-11 PROCESSES

No.	Reference	Concerns
F 1	Kirk, R.E., Othmer, D.F.: Encyclopedia of Chem. Tech., Interscience, N.Y.	Processes in general
F 2	Perry, J.H. (ed):Chemical Engineers, Handbook 4. ed., McGraw-Hill, New York (1964)	Unit operations and processes in general
F 3	Shreve, R.N.: The Chemical Process Industries McGraw-Hill N.Y., (1956)	Processes in general
F 4	Gillman, J.L. Jr.: Chem. Eng. Progr. 53 68 (1957)	Summary on salt production
F 5	Tanaka, K., Nishida, N., etal.: Tokyo Kogyo Shikensho Hokoku 51, 437 (1936)	Electrolysis of seawater for $NaOH+Cl_2$ production; description of pilot plant
F 6	Nishid, K.: Kogyo Kagaku Zasshi 61 623 (1958)	Description of equipment in a pilot plant
F 7	Salinewater Conversion Plant No. 1 Free Port Texas, Third Annual Report. Saline Water Conversion Prog. Rept. No. 123	Information on LTV plant
F 8	Badger W.L. and Ass.: Operation of Pilot Plant LTV Evaporator at Wrights Wille Beach, N.C.: O.S.W. Res. Dev. Prog. Rept. No. 26	" "
F 9	A New Process for the Production of Fresh Water from the Sea. O.S.W. Res. Dev. Prog. Rept. No. 47(1961)	New desalination process
F 10	Mantell, C.L.: Electrochemical Engineering 4th ed, McGraw-Hill, N.Y. 1960	Electrochemical processes

XI-13 SCALE CONTROL

No.	Reference	Concerns
R 1	Dunseth, M.G., Salutsky, M.L., Ind. Eng. Chem. 56 No. 56-61(1964)	Scaling and precipitation
R 2	Badger, W.L., Banchero, J.T.: Proc. Symp. Wash. Natl. Acad. Sci., Natl. Res. Council Publ. No. 568 (1957)	Studies of scaling prevention
R 3	Badger, W.L.: OSW Washington D.C. Prog. Rept. No. 25	Summary on scale control
R 4	Standiford, F.C., Sinek, J.R.: Chem. Eng. Prog. 57 No. 1, 58-63	Scaling prevention in seawater evaporation
R 5	Herbert, L.S., Sterns, U.S.: Adv. Chem. Ser. No. 38 52-64 (1963)	Scaling in flash evaporators
R 6	Fitzpatrick, W.: Power 99 No. 2 P. 106-108	Scaling and scaling prevention
R 7	Fink, F.W. Advances in Chem. Ser. No. 27 P. 27 (1960)	" "
R 8	Mulford, S.F.: Scale Control in Seawater Evaporators - Point Loma I; OSW, Sal. Water Conv. Rept. No. 133	
R 9	Louis, E.M.: Chem. Eng. 69 No. 5 103 (1963)	Cleaning by chemical methods

XI-13 CORROSION

No.	Reference	Concerns
T 1	Fink, F.W.; Adv. Chem. Ser. No. 27 P. 27 (1960)	Corrosion of metals in seawater
T 2	Fink, F.W.: Reprinted Battelle Tech. Rev. 5-8 (1963)	"
T 3	Fink, W.F.: Batelle Mem. Inst. Corrosion of Metals in seawater O.S.W. Res. Dev. Prog. Rept. No.46 (1960)	"
T 4	Moore, R.E.: Chem. Eng. 70 No. 20 124 (1963)	Construction materials for salt plants
T 5	Ibid 70 No. 21 224 (1963)	

XI-14 GENERAL

No.	Reference	Concerns
A 1	Tallmadge, J.A., Butt, J.B., Solomon, H.J.: Ind. Eng. Chem. 56 No. 7 44 - 65 (1964)	Litterature survey on production of chemicals from seawater
A 2	Schamus, J.J. et. al. Office of Saline Water, Research and Dev. Prog. Report No. 146, Sept. 1965: Bibliography of Saline Water Conversion Literature	Literature survey on production of freshwater from seawater and brine
A 3	Oil Paint and Drug Reporter, HI-LO Chemical Price Issue, 1960	Prices of chemicals on the U.S. market
A 4	Statistical Summary of the Mineral Industry, World Production, Exports and Imports 1958-1964, London 1966	World production imports and exports of sundry materials
A 5	Minerals Yearbook 1964 Bureau of Mines U.S. Dept. of the Interior, 1966	"
A 6	Ellis, C.B.: Fresh Water from the Ocean. The Ronald Press Co. N.Y. 1954	
A 7	Armstrong, E.F., Miall, L.M. Raw Materials from the Sea. Chemical Publishing Co. Inc. N.Y. 1946	

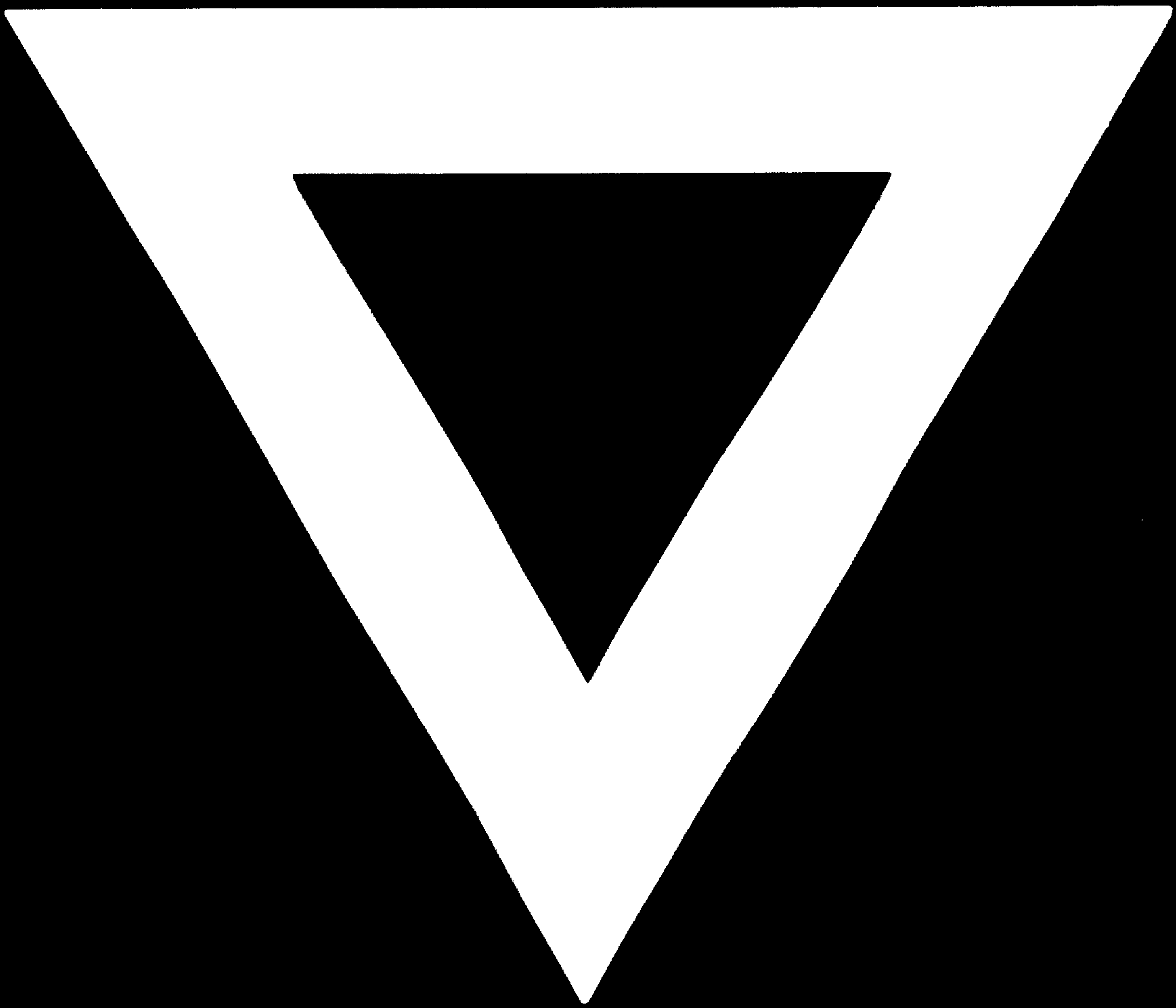
XI-15 REPORTS ON PRODUCTION FROM SEAWATER IN ICELAND

No.	Reference	Concerns
I 1	Baldur Líndal, Ísleifur Jónsson, Jóhann Jakobsson og Unnsteinn Stefánsson: On saltiness of the sea at S-W coast of Iceland. Journal of the Icelandic Engineering Society No 1-2 (1960) Vol. 45	
I 2	Baldur Líndal: On processes, energy requirements and location of a plant for production of salt from seawater The State Electricity Authority, Dept. of Geothermal Drilling, 1954	
I 3	Baldur Líndal: Seawater Chemical Plant. The State Electr. Authority, Dept. of Geothermal Drilling, 1955	General considerations on a seawater chemical plant
I 4	Baldur Líndal and Ísleifur Jónsson: Chemicals from the sea and the salt market. The State Electr. Authority, Dept. of Natural Heat, 1958	
I 5	Extraction of Salt from Seawater. Prepared for the Government of Iceland by the Mantistee Engineering Associates, 1960	Salt Factory in Iceland
I 6	Patel, M.S.: Report on the possibility of Production of Salt in Iceland. The State Electricity Authority, Dept. of Natural Heat, 1959	"
I 7	Baldur Líndal: The Extraction of Salt from Seawater by Multiple Effect Evaporators using Natural Steam, U.N. Conference on new sources of Energy. Sept. 1961	

APPENDIX XII. A LIST OF CHEMICAL PUBLICATIONS AND SUBSCRIBERS IN THIS COUNTRY

Industrial and Engineering Chemistry, (U.S.A.)	University Research Institute (1943-1962)
Chemistry, (U.S.A.)	The Fertilizer Plant, Inc., (1952-)
Chemical Engineering, (U.S.A.)	University Research Institute, (1945-)
	Baldur Líndal (1961-)
	The Fertilizer Plant, Inc., (1952-)
Chemical Engineering Progress (U.S.A.)	The Fertilizer Plant, Inc., (1952-)
	State Electricity Authority (1961-)
British Chemical Engineering (England)	Baldur Líndal Sig. V. Hallsson (1957-)
Transactions of the Institution of Chemical Engineers (England)	Sig. V. Hallsson (1957-)
Chemical Week (U.S.A.)	Baldur Líndal (1965-)

C-550



84.11.02

AD.86.07

ILL 5.5+10