PRODUCTION OF FUELS IN ICELAND

Study Group on Hydrogen and Hydrogen Derived Fuels

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ABSTRACT
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Since early 1979 a study group, appointed by the General Director of
the National Energy Authority (NEA), has examined the possibilities of
producing synthetic fuels in Iceland. The report of the study group
deals mainly with technical aspects of electrolytic hydrogen and other
fuels (methanol and synthetic gasoline), which can be produced from
hydrogen and imported coal. The study group has reached the conclusion
that hydrogen will hardly be used as a fuel in Iceland during the
remainder of this century. Still, an estimate of the production cost of
electrolytic hydrogen for use in the production of other fuels was worked
out. The study group's examinination of methanol as a fuel show,that it
is unlikely to be used as such in the coming years for technical and
economic reasons. On the other hand a process exists which converts
methanol into synthetic gasoline at a small cost. The study group did
a preliminary feasibility study for the production of syntehtic
gasoline from methanol, which would be made from electrolytic hydrogen
and imported coal. For comparison it was estimated what it would cost
to produce gasoline entirely form coal. Both these studies refer to
the production of 110.000 tonnes/year of gasoline. With present technology
and likely prices of electricity and imported coal it seems clear that
electrolytic hydrogen is still too expensive for it to compete with coal
in the production of fuels. As coal prices rise and methods for electrolysis
are improved, in the next few years, the use of electrolytic hydrogen might
become more feasible. The study group's studies show that it costs
507-622 $/tonne (US$ in January 1979) to produce synthetic gasoline from
electrolytic hydrogen and coal but 390-513 $/tonne from imported coal only.
The study group recommends that progress in the technology of electrolysis
and production of synthetic fuels be watched. Cooperation with nations
considering synthetic fuels production should be enhanced. Other energy
utilization alternatives should be evaluated to enable their comparison
with domestic fuel production. Icelandic peat resources should be
investigated more fully. The NEA should coordinate further investigations
of domestic fuel production.

LIST OF CONTENTS
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LIST OF TABLES

LIST OF FIGURES

UNITS AND SYMBOLS
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Prefixes:

$m = 10^{-3}$ (milli-)

$k = 10^{3}$ (kilo-)

$M = 10^{6}$ (mega-)

$G = 10^{9}$ (giga-)

$T = 10^{12}$ (tera-)

Units:

J = joule (energy)

W = watt (power)

h = hour (time)

g = gram (mass)

m = meter (length)

V = volt (voltage)

GJ = energy unit (= 278 kWh)

m\$ = millidollar (= 0.001 \$)

\$/GJ = energy price (= 3.48 m\$/kWh)

m\$/kWh = energy price (= 0.278 \$/GJ)

$Nm^{3}H_{2}$ = normal (standard) volume of hydrogen

MJ/kg = heating value

kg/m^{3} = specific mass

M\$ = megadollar (= a million dollars)

1   INTRODUCTION

At the turn of 1978/1979 the General Director of the National Energy
Authority (NEA) appointed a study group to write a report on hydrogen
and hydrogen derived compounds. Appointed to the group were representa-
tives from the NEA, the State Fertilizer Plant and the Science Instit-
ute of the University of Iceland, they are:

> Dr. Bragi Árnason, chemist
>
> Gunnlaugur Jónsson, physicist and economist
>
> Dr. Jón Steinar Gudmundsson, engineer (chairman)
>
> Runólfur Thórdarson, engineer

The study group was commissioned to draft a report based on the most
recent available information about the possibility of using hydrogen
and hydrogen compounds, other than hydrocarbons, as fuels in the
Icelandic energy sector in the future. With the report an attempt
should be made to evaluate as realistically as the present state of
knowledge allowed the technical and economic prerequisites for this
kind of hydrogen utilization and their development until the end of
this century. The report should amongst other things deal with each
of the following issues separately:

1.   The present state and likely development of the fuel market.

2.   The present state and likely development of methods to store
      hydrogen as a gas or liquid or in metal hydrides for use in
      vehicles on land, sea or in the air.

3.   The present state and likely development of means for hydrogen
      storage in tanks and large scale hydrogen transport on sea.

4.   The present state and likely development of engines which burn
      hydrogen as a fuel both in vehicles and in industry.

5.   The present state and likely development of electrolytic
      hydrogen production processes.

6.   The present state and likely development of thermochemical
      processes to produce hydrogen at temperatures which permit
      the use of geothermal energy.

The study group gathered information on hydrogen and hydrogen compounds in various ways. Information (1) from an international conference on hydrogen, which Bragi Árnason and Runólfur Thórdarson attended during the summer of 1978, was already available. It was after this conference that Bragi Árnason wrote a report (2) in which he discusses the possibility of substituting hydrogen or methanol for todays fuels in Iceland. Various journals and books on hydrogen and other fuels could also be found in Icelandic libraries. The study group examined carefully articles that appeared during the year and many research institutes and private companies in the United States, Great Britain, New Zealand and Sweden were contacted for further information.

In March/April 1979 Jón Steinar Gudmundsson had the opportunity to visit some companies and institutions involved in hydrogen and fuel matters in Great Britain to gather information concerning the state of these matters in the countries of the European Economic Community (EEC) and in European countries in general. A short report (3) of the visit and the information collected was prepared. In late April 1979 Svensk Metanolutveckling AB held a meeting to discuss Nordic cooperation in the field of new fuels. Jón Steinar Gudmundsson was the representative of the NEA at this meeting while Finnbogi Jónsson attended on behalf of the Ministry of Industry.

In May/June Bragi Árnason and Jóhann Már Maríusson of the National Power Company were invited to the United States by the Independence Foundation/ Eisenhower Exchange Fellowships Inc. amongst other things to acquaint themselves with the production of synthetic fuels. They visited many firms and research institutions and collected numerous articles on hydrogen and fuel matters. An account (4) of the chief results of the visit was drafted. Then in August 1979 Jón Steinar Gudmundsson (on behalf of the NEA) and Runólfur Thórdarson (on behalf of the State Fertilizer Plant) went to the United States to study newly developed electrolysis techniques and other matters concerning the task of the study group. Two oil companies, an electrolysis company and a research institution were visited. A report (5) on the trip was written.

The study group was originally commissioned to write a report on "hydrogen and hydrogen compounds, other than hydrocarbons". Methanol is generally considered a hydrogen compound while gasoline is a hydrocarbon. When the group began its work its members deemed it appropriate to expand the

scope of the report and include synthetic gasoline. This was done with the knowledge of the General Director of the NEA.

In the beginning the group put greatest emphasis on the various aspects of hydrogen production while later on the attention turned more towards the production of synthetic gasoline. Runólfur Thórdarson worked out the plan for hydrogen production in Iceland which here appears as chapter 4. On the other hand Bragi Árnason wrote the groups report entitled "Hydrogen and Hydrogen Compounds" (6) which among other things treats in detail the present state and plausible development of methods to produce, store, distribute and burn hydrogen as a fuel. The members of the study group feel that a realistic appraisal of hydrogen as a future energy carrier in Iceland has been made in accordance with its letter of commission. Less has been accomplished regarding hydrogen compounds like methanol and synthetic gasoline, since the scope of that issue is far too great for the study group to handle with any sort of completeness.

This is the study group's report to the General Director of the NEA and it mainly deals with todays knowledge and present technology. In other reports (3,4,5,6) from the group the most relevant technological developments are treated and ideas about future synthetic fuel production in Iceland are discussed.

Around midyear 1979 the Minister of Industry appointed a committee (the Synthetic Fuels Committee) to work out recommendations for a research plan for the possible production of fuels in Iceland. Two members of the study group, Bragi Árnason and Jón Steinar Gudmundsson, are also members of the Synthetic Fuels Committee and hence close cooperation and information flow has existed between the two groups. Drafts of this report were circulated along with other material among members of the Synthetic Fuels Committee etc. In March 1980 Thorsteinn Ólafsson, chairman of the Synthetic Fuels Committee, and Jón Steinar Gudmundsson visited the United States for discussions with consultant firms regarding the committee's research plan.

2   THE FUEL MARKET

It has been estimated that harnessable hydroelectric energy in Iceland
amounts to 35 TWh/year. However, the boundary between harnessable and
nonharnessable hydroelectric energy is dependent on the building cost
of hydroelectric power plants and energy prices at each time. It is
therefore likely that the above estimate will increase with rising
energy prices. Much less is known about harnessable geothermal energy.
In recent years it has, however, been stated that all the high temperature
geothermal fields combined could possibly yield as much electricity as the
rivers. Because of the uncertainty in the estimates of harnessable
hydroelectrice and geothermal energy the NEA is revaluating the country's
energy sources, and already some signs indicate that the 35TWh/year
estimate of harnessable hydroelectric energy is too low.

In 1978 2674 GWh of electricity were generated,less than 5% of the
harnessable energy from the waterfalls and high temperature areas.
2605 GWh (97.4%) of electricity were generated in hydroelectric power
plants, while 18 GWh (0.7%) were generated in power plants using geothermal
steam. The remaining 50 GWh (1.9%) were generated in electric power plants
burning oil. At the same time the total utilization of geothermal energy
amounted to 3600 GWh. 2400 GWh (2/3 of the total) were used for district
heating and 1200 GWh for other purposes such as electricity generation.
In 1978 603.000 tonnes of imported fuels were sold in Iceland. Table 2.1
shows the use of the various fuels in recent years. The total sale of
oil products in 1978 is equivalent to 7250 GWh using the lower heating values of
the various fuels. In 1978 when the total energy used was 13.455 GWh of heat
and electricity, 53.9% came from various fuels, 26.8% from geothermal
areas and 19.4% were hydroelectric. More than half the energy used in
the country is therefore imported. Of the 603.000 tonnes of fuels sold
in 1978, distillate fuel was 51.1%, gasoline 26.8% and residual fuel
oil 22.1%. The fishing fleet is the largest single fuel consumer in
Iceland and its use is a quarter of the total.

A forecast [8] of the domestic fuel demand until the year 2000 has been
drafted. Table 2.2 shows the use of fuels in 1977,predicted demand in
1980, 1985, 1990, 1995 and 2000. The main results of the forecast are
that the total demand will increase by 5% from 1977 till 1980 but after

that basically ramain constant for the rest of the period till the end
of the century. During this period the total demand for fuels will
therefore be approximately 600.000 tonnes each year. It is worth
noting that according to an electricity forecast [9] the demand for
electricity will double till the year 2000.

Lately, oil prices have risen sharply and future price increases are
to be expected. Figure 2.1 shows how oil prices have changed on the
Rotterdam market for the past three years. The price of most of the
imported fuel is determined by oil price developments on the Rotterdam
market. According to commercial statistics the import value of oil
products accounted for 10-12% of the country's total import until
recently (e.g. 11.7% in 1977 and 10.9% in 1978). But a drastic change
has occurred. As can be seen from figure 2.1 the Rotterdam prices
increased tremendously in 1979. That year the imported oil products
cost a total of 53.9 billion Icelandic krónur which was 18.5% of the
total cost of all import, the increase from the precious year being 70%.
These price increases have put severe pressure on the national economy
and at the same time stimulated considerable interest in domestic fuel
production.

TABLE 2.1

Sales of imported fuels 1972-1978

Fuel	1972 k tonne	1973 k tonne	1974 k tonne	1975 k tonne	1976 k tonne	1977 k tonne	1978 k tonne
Gasoline	64,4	71.4	76,4	77,7	78,8	86,7	90,8
Aviation Gasoline	2,2	2,7	2,4	2,2	2,1	2,2	2,3
Domestic Comp.	1,7	1,7	1,6	1,6	1,5	1,6	1,5
Foreign Comp.	0,5	1,0	0,8	0,6	0,6	0,6	0,8
Jet Fuel	79,2	76,7	70,9	62,9	60,4	65,8	67,2
Domestic Comp.	50,1	56,5	53,2	49,1	46,0	48,7	53,0
Foreign Comp.	29,1	20,2	17,7	13,8	14,4	17,1	14,2
Kerosine	1,3	1,8	1,6	1,7	1,8	1,7	1,5
Distillate Fuel	303,0	332,3	337,2	334,5	300,7	309,7	308,0
Space Heating	152,7	159,6	141,7	134,1	111,3	104,3	95,4
Fishing Vessels	75,1	85,5	110,1	120,9	118,3	130,1	138,6
Freighters	...	...	...	...	...	...	...
Cars	26,4	29,0	27,4	25,2	25,0	25,4	25,6
Electricity Gen.	10,7	19,7	18,2	17,9	13,5	16,3	12,2
Industry etc.	38,1	38,5	39,9	36,4	32,6	33,6	36,3
Residual Fuel Oil	93,9	107,9	99,3	95,1	105,1	125,0	133,0
Total	544,0	592,8	587,9	574,1	548,9	591,1	602,8

TABLE   2.2

Forecast of fuel consumption 1980-2000

Fuel	1977 k tonne	1980 k tonne	1985 k tonne	1990 k tonne	1995 k tonne	2000 k tonne
Gasoline	87	94	110	121	129	133
Aviation Gasoline	2	2	2	3	3	3
Jet Fuel	66	70	81	94	109	126
Kerosine	2	2	2	3	3	3
Distillate fuel	310	292	244	218	218	202
Space Heating	104	70	20	2	1	1
Fishing Vessels	130	150	150	140	130	120
Cars	25	27	30	33	36	40
Electricity Gen.	16	10	9	8	7	6
Industry etc.	34	35	35	35	35	35
Residual Fuel Oil	125	150	174	169	165	162
Fish Meal Factories	70	84	98	90	82	75
Grassdrying Plants	3	4	6	7	7	7
State Cement Plant	13	13	13	13	13	13
Whaling Industry	9	9	9	9	9	9
Fishing Vessels	10	15	20	20	20	20
Other	20	25	28	30	34	37
Total	591	610	613	608	618	628

Oil prices 1977-1979, Rotterdam spot market according to "Platt's Oil Gram".

Figure 2.1

US $ per tonne

Gasoline

Distillate fuel

Residual fuel oil

1977   1978   1979
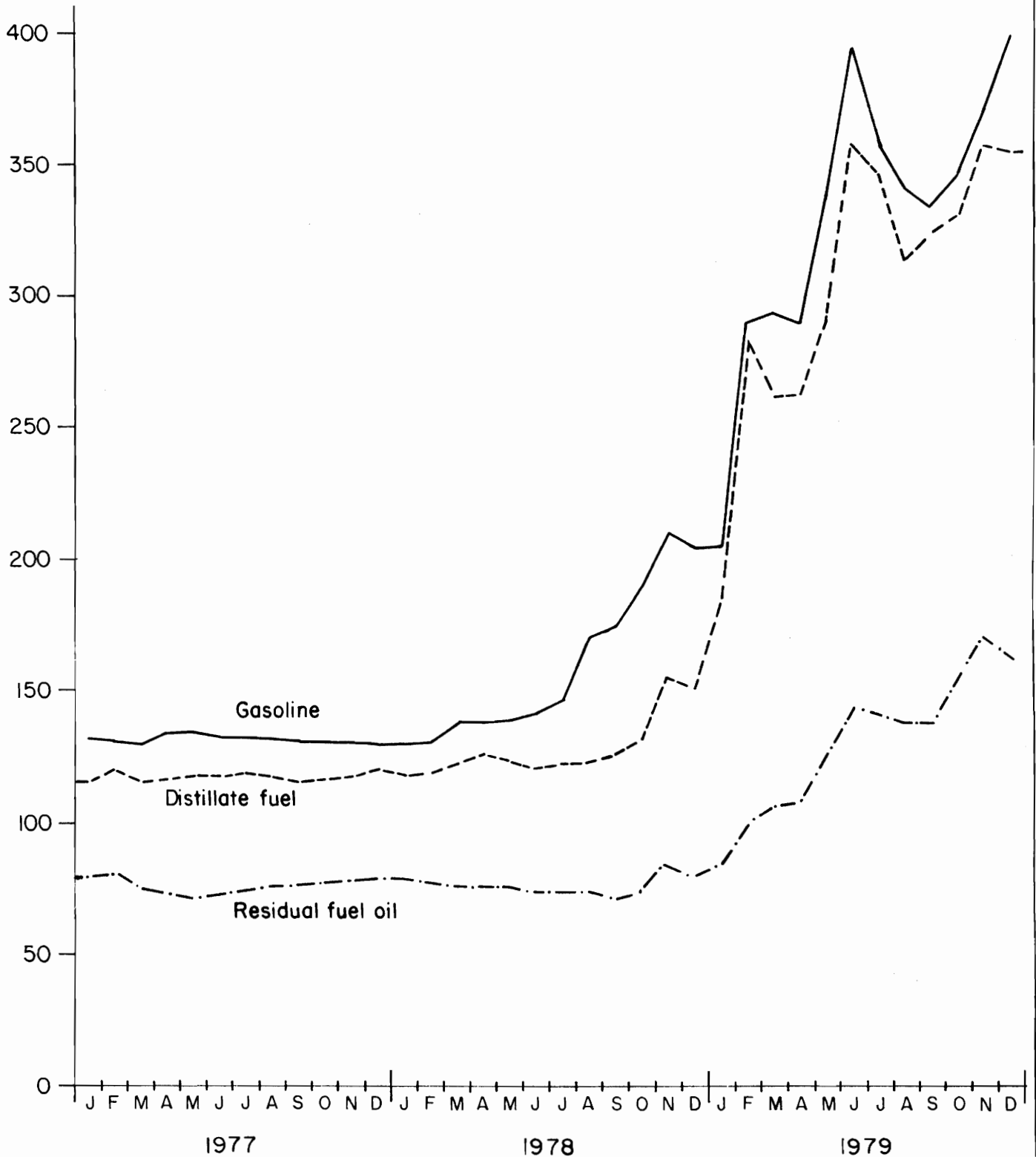
3   HYDROGEN AS AN ENERGY CARRIER

Hydrogen and electricity are energy carriers which have in common that they can easily be produced in Iceland but can hardly replace imported fuels. The study group was appointed to write a report on the present state and likely development of methods to produce, store, distribute and burn hydrogen and hydrogen compounds till the end of this century. A special report [6] on the production and possible use of hydrogen and hydrogen compounds in place of imported fuels was prepared. In this chapter the most important points regarding hydrogen as a future energy carrier in Iceland will be discussed.

Today chemical and petroleum industries all over the world produce hydrogen on a large scale. In the chemical industry hydrogen is chiefly used in the production of ammonia and in the petroleum industry to enhance the production of light oil products from crude oil. Most of the hydrogen used today is produced from natural gas and steam (water vapor). Hydrogen produced from oil and coal is a small fraction of the total world production. The hydrogen produced by electrolysing water (hydrolysis) as is done in the State Fertilizer Plant is insignificant compared to the total.

When the world's oil and natural gas resources will begin to dwindle in coming decades it is likely that hydrogen will be produced to a greater extent than presently from coal. This probably also applies to the production of hydrogen by electrolysis. To find inexpensive processes with which hydrogen can be produced from coal and electricity considerable research on improved techniques of coal gasification and electrolysis is now being carried out. If no unforseen stumbling blocks retard the development of new electrolytical techniques it should be possible within many years to produce less expensive hydrogen than present day technology permits. Because synthetic fuel production is very much on the agenda in Iceland it is necessary to gather information about the cost of hydrogen production with the various production processes. Numerous estimates of the production cost of hydrogen exist, most of them American. Such estimates may not apply given Icelandic circumstances. They can, however, be used to campare the various production processes.

Figure 3.1 shows the production cost of hydrogen as a function of the price of raw materials and energy for different production methods [10]. In these plants hydrogen is produced from natural gas, oil, coal and by electrolysis. The plant's output is 255 tonnes/day and all refer to American circumstances and prices in 1979 given the same assumptions regarding capital cost. Three electrolytical plants are shown in figure 3.1. The top line shows the traditional electrolytical process as is used in the State Fertilizer Plant. This line is, however, not comparable with the production cost of hydrogen given in chapter 4 where the assumptions are completely different. Figure 3.1 is still useful since it reveals the gains to be made with improved electrolytical processes. The middle line shows electrolysis with the SPE-technology which has already been developed. The energy conversion efficiency (77.6%) is comparable with traditional methods (75.7%) and the production cost of hydrogen should have gone down because of less capital investments. Today's SPE-technology has not yet been used on a large scale and these cost calculations should, therefore, be viewed with care [5]. The bottom electrolysis line in figure 3.1 shows the production cost with the SPE-technology being developed (90% energy efficiency). The SPE-lines should merely be considered as indicators of the improved technology which can be expected in the next few years. The technology need not necessarily be SPE since other electrolytic methods are continuously being researched and developed.

It is clear that technological hindrances do not prevent the production of hydrogen by the electrolysis of water or from oil or coal in Iceland. It is also evident that hydrogen can be burnt in large boilers and possibly used to drive engines. In many parts of the world experiments with hydrogen as a fuel for internal combustion engines are being performed. Sufficient technology to enable the use of hydrogen as a fuel, therefore, seems to exist or will come into existence in the near future. The storage and distribution of hydrogen is, however, a different matter altogether.

Hydrogen can be stored and transported as a liquid at low temperatures, as a gas or in metal hydrides. The necessary technology to store and distribute hydrogen exists to a certain extent already. Gaseous hydrogen can be handled as other gases and can easily be stored in tanks and transported along pipelines. To store and distribute liquified hydrogen,

however, methods very different from those used presently to handle
conventional liquid fuels are required. The apparatus needed to handle
liquified hydrogen is both delicate and expensive compared with the
apparatus used to store and distribute gasoline and distillate fuel.
The available methods for storing and distributing gaseous and liquified
hydrogen are on a large scale and are ill suited to servicing smaller
vehicles like automobiles and small fishing boats. The use of metal
hydrides makes smaller units possible and may eventually be used in
cars and fishing boats. But the hydride technology is still in the
development stage and it is unlikely that metal hydrides can be used
to store and distribute hydrogen economically in the near future.

After careful examination of the accessible information, the members of
the study group are of the opinion, that hydrogen will hardly become a
major fuel in Iceland before the end of this century. A necessary
prerequisite is an economical storage and distribution technology.
Research in this field is, however, going on in various parts of the
world.

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The production cost of hydrogen as a function of
the cost of energy and raw materials

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Figure 31

Plant size 255 tonnes/day
Prices as in the US 1979
According to Gregory et. al (10)

Hydrogen prices ($/GJ)

Traditional electrolysis

From coal

Present SPE-electrolysis

Oil

Future SPE-electrolysis

Natural gas

($/GJ)

(m$/kWh)
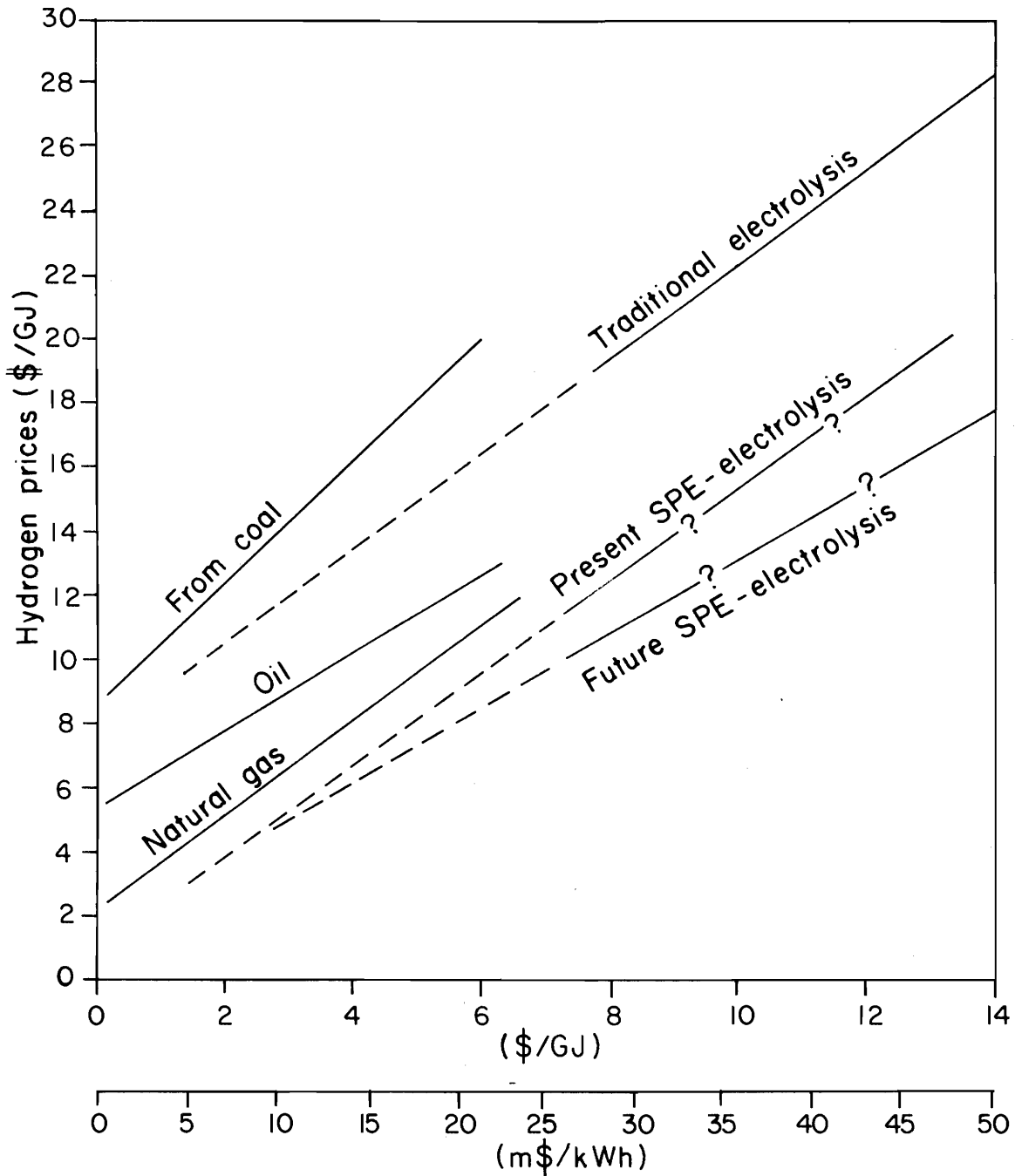
Prices of raw materials and energy

4   THE PRODUCTION OF HYDROGEN IN ICELAND

For the past 25 years the State Fertilizer Plant has produced hydrogen for use in ammonia production. Today there are 10 electrolysers in the plant and the annual production is 2000 tonnes. In the month of November 1977 the State Fertilizer Plant had a detailed study for ammonia production for export carried out. Exact cost estimates of hydrogen production with electrolysis therefore exist.

The study group did a study of hydrogen production in Iceland using domestic resources. The study refers to the best available technology for large scale hydrogen production and the electrolysers of Norsk Hydro are taken as examples since the electrolysers the State Fertilizer Plant uses today are of that type. A flow diagram for this kind of production is shown in figures 4.1 and 4.2 while figure 4.3 is of an electrolyser cell. These are dipole electrolysers.

The capital investment for four plant sizes was estimated. The main plant variables and capital cost are shown in table 4.1. The specific mass of hydrogen gas under standard conditions is 0.09 kg/m^3. In table 4.2 the investment cost is itemized. Included under the article "Plant" is the building cost of the hydrogen plant itself plus the necessary electrical apparatus. Article "other" includes such things as: Office, maintenance, laboratory, fences, site repairs, purchase, engineering, the training of employees etc. Import duties and taxes are not taken into account in the calculations. It can be seen from the above that the estimates refer to a complete hydrogen plant. The plant would be connected to a 220 kV transmission system and use ordinary water to produce gaseous hydrogen and oxygen. The plant site can be chosen where electricity, water, port facilities, a labor force and sufficient space is available.

When the cost estimates were worked out the following values were used:

1. Electricity requirement = 4.56 kWh/Nm^3H_2

2. Water requirement = 0.0456 m^3/Nm^3H_2

3. Maintenance = 1.5% of the capital cost

4. Interests = 12%

5. Depreciation and amortization time = 15 years

6. Even annual payments

7. Insurance = 0.25% of the capital cost

8. Labor contracts as in the state factories early 1979

9. Operation time = 350 days/year

The aforementioned interests, 12%, are rather high for this large a project but the amortization time is also unusually long. The estimated cost of hydrogen production (in $/Nm^3H_2$) is shown in table 4.3 and figure 4.4 for varying electricity prices (in m$/kWh). The graph in figure 4.4 shows the estimated cost of hydrogen (in $/GJ) as a function of the electricity price. The calculations are based on the higher heating value of hydrogen 142 MJ/kg. The figure shows that the production cost is lowest for the largest plant and continues to decrease as the plant gets larger, e.g. in plant-type IV the cost is 8.6 $/GJ if the electricity price is 15 m$/kWh. For further clarification figure 4.5 was drawn. It shows the production cost of hydrogen when the cost of electricity is not included as a function of the number of electrolysers. The figure can be used to work out cost estimates for hydrogen production in plants of other sizes than the four referred to earlier.

TABLE 4.1

Main variables of hydrogen plant

Size	Hydrogen production				Electrolysers	Power (MW)	Employees	Capital cost (M$)
	Nm³/day	tonnes/day	GJ/day	tonnes/year				
I	200.000	18	2560	6.300	30	40	79	19,9
II	400.000	36	5120	12.600	55	80	88	35,0
III	600.000	54	7680	18.900	80	120	97	50,7
IV	1.000.000	90	12800	31.500	132	200	107	78,5

TABLE 4.2

Capital cost of hydrogen plant (M$)

	Size			
	I	II	III	IV
Plant	14,8	27,5	38,9	61,3
Other	5,1	7,5	11,8	17,2
Total	19,9	35,0	50,7	78,5

TABLE 4.3

The production cost of hydrogen ($/Nm^{3}H$_2$)

	Size			
	I	II	III	IV
Electricity*	0,0045x	0,0045x	0,0045x	0,0045x
Operating material	0,001	0,001	0,001	0,001
Maintenance	0,0046	0,00375	0,00362	0,00336
Salaries	0,0167	0,00836	0,00643	0,00436
Capital	0,0417	0,0367	0,0354	0,0329
Insurance	0,0007	0,00063	0,0006	0,00056
Total	0,0644	0,0504	0,04705	0,0422
	+ 0,0045x	+ 0,0045x	+ 0,0045x	+ 0,0045x

* The cost of electricity in the hydrogen production is 0.0045x where
  x is the cost of electricity in m$/kWh delivered to the plant.

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Transformer and rectifier diagram including
a battery of electrolysers
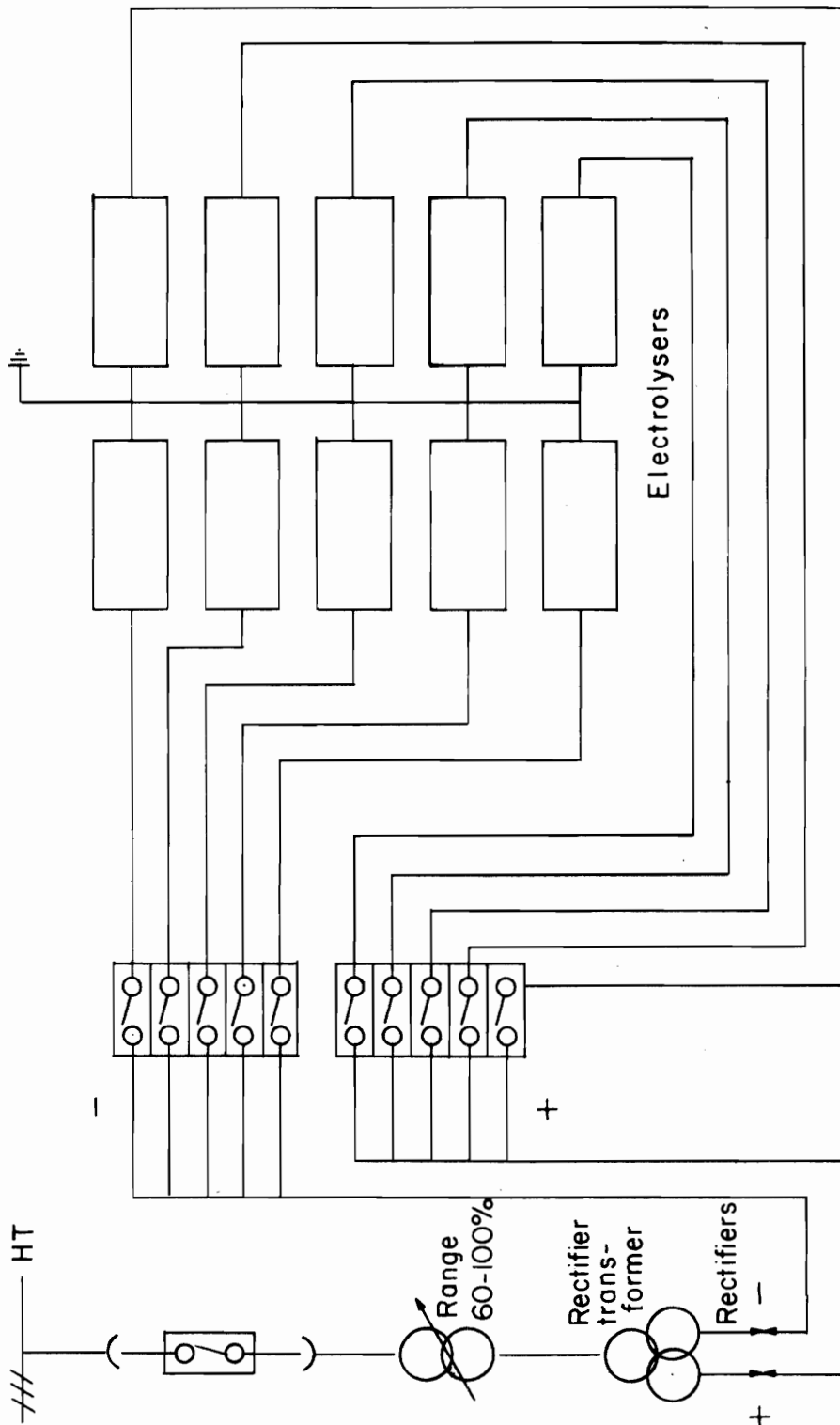
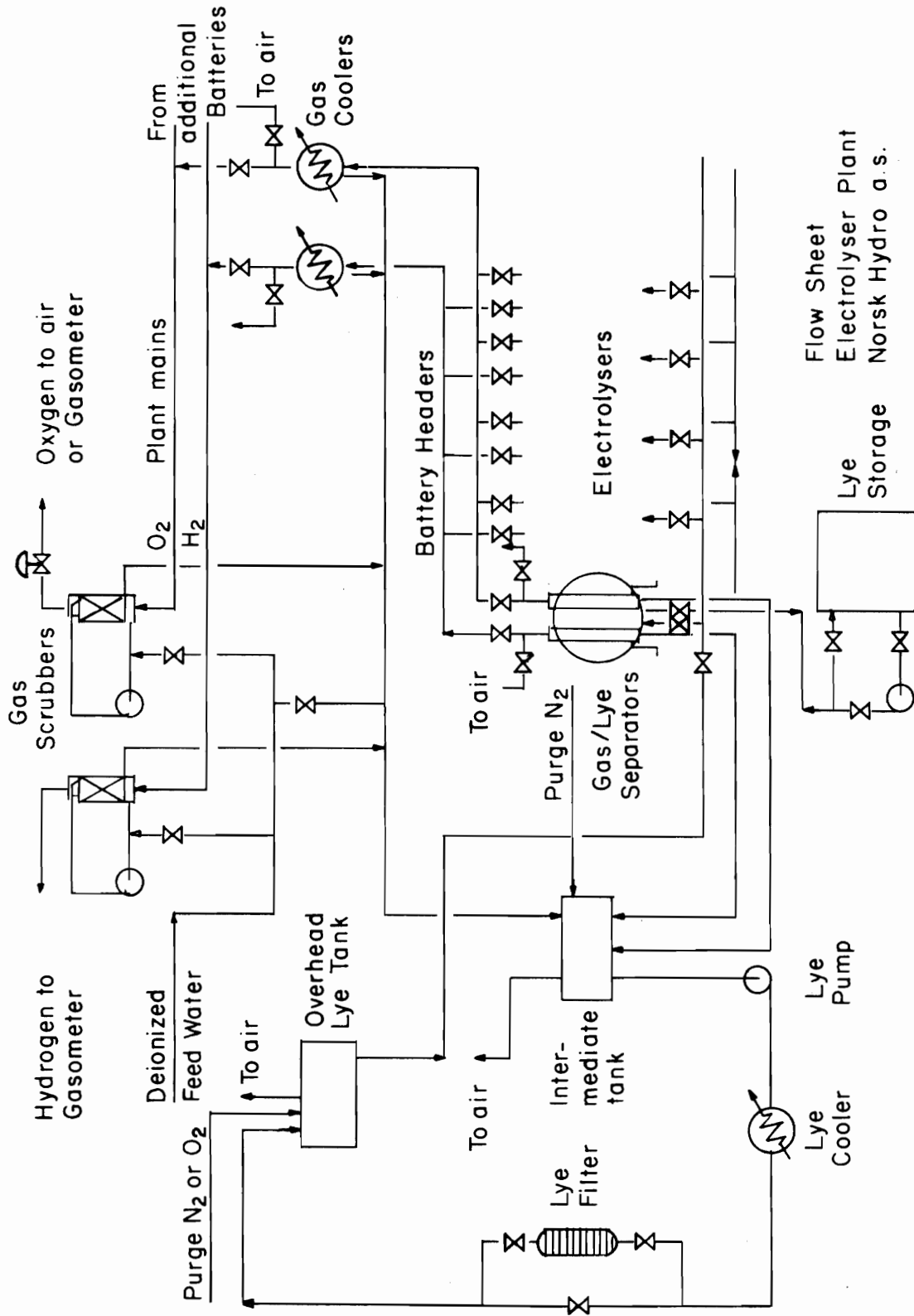| 80.03.19 |
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Mynd 4.1

Electrolysers

HT

Range 60-100%

Rectifier trans- former

Rectifiers

Transformer and rectifier diagram
including a battery of electrolysers.
Norsk Hydro a.s.

From additional Batteries

To air

Gas Coolers

Oxygen to air or Gasometer

Plant mains

O_2 H_2

Gas Scrubbers

Battery Headers

Electrolysers

Flow Sheet Electrolyser Plant Norsk Hydro a.s.

Lye Storage

To air

Purge N_2

Gas/Lye Separators

Hydrogen to Gasometer

Deionized Feed Water

To air

Overhead Lye Tank

To air

Inter-mediate tank

Lye Pump

Purge N_2 or O_2

Lye Filter

Lye Cooler

Fore electrode – both sides

Electrode

Gasket

Diaphpragm frame w/diapragm

Gasket

Fore electrod – both sides

Electrode

Gasducting

Lyeducting
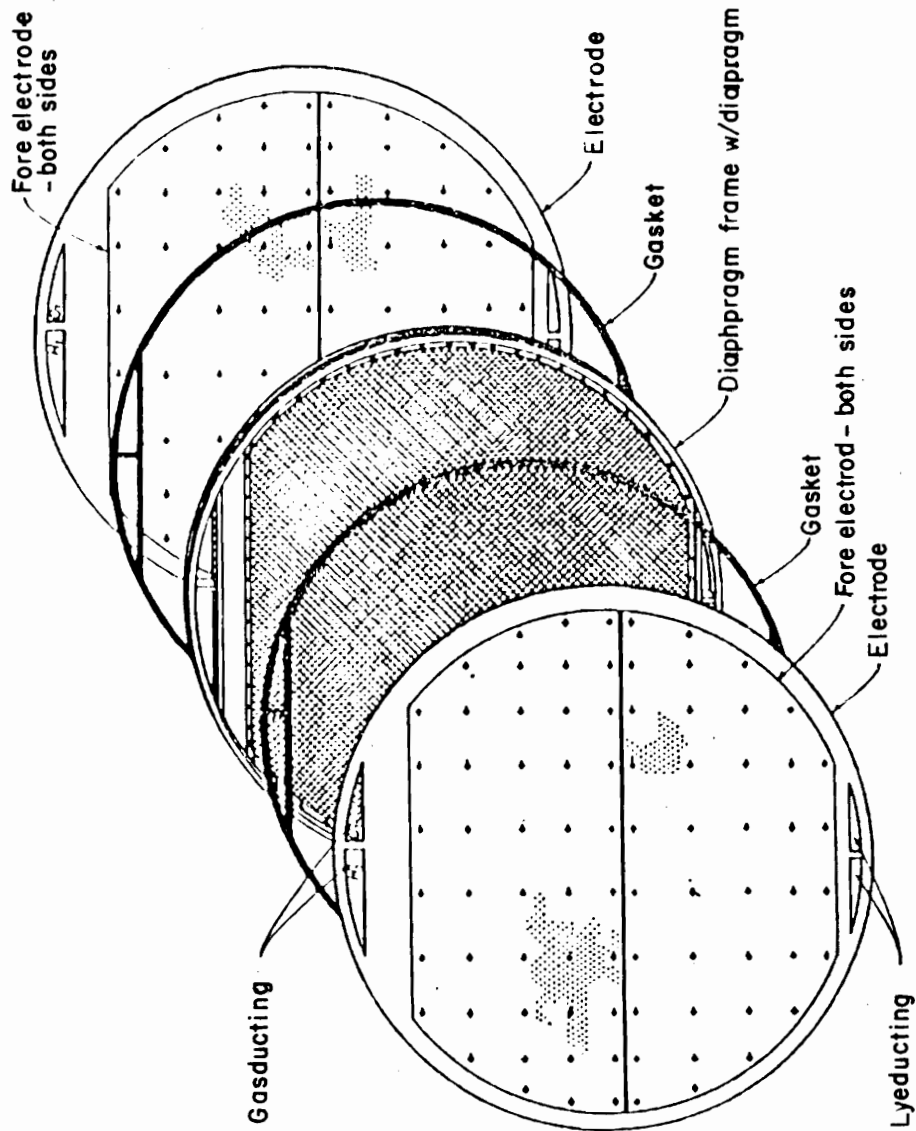
Norsk Hydro Electrolyser – Explooded View of one Electrolyser Cell

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The production cost of hydrogen as a function
of the electricity price and plant size.

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Figure 4.4

Size	Hydrogen (tonnes/y)	Power (MW)
I	6,300	40
II	12,600	80
III	18,900	120
IV	31,500	200

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The production cost of hydrogen
less the electricity cost.

Figure 4.5

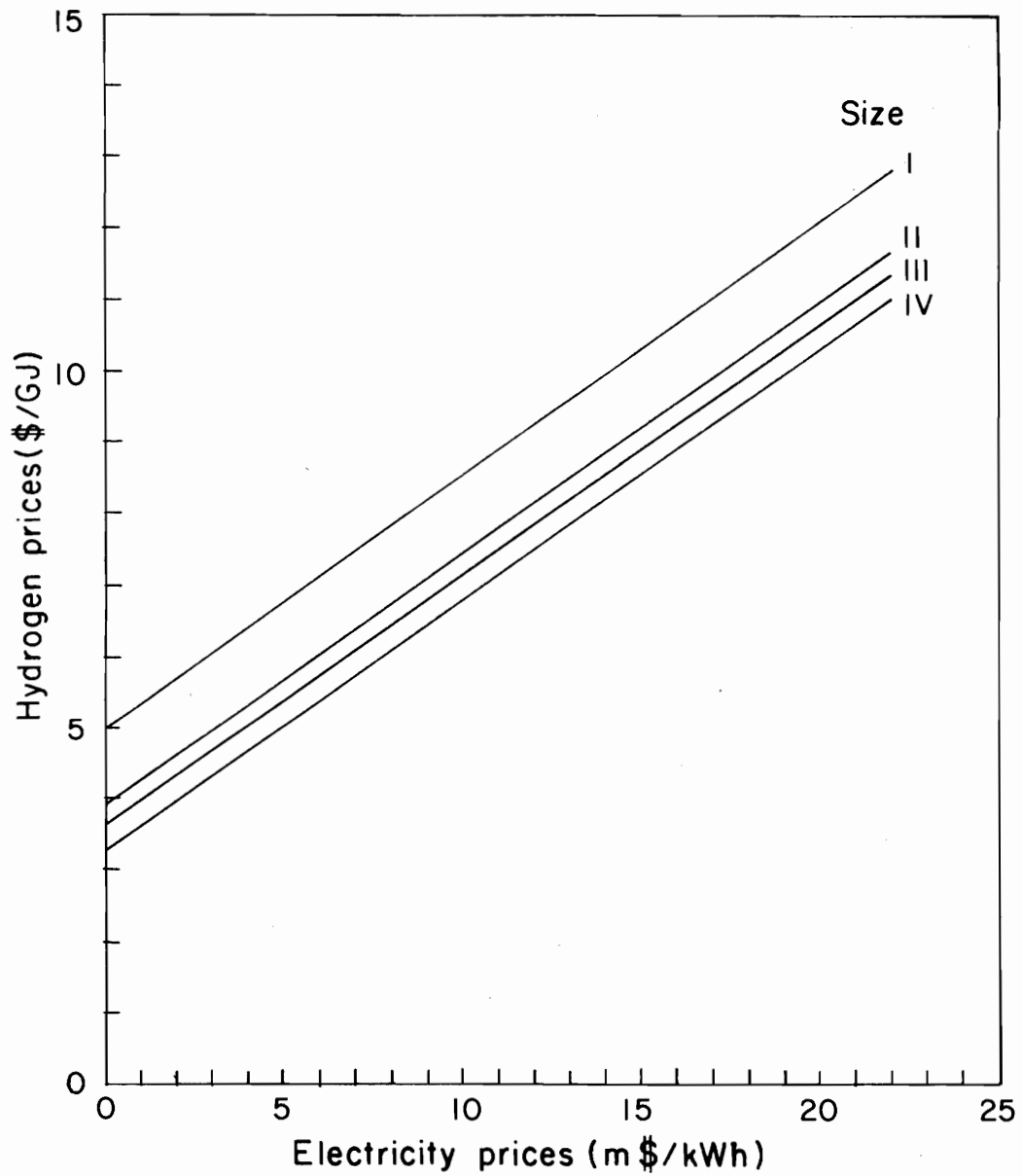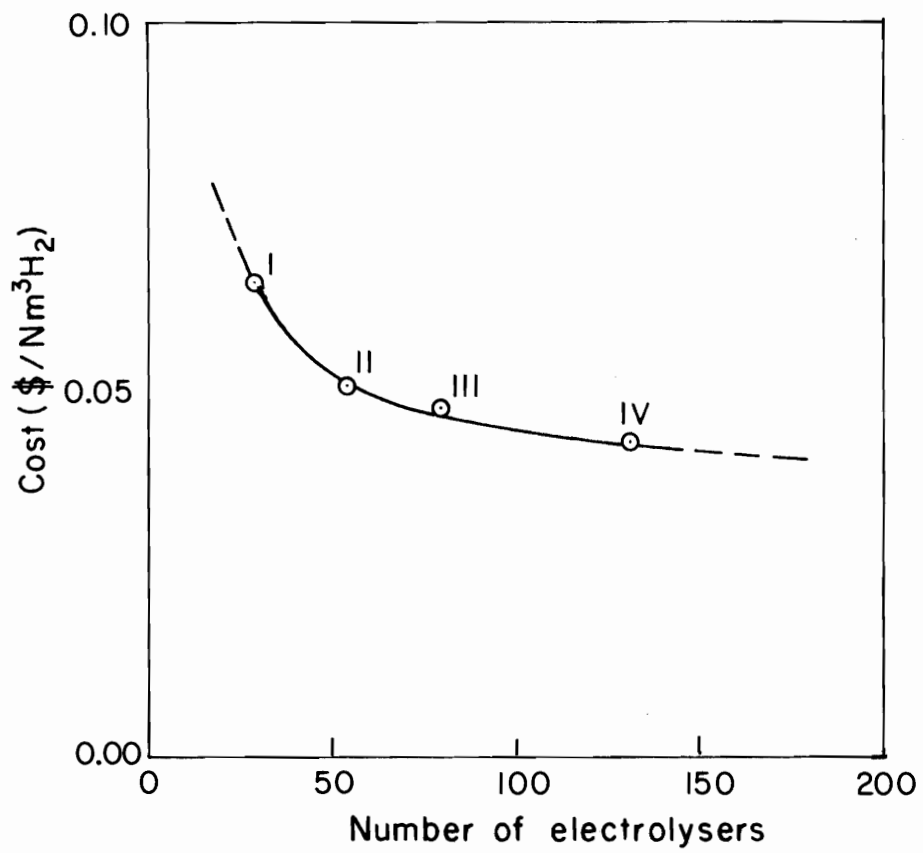ORKUSTOFNUN

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5 METHANOL AS A FUEL

In various parts of the world interest in using methanol as fuel for
vehicles is growing [11-16]. The possibility of using either pure
methanol or gasoline mixed with methanol for gasoline engines is being
speculated but for diesel engines the most feasible option seems to be
to inject pure methanol after the diesel oil has been ignited by
compression. In Sweden [11] and elsewhere [14,17,18] experiments have
been performed which give reasonable indications of the advantages
and disatvantages of methanol as fuel. It is clear that gasoline
engines can run on gasoline mixed with 15-20% methanol without
significant engine alterations being necessary and the same seems to
apply to pure methanol. Diesel engines have been altered so as to run
on 85% methanol and 15% diesel oil. Experiments which encourage certain
hopes for methanol as a general vehicle fuel have already been performed.
However, the combustion technology is still in the research and develop-
ment stage. Methanol can be stored in the same way as gasoline except
it is undesirable that the methanol get into contact too much moisture.
Water and methanol mix easily and that can cause certain difficulties if
methanol is to be used in vehicles. The heating value of methanol is
only half that of gasoline so twice as much methanol must be supplied to
satisfy the same energy demand.

The production of methanol (CH_3OH) requires carbon (C), hydrogen (H) and
oxygen (O). In Iceland the hydrogen and oxygen could be provided by
electrolysing water, however the carbon poses more of a problem. The main
sources of carbon (other than hydrocarbon) in the world have been pointed
out [19]. A few of the possibilities that can perhaps be used in Iceland
are: carbon extraction from seawater, the atmosphere or shell sand.
Other potential carbon sources that have been mentioned are peat and
industrial waste gases. To extract carbon from seawater or the atmosphere
is a distant option but peat is on the other hand used as a fuel for
power generation in many countries (e.g. Finland, Ireland, the Soviet
Union). Experiments designed to show that the production of gaseous and
liquid fuels from peat is possible have been conducted [20]. These
experiments are still in their initial stages and the final results are
uncertain. Presently too little is known about the quantities, quality,
distribution and extractibility of peat in Icelandic peat beds to
determine whether the raw material is available in Iceland. The study

group therefore concludes that economically feasible methods to extract carbon from seawater, air or peat do not exist and emphasizes that the value of the peat beds as a resource is totally undetermined. To process carbon from shell sand and industrial waste gases are definite possibilities in Iceland. 60,000 tonnes/year of carbon dioxide (CO_2) could be made available from the State Cement Plant (the carbon dioxide comes from the shell sand used in the production of the cement). Carbondioxide can be used in conjunction with hydrogen to produce methanol with well established methods. Theoretically it should be possible to produce 40,000 tonnes of methanol anually from the above quantity of carbondioxide. In addition 8000 tonnes/year of hydrogen would be needed. No technical obstacles seem to prevent the installation of the necessary devices in the State Cement Plant to collect the carbondioxide and produce the methanol. The cost of such equipment is however not known so it is difficult to give a realistic estimate of the production cost. It is a well established fact that twice as much hydrogen is needed to produce methanol from carbondioxide as from carbon monoxide (CO). The study group's investigations seem to indicate that using carbon dioxide from the State Cement Plant to produce methanol is too expensive an option.

33,000 tonnes/year of coal and coke will be used in each furnace in the ferrosilicon plant at Grundartangi when full production is under way. The first furnace is already in operation and the second one is being installed. Both the furnaces are "open" and therefore yield carbon dioxide instead of carbon monoxide. Assuming the coal is 60% carbon the two furnaces will yield 145,000 tonnes of carbondioxide annually. The members of the study group believe it is unlikely that methanol production in connection with "open" ferrosilicon furnaces will be economical since basically the same process would be applied as in the case of carbon dioxide from shell sand. In the future, however, it may become possible to produce ferrosilicon in "closed" furnaces which would yield carbon monoxide. That would open whole new dimensions in the production of methanol, which should be examined very thoroughly. Theoretically a single "closed" ferrosilicon furnace could yield 46,000 tonnes/year of carbon monoxide which would suffice for the production of 52,800 tonnes/ year of methanol and would require 6,600 tonnes/year of hydrogen. The needed technology to process methanol from carbonmonoxide is well known but the extraction of carbon monoxide is less well known. It is not quite clear yet if it will be possible to "close" the ferrosilicon

furnaces and it is not known how the exhaust should be handled to be of
optimum use in methanol production. It is worth mentioning that 45,000
tonnes/year of carbon anodes are used in the aluminium smelter at Straums-
vík. If the anodes are assumed relatively clean of impurities 160,000
tonnes/year of carbon dioxide could theoretically be extracted from this
source. Another possibility is to produce methanol from imported coal
using well tested methods. The coals are gasified and a gas mixture
consisting mainly of carbon monoxide and hydrogen is created. The gas
mixture then undergoes a chemical reaction with the aid of a special
catalyst at high temperature and pressure, which yields methanol. Recently,
detailed studies for the production of methanol from coal and from coal and
hydrogen have been worked out (21). This study was done by the British
National Coal Board for the European Economic Community (EEC). Surplus
electricity form nuclear power plants was to be used in the production.
The study can easily be adopted to Icelandic circumstances since it makes
no difference at all whether the electricity used in electrolysing water
to produce hydrogen comes from a hydroelectric power plant or a nuclear
power plant. The study is based on large scale production using only
existing technologies.

When the production of methanol from coal and hydrogen is being studied
an idea of future coal price developments is essential. The International
Energy Agency (IEA/OECD) has published a coal forecast for the OECD
countries till the year 2000 (22). IEA predicts that coal prices around
the middle of this decade (1985) will be 34-55$/tonne cif (in 1976 dollars).
Using 1979 dollars and assuming 10% dollar inflation gives coal prices in
the range 45-75 $/tonne. Other sources (21) also state that a realistic
estimate of coal prices around the turn of the century is 1.5-2.5 $/GJ.
This price range will be referred to in what follows.

The aforementioned study by the National Coal Board (21) has been
adjusted to 1979 prices and a plant size suitable for the Icelandic fuel
market has been chosen (see chapter 6). Figure 5.1 shows the estimated
production cost of methanol from coal and from coal and hydrogen. From
the figure it can be seen that if the coal price will be 1.5 $/GJ the
hydrogen must cost less than 5.8 $/GJ for it to be more economical to
use domestically produced hydrogen by electrolysis. If the coal price
will be 2.5 $/GJ the hydrogen must cost less than 7.7 $/GJ. This result
is of the utmost importance when the economic feasibility of domestic

fuel production is being evaluated. Figure 5.1 refers to the higher
heating value of hydrogen (142 MJ/kg) and of methanol (23 MJ/kg) and
shows that methanol costing 6.6-8.8 $/GJ (152-202 $/tonne) can be
produced from coal only if they cost 1.5-2.5 $/GJ. According to
Swedish sources (11) the world market price of methanol in 1978 was
102-136$/tonne or 112-150 $/tonne in 1979 assuming 10% dollar inflation
which is about 25% lower than methanol can be produced for using im-
ported coal. Information on the price of imported methanol are not
available.

Because of the possibility of mixing gasoline with 15-20% methanol it
is worthwhile looking briefly at what the production of this methanol
would involve. The gasoline demand in Iceland is expected to amount to
110,000 tonnes in 1985 and 15% methanol mixing corresponds to 16,500
tonnes of gasoline (the methanol mixing percentage refers to heating
value). If the lower heating value of gasoline is 44 MJ/kg and that of
methanol 20 MJ/kg 36,300 tonnes of methanol will be needed. This is so
little that the smallest coal gasification ovens considered in plans for
the large scale production of methanol from coal (with or without using
hydrogen from electrolysis) are five times larger. Hence small scale
production of methanol in Iceland seems feasible only in conjunction with
other forms of industry like cement and ferrosilicon production.

Mixing 85% methanol an 15% diesel oil for use in the diesel engines of
fishing boats and automobiles requires much more methanol than the 15%
mixing of gasoline previously mentioned. In 1985 the total diesel oil
consumption of the fishing fleet and automobiles is expected to be
approximately 180,000 tonnes. The heating value of 85% of this diesel
oil is equivalent to 336,600 tonnes of methanol or almost ten times as
much as was needed in the gasoline case. This methanol could easily be
produced from imported coal or from coal and hydrogen produced by
electrolysis. It seems desireable that fuel production in Iceland make
use of the easily available hydrogen from the electrolysis of water and
hence the following estimates are based on the assumption that the
methanol be produced from coal and hydrogen. 219,000 tonnes of coal and
40,300 tonnes of hydrogen will be needed annually for the above methanol
production (336,600 tonnes). The study prepared by the National Coal
Board in Great Britain (21) is used and the calculations are based on
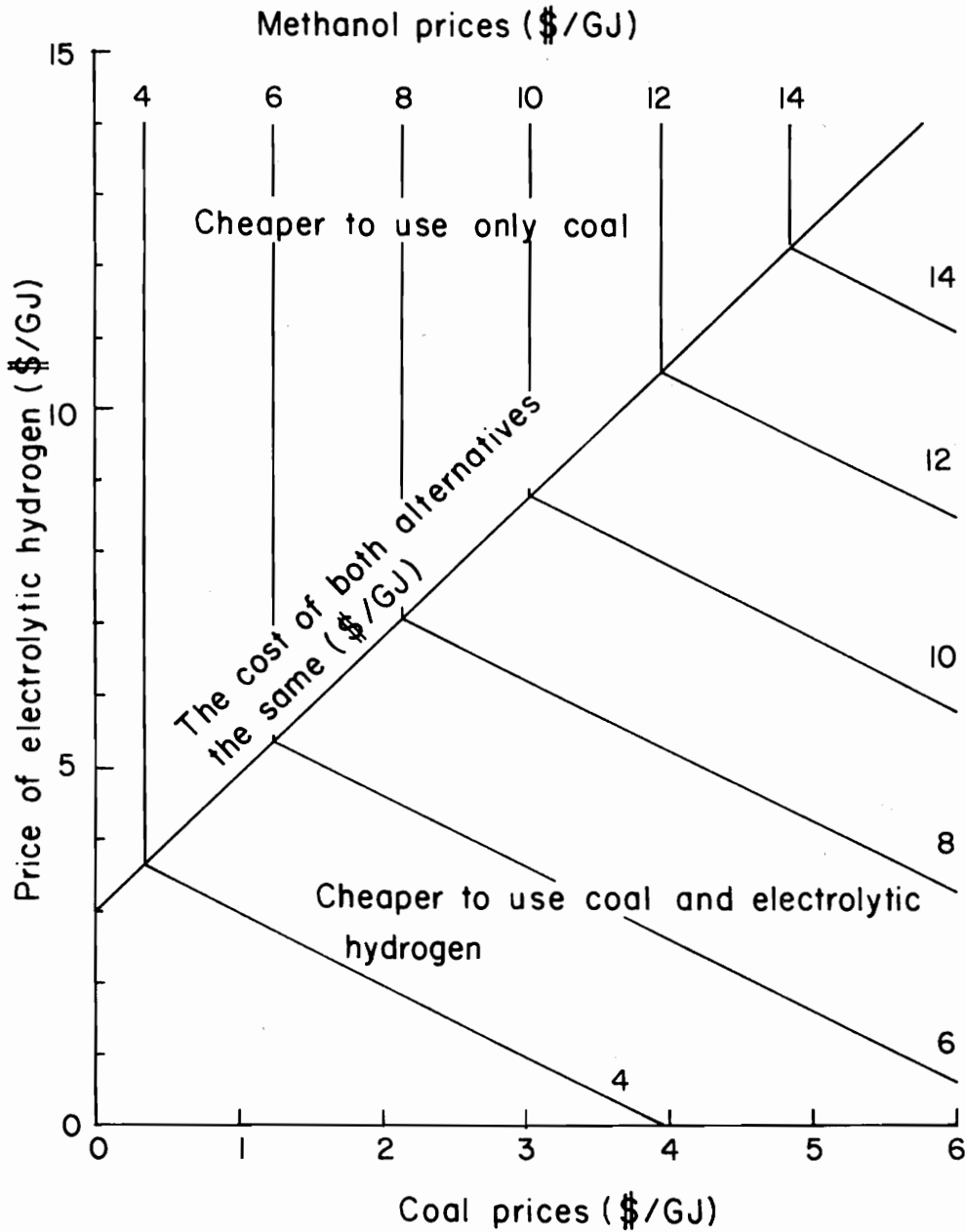standard American coals (80% ash free coal, 11.2% hydrogen, 8.8% ash).

Table 4.1 shows that a plant with 170 electrolysers could supply the
necessary hydrogen. With the aid of figure 4.2 and information in
chapter 4 the price of the hydrogen is found to be 8.4-10.2 $/GJ if the
electricity would cost 15-20 m$/kWh. These hydrogen prices are higher
than 5.8-7.7 $/GJ and figure 5.1 then shows that it would be more
economical to use only coal in the methanol production. According to
the above hydrogen prices (8.4-10.2 $/GJ) and likely coal prices
(1.5-2.5 $/GJ) the methanol would cost 196-246 $/tonne if coal and
hydrogen were used in the production. Hence the methanol would be
20-30% more expensive than it would be processed solely from coal.

Comparable calculations for 100% methanol in place of all gasoline
consumed in the country can be done. 242,000 tonnes of methanol are
needed to supply the same energy as 110,000 tonnes of gasoline. Domestic
methanol production using hydrogen and coal would require 158,000 tonnes
of coal and 29,000 tonnes of hydrogen. The hydrogen plant would have to
consist of 122 electrolysers (from table 4.1) and the resulting hydrogen
prices are 8.6-10.4 $/GJ if the electricity prices are taken as before
to be 15-20 m$/kWh. These are slightly higher prices than from the plant
with 170 electrolysers. As could be expected the hydrogen prices are
higher than 5.8-7.7 $/GJ and it would make more sense to produce the
methanol solely from coal. The methanol from this plant would cost
8.7-10.8 $/GJ or 200-248 $/tonne which is 20-30% higher than it would
be produced solely from imported coal.

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The production cost of methanol from coal	Vinnslut.
only or from coal and electrolytic hydrogen.	F-19060

Figure 5.1

Methanol prices ($/GJ)

Cheaper to use only coal

The cost of both alternatives the same ($/GJ)

Cheaper to use coal and electrolytic hydrogen

Price of electrolytic hydrogen ($/GJ)

Coal prices ($/GJ)

Plant size 266.200 tonnes/year

US $ January 1979

Likely coal prices 1.5 - 2.5 $/GJ

According to Merrick et. al. (21)

6   SYNTHETIC GASOLINE

The study group has reached the conclusion that hydrogen will hardly become an energy carrier in Iceland during this century and the same applies to methanol (both mixed and unmixed) because of the uncertain future of methanol combustion technology. If fuel demand in Iceland is to be met with domestic fuel production the only alternative left is the production of synthetic gasoline which is feasible only if it turns out to be more economical than gasoline import. Methods to produce synthetic distillate fuel (diesel oil) have not been developed except to a limited extent.

Gasoline can be processed from methanol (5,23) and coal (24) using existing techniques. Methods to produce oils from coal which can then be refined in the same way as crude oil to yield gasoline, diesel oil and other oil products are being developed (5,21,25,26). It is unlikely, however, that this development will be completed until after 1990 and reliable plans cannot be based on it. In South Africa gasoline is presently produced from coal with the Fischer-Tropsch method. The Fischer-Tropsch method yields all types of oil products, low density gases and heavy tars alike and gasoline is approximately 1/3 of the total. This method is therefore hardly suitable for Iceland unless an oil refinery be built and a substantial chemical industry established. Hence the discussion will from now on center on the production of gasoline from methanol using the Mobile method which the study group believes is the most promising for Iceland.

The Mobil oil company has developed the necessary technology to produce gasoline from methanol. Diesel oil cannot be produced using this method. There is no plant in operation today which uses the Mobil method to produce gasoline. However, many aspects of the technology are used in oil refineries all over the world. Representatives of the Mobil oil company believe that such a plant could be built without delay and plans are underway for a 4,000 tonnes/year experimental plant in West-Germany and 520,000 tonnes/year plant in New Zealand. The study group carried out a preliminary study for 110,000 tonnes/year gasoline production which is the expected gasoline demand in 1985 as can be seen in table 2.2 . The group based its calculations on the Mobil method. The gasoline is produced by letting the methanol flow over a special catalyst at a

temperature of 400°C and a pressure of 10 bar. Approximately 80% of
the methanol is then converted to gasoline and the remaining 20% to
gases and tars. 2.37 tonnes of methanol are required to produce 1 tonne
of gasoline using the Mobil method (29). The study group used a study
by the National Coal Board when it estimated the production cost of
methanol from coal and electrolytic hydrogen. This study is based on
the ICI method to produce methanol which yields the methanol 98% pure.
Hence the study group estimated that 2.42 tonnes of methanol would be
needed to produce each tonne of gasoline or altogether 266,200 tonnes/
year of methanol. A methanol production plant using coal and hydrogen
would need 31,900 tonnes/year of hydrogen and 173,300 tonnes/year of
coals according to the National Coal Board's study (21). Using infor-
mation in chapter 4 it can be seen that to produce 31,900 tonnes/year of
hydrogen a plant consisting of 134 electrolysers would be required.
Such a plant would need 202 MW of electric power, the initial cost would
be 80 M$ and the number of employees 108. Table 4.1 shows that this
corresponds to plant size IV discussed in chapter 4. From such a plant
the hydrogen would cost 8.6 $/GJ assuming the electricity would cost
15 m$/kWh.

In figure 5.1 the production cost of methanol from a 266,200 tonnes/year
methanol plant using only coal and coal and hydrogen from electrolysis,
based on the higher heating values, is shown. The figure is based on
plans from the National Coal Board's study for a 3,300,000 tonnes/year
methanol plant which is then 12 times larger than would be needed for
synthetic gasoline production in Iceland. The National Coal Board's
studies   refer to prices as of January 1977. The study group has
adjusted the cost estimates in the studies by two years and made the
necessary adjustments in the estimates of the capital cost so as to take
into account a 12.4 times smaller plant. A 10% annual dollar inflation
was assumed and the capital cost increased accordingly. In the study
from the National Coal Board an economy of scale exponent of 0.9 was
assumed for all capital cost factors. The study group based its calcu-
lations on the quantities of coal used in the production since the capital
cost of the National Coal Board's methanol plant is predominantly depend-
ant on the coal throughput and not the methanol. The study group esti-
mated that for a methanol plant producing 266,200 tonnes annually the
specific capital cost ($/kW coal use) increased by 56% when prices were
adjusted and the size reduced. By reducing the size of the plant twelve-

fold and adjusting prices to 1979 the capital cost only dropped eight-fold. The study group made the same adjustment for the production of methanol using only coal. The main results of these reevaluations are shown in table 6.1.

In chapter 5 it was shown that hydrogen from electrolysis had to cost less than 5.8-7.7 $/GJ for its use in methanol production to be economical, given likely coal prices at 1.5-2.5 $/GJ. These values are taken from figure 5.1 which also shows that the methanol would cost 6.6-8.8 $/GJ using only imported coal. The hydrogen from a plant of a suitable size for domestic fuel production would cost 8.6 $/GJ given electricity prices at 15 m$/kWh. These hydrogen prices are 12-48% higher than hydrogen used in place of imported coal can cost for the replacement still to be advantageous. It follows that methanol (and therefore gasoline) produced from imported coal and hydrogen from electrolysis would be more expensive than gasoline produced solely from coal. For a better idea of which is the most practical option, domestic production costs must also be compared with the price of imported gasoline.

In 1976 the Mobil oil company estimated (29) that it would cost (production cost less the cost of raw materials) 0.048 $/gallon to produce gasoline from methanol. Assuming 10% dollar inflation this cost becomes 0.023 $/kg (23$/tonne) in 1979 or 0.52 $/GJ if the lower heating value of gasoline is taken to be 44 MJ/kg. Figure 5.1 can be used to determine the production cost of methanol using imported coal and hydrogen from electrolysis even when it is less expensive to use coal only.
The methanol price lines are simply continued across the dividing line from each half respectively. That is how the production cost of methanol using imported coals and hydrogen from electrolysis was found to be 8.7-9.4 $/GJ when the hydrogen cost 8.6 $/GJ (electricity prices at 15 m$/kWh) and the coals 1.5-2.5 $/GJ. Assuming the higher heating value of methanol is 23 MJ/kg, 8.7-9.4 $/GJ are equivalent to 200-216 $/tonne of methanol. This gives the production cost of gasoline using the Mobil method as 507-546 $/tonne. To get a better idea of the production cost of gasoline in a plant producing 110,000 tonnes/year the gasoline price was also determined for electricity prices at 5 m$/kWh and 25 m$/kWh.

Figure 6.1 shows the estimated production cost of gasoline from coals and hydrogen. The horizontal axis shows the electricity price to the hydrogen plant and the cost of hydrogen from a plant producing 31,900 tonnes/year. The gasoline price was calculated for two coal prices, 1.5 $/GJ and 2.5 $/GJ. It has already been made clear that the hydrogen must cost less than 5.8-7.7 $/GJ for it to be advantageous to use hydrogen from electrolysis rather than hydrogen extracted from coal. Figure 6.1 clearly shows that if electricity prices will be in the range 15-20 m $/kWh which is likely it would be more economical to use only coal instead of coal in conjunction with hydrogen from electrolysis. The hydrogen is simply too expensive to compete with imported coals. Likely gasoline prices are according to figure 6.1 in the range 507-622 $/tonne if imported coal and hydrogen from electrolysis are used.

For comparison it is worth mentioning that recent information (5) from the Mobil oil company indicates that a 420,000 tonnes/year synthetic gasoline plant, which uses coal (Wyoming coal, price unknown) to produce the methanol yields the gasoline at 434 $/tonne (1.2 $/gallon) in 1979 dollars. This cost is somewhat lower than the study group's estimated cost and understandably so since this plant is almost 4 times larger than the plant the study group based its estimate on. On the same basis the Mobil oil company reports that gasoline produced using the Fischer-Tropsch method would cost 648 $/tonne (1.8 $/gallon). To get an idea of the capital cost of a plant using the Mobil method to convert methanol into gasoline in Iceland information from 1976 can be referred to. At that time Mobil estimated that a 420,000 tonnes/year gasoline plant would cost 28 M$. Assuming 10% dollar inflation and taking into account the decreased economy of scale of a smaller plant the study group estimated that a 110,000 tonnes/year gasoline plant would cost 17 M$ in 1979. The economy of scale exponent 0.6 was used as is common practice for similar plants in the chemical industry rather than 0.9 used by the National Coal Board. The total capital cost of the hydrogen, methanol and gasoline plants is therefore approximately 138 M$. The capital cost of power plants and transmission systems must be added to this amount if the total investment cost for the national economy is to be found.

A hydrogen plant in conjunction with the production of 110.000 tonnes/year of gasoline uses 202 MW for 350 days (8,400 hours) per year, which corresponds to 1697 GWh/year of electrical energy. A hydroelectric plant

meeting this demand would have to generate 1,786 GWh/year assuming 5%
losses in transmission and it should be 298 MW if its operation time is
250 days (6,000 hours) per year. According to estimate by the NEA such
a plant could cost 238 M$. To this initial cost another 20% should be
added to cover the power plant's share in the main transmission system.
The total initial cost in the electric system associated with the gaso-
line production comes to 286 M$ (US$ January 1979).

To produce gasoline in Iceland entirely from coal 504.200 tonnes/year
must be imported for the production of the required 266,200 tonnes/year
of methanol. The methanol from such a plant would cost 6,6-8,8 $/GJ
assuming coal prices in the range 1,5-2,5 $/GJ. Synthetic gasoline
produced solely from coal should then cost 390-513 $/tonne. Figure 6.2
shows the production cost of gasoline as a function of coal prices.
Table 6.1 shows that the estimated capital cost of a methanol plant
yielding 266,200 tonnes annually is 128 M$. Neither hydrogen plant nor
power plants are needed and the total investment for a 110,000 tonnes/
year gasoline plant comes to 145 M$ or 34% of the total in the case of
gasoline production from coal and hydrogen. If the gasoline prices in
figures 6.1 and 6.2 are compared it can be seen that given the electricity
price at 20 m$/kWh it would cost 20-50% more to use hydrogen from
electrolysis than not at all (i.e. only coal) and given the electricity
price at 15 m$/kWh it would cost 6-30% more.

In the calculations, which appear here, the cost of port facilities and
other additional cost related to a domestic fuel industry has not been
estimated. It has not been possible to estimate this additional cost
in this report and the above gasoline prices must hence be taken as
minimum prices. The accuracy of the estimates of the capital cost of
the methanol and gasoline plants is also not too great.

Table 6.1

A comparison of methanol plants by size, price and production method

Plant	Plan	Production and raw material (tonne/year)			Unit cost* ($/kW)	Capital cost (M$)
		Methanol	Coal	Hydrogen		
Methanol from coal and hydrogen from electrolysis	NCB:1977	3,300,000	2,148,400	395,300	143	325
	OS:1979	266,200	173,300	31,900	223	41
Methanol from coal only	NCB:1977	3,300,000	6,200,000	-	153	1002
	OS:1979	266,200	504,200	-	238	128

*With reference to the heating value of coal

NCB = National Coal Board [21]

OS = National Energy Authority, Study Group

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The production cost of synthetic gasoline.

Vinnslut.

F-19061

Figure 6.1

Plant size 110,000 tonnes/year

ORKUSTOFNUN

The production cost of gasoline as
a function of coal price.

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Vinnslut.
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Figure 6.2

Plant size 110,000 tonnes/year
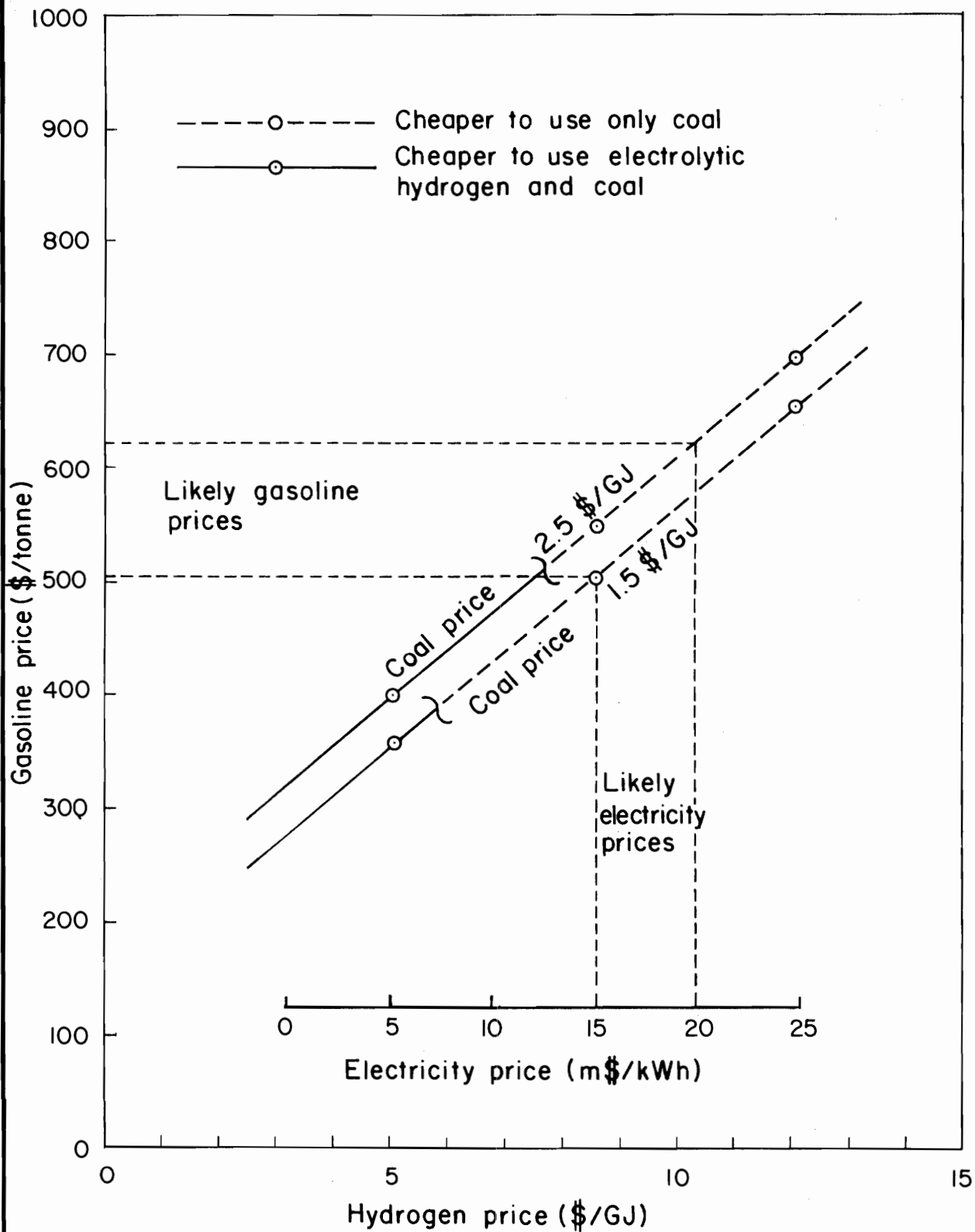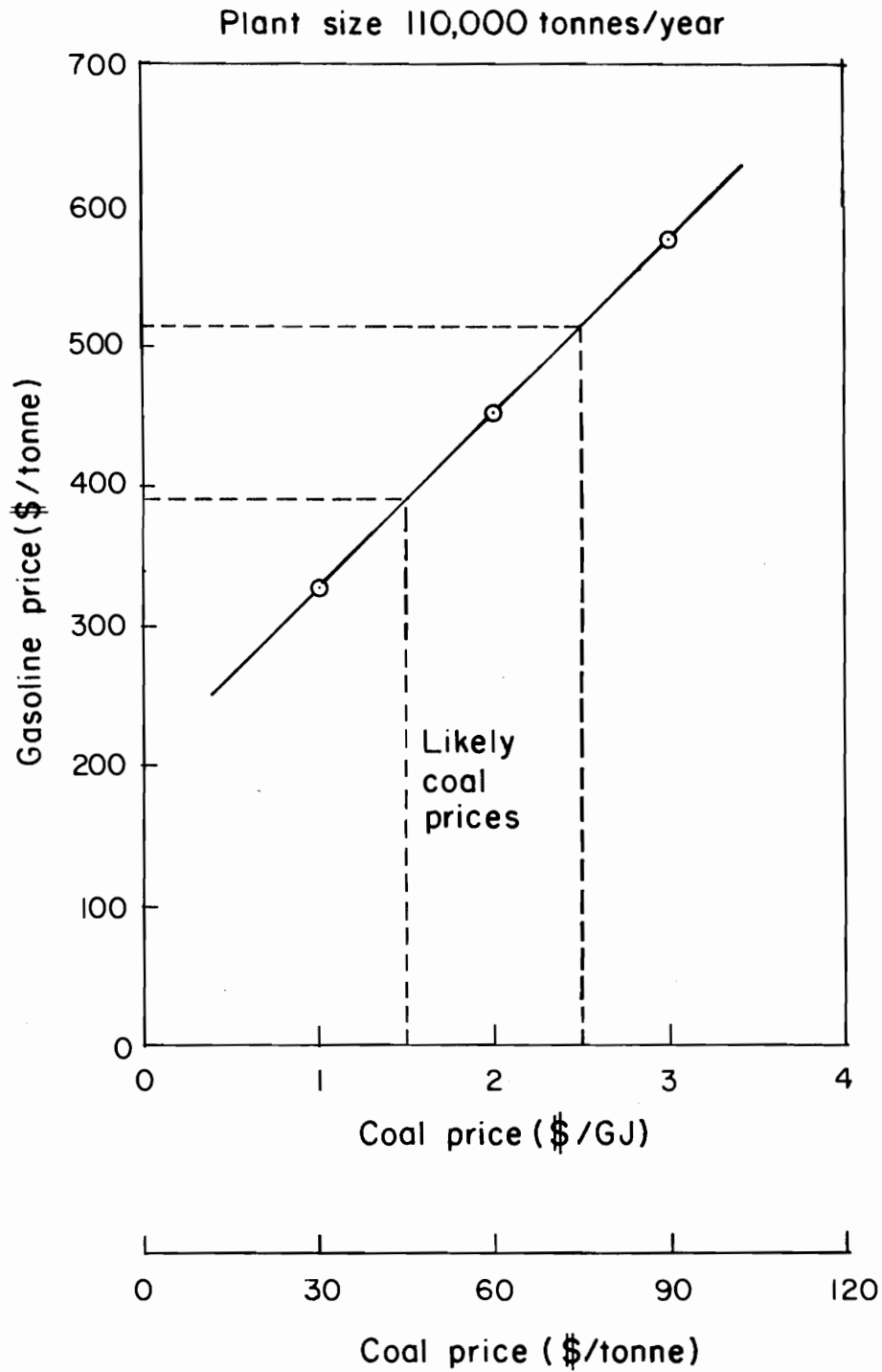
7   DISCUSSION

In this report the study group has concentrated on those production technologies of liquid fuels which are most likely to give positive results in the near future. Less has been done about technologies which are still being developed and could be commercialized around the turn of the century or later. This choice of topics for treatment was made with decisions about further and more detailed research in mind, which are likely to follow. In the preceding chapters emphasis was put on estimating the cost of synthetic gasoline using production methods already available. Still there are uncertainties which could have a decisive influence on the future of an Icelandic fuel industry. In this chapter a few items, which the study group believes should be born in mind, will be discussed.

When decisions about domestic gasoline production are made likely price developments of the fuels and raw materials entering the picture must be taken into account. Especially the developments of the prices of crude oil and coal abroad and the production cost of electricity and hydrogen in Iceland. It is hardly disputed that the price of crude oil will continue to rise and disturbances in oil exports of the production countries will become more frequent. Hence it is essential to have secure agreements ensuring imports or produce fuels domestically. It is likely that coal prices will rise along with the price of crude oil. The same can be said of natural gas, its price will follow that of crude. In this context it is worth noting that electrical energy is generally considered more valuable than the energy from oil, coal or gas. It follows that the market price of electricity will rise in the future.

The production cost of electrolytic hydrogen is largely determined by the capital cost of the plant and the electricity price. As has already been stated the electricity from the next hydro power plants will probably cost 15-20 m$/kWh.

The purpose here is not to discuss the price of electricity. However the technology of electrolysis is on the agenda. The study group is of the opinion that the development of this technology is of immense importance. Today it seems clear that electrolytic hydrogen cannot compete with imported coal. For it to cost the same to use electrolytic hydrogen

and coal as only coal to produce synthetic gasoline the price of the hydrogen must decrease by 10-44%. This comparison of course depends on the electricity and coal prices used for reference. Table 7.1 shows how large the price decreases have to be given likely electricity and coal prices.

During the next few years improved and less expensive methods of electrolysis can be expected. Figure 3.1 shows e.g. a study which predicts a decrease of up to 50% in the price of hydrogen produced using a new technique of electrolysis. The study group does not believe this goal can be achieved in the near future. Another study (30) on the other hand assumes a 25% decrease in the production cost of hydrogen using the same electrolysis technology and modified versions of traditional technology. According to this and other information the study group concludes that no more than a 25% decrease in the production cost of hydrogen can be expected. Along with increasing coal prices and improved electrolysis methods future developments will be in favour of electrolytic hydrogen.

This report has treated the possible use of both methanol and synthetic gasoline as fuel. The conclusion was reached that the combustion technology of methanol was still in the development stages and hence uncertain whether it could become a fuel alternative in Iceland and also that it would be unwise for Iceland to adopt a new fuel if other nations would not do the same. It is appropriate to compare the production cost of methanol and that of synthetic gasoline. As stated in chapter 6 the gasoline costs 507-546 $/tonne if electricity costs 15 m$/kWh and the coal 1.5-2.5 $/GJ. To produce gasoline with the Mobile method costs approximately 23 $/tonne (gasoline) and the energy efficiency is 93%. The gasoline is hence 12-13% (up to 15%) more expensive than methanol. On the other hand the twofold distribution cost of methanol and the cost of altering engines and equipment to enable the use of methanol count in favour of gasoline. To use synthetic gasoline no engine alterations are required. The advantages of gasoline over methanol hence seem obvious.

In this report the production cost of synthetic gasoline solely from coal is estimated to be in the range 390-513 $/tonne (or 400-500 $/tonne) but 507-622 $/tonne (500-600 $/tonne) from electrolytic hydrogen and coal. According to figure 2.1 the import price of gasoline in 1979 was somewhere

between 200-400 $/tonne. It is not the intention of the study group to
speculate about future gasoline prices. However its members believe that
300-400 $/tonne will give a more realistic comparison with the production
cost of synthetic fuels. Hence one can say that (in US$ January 1979)
it costs 300-400 $/tonne to import gasoline 400-500 $/tonne to produce
gasoline using only coal and 500-600 $/tonne to produce gasoline from
electrolytic hydrogen and coal. One should also bear in mind the pro-
duction cost of synthetic gasoline in large foreign synthetic fuel plants.
The Mobil company estimates that it will cost 434 $/tonne to produce
gasoline from coal only in a four times larger plant than is discussed
in this report. Table 6.1 also shows that the capital cost of a twelve
times larger methanol plant than is needed in connection with domestic
fuel production is only eight times greater. Therefore the question
arises whether it would not be cheaper to import synthetic fuels from
large synthetic fuel plants rather than produce them in a small plant
domestically.

It is worthwhile to examine the ratio between savings in foreign currency
and capital cost resulting from synthetic gasoline production in Iceland.
Table 7.2 shows the capital cost associated with a 110,000 tonnes/year
gasoline industry (US$ January 1979). The capital cost in the case of
gasoline production from electrolytic hydrogen and coal (alternative A)
is estimated at 424 M$ but only at 145 M$ if imported coal are solely
used in the production (alternative B). The capital cost of A is hence
almost three times greater than that of B. It is worth noting that in
alternative A the capital cost of the electric system associated with
the production amounts to 67% (2/3) of the total cost and hence plays a
crucial role for the economic feasibility of domestic fuel production.
In alternative A 173,300 tonnes/year of coal have to be imported according
to table 6.1 but 504,200 tonnes/year in alternative B. For simplification
one can assume an average gasoline price of 350$/tonne (300-400 $/tonne)
and coal price of 60 $/tonne (45-75 $/tonne). The savings in gasoline
imports then amount to 39 M$/year in both instances. In alternative A
the coal import comes to 10 M$/year but 30 M$/year in alternative B.
Savings according to alternative A will be 29 M$/year or 7% of the
capital cost. According to alternative B import is reduced by 9 M$/year
which is 6% of the estimated capital cost. These percentages refer to
uncertain average prices of imported fuels (gasoline and coal) and are
therefore only for reference since this is merely a preliminary study.

Much has already been said about synthetic gasoline but very little
about distillate fuel (diesel oil). However if one considers the use
of these fuels in Iceland one might think it more appropriate to do the
opposite since table 2.2 shows that in 1985 it is predicted that the use
of diesel oil will be twice as great as that of gasoline. One of the
reasons for this is that the study group is of the opinion that gasoline
production with the Mobil method will be most likely to give positive
results in Iceland in the near future. The Mobil method is already
available and can be used to convert methanol into high octane gasoline.
Presently it is being modified to allow the production of diesel oil but
little is known about the future potential of that technology. If Mobil
succeeds in converting methanol into diesel oil the production cost should
not differ greatly from that of gasoline. Nothing has so far been said
about jet fuel although table 2.2 shows that in 1985 the use of jet fuel
is thought to have reached 75% of the use of gasoline. The study group
has not examined the possibility of producing jet fuel using the Mobil
method but believes it should be done. A quick look indicates that
nothing should stand in the way of producing jet fuel using the same
methods as are used to produce gasoline.

Because of the huge investments associated with a fuel industry in Iceland
the construction pattern is of the utmost importance. Considering an
annual production of 110,000 tonnes of gasoline from electrolytic hydrogen
and imported coal the initial cost amounts to 424 M$ which is equal to
half the state budget. It will therefore be a major task for the nation
to set up such an industry to say the least. Still a 110,000 tonnes/year
gasoline plant seems to be of a suitable size as a first step in the
setting up of a domestic fuel industry. The smallest possible size of
a fuel industry is first and foremost determined by the capacity of the
coal gasifier in the methanol plant. Koppers-Trotzek gasifiers use e.g.
up to 15 tonnes/hour of coal (3) but according to table 6.1 20 tonnes/
hour of coal are needed for the methanol production. Further steps in
the expansion of a domestic fuel industry could be aimed at meeting the
demand for gasoline and jet fuel around 1990, when the use of these fuels
is projected to have risen to 220,000 tonnes/year. Next one can conceive
of doubling the production capacity again by setting up a distillate fuel
plant, if the necessary technology will then have been developed.

Recent information from the Mobil oil company (3) indicates that it will
cost 50% more to produce gasoline with the Fischer-Tropsch method than
with their own (see chapter 6). Information such as this must be taken
with care since the technical details of the comparison are unknown.
And the Mobil company has vested interests in the matter. Explanations
of the huge cost differences can perhaps be sought in the advantages
and disadvantages of the methods. The Mobil method yields almost ex-
clusively gasoline but the Fischer-Tropsch method all sorts of hydro-
carbons. In South Africa e.g. where the Fischer-Tropsch method has been
used now for 25 years the gasoline and diesel oil share of the production
is only 1/3 and that of gases approximately 1/2. To get more gasoline
further processing in an oil refinery is required which increases the
production cost. In other respects the methods are similar if all the
production steps are taken into account. Hence the Fischer-Tropsch
method seems to suit a market demanding both liquid fuels and gas. On
the other hand it should be kept in mind that the Fischer-Tropsch method
has been under constant development in recent years. A new plant is e.g.
now being set up in South Africa which is supposed to yield more gasoline
and diesel oil than the previous one. the study group hence concludes
that the Fischer-Tropsch method should not be excluded as a possible
synthetic fuel production method in Iceland, especially since the matter
has not been investigated thoroughly.

The environmental impact of a fuel industry in Iceland could be substan-
tial and this will be a decisive factor in the decision process. It is
presently clear that hydrogen will not be used as a fuel during this
century so domestic fuel production will have to rely on carbon from
some source. It is untimely to work out detailed plans regarding waste
gases from large scale industry or Icelandic peat as carbon sources and
hence it is necessary to assume imported coal as the carbon source. But
there is still reason to examine these and other carbon sources carefully.
Large scale imports of coal are bound to cause many of the same pollution
problems developed industrial nations are struggling with today. Dust
particles and sulphur in the atmosphere and polluting effluents can be
mentioned in this context. Means to dispose of coal ash must be devel-
oped and the danger of oil spills in rivers and off-shore is increased.
The effects on human settlements in the vicinity of a fuel plant must
also be considered. It is only the intention here to point out that
environmental considerations must be taken into account from the outset,
but not to pinpoint all the difficulties likely to arise.

Because of the likely environmental impact of domestic fuel production
it is to be expected that only the production method involving the least
import of coal will seriously be considered. Table 6.1 shows that the
production of synthetic gasoline from coal only requires almost three
times as much coal import as the production of gasoline from electro-
lytic hydrogen and coal. The latter method is more expensive however
(see chapter 6). The study group is of the opinion that it is out of
the question to set up a fuel plant in Iceland which doesn't utilize
domestic energy resources. Hence only fuel production from electrolytic
hydrogen and coal should be considered, the case of plants using only
coal is only for comparison.

A decision regarding a domestic fuel industry must take into account
possible alternative uses Icelandic energy can be put to. The question
is whether it is correct to use electricity to produce hydrogen when other
uses can be found for the electricity. This is a complicated matter and
it is not the intention of the study group to give a complete description
of it. However one must also consider these alternative uses. It has
already been said that electrical energy is in general more valuable than
fuel energy. In many countries fuel is e.g. burnt to generate electricity
at an efficiency of 1/3. The price of electrical energy must be corre-
spondingly higher. Two not unrelated issues are also important when the
industrial use of electrical energy is determined. Because electricity
is a more valuable energy carrier than oil, coal and gas the study group
considers it unwise to use electricity where fuels can be used, except
under special circumstances e.g. ammonia production. In other words
the study group believes that electricity will be best used when it is
out of the question to use oil, coal or gas, e.g. electrolysis and
electrical smelting. An evaluation of the alternative energy uses open
to Iceland must hence be worked out so that an informed choice between
the various options can be made.

Table 7.1

"Necessary" price decreases of electrolytic hydrogen

Coal price	Electricity price	
($/GJ)	15 (m$/kWh)	20 (m$/kWh)
1.5	33%	44%
2.5	10%	25%

Table 7.2

Estimated capital cost* of a gasoline industry (110,000 tonnes/year)

Type of industry	Capital cost (M$)	
	Alternative A	Alternative B
Electricity	286 (67%)	—
Hydrogen	80 (19%)	—
Methanol	41 (10%)	128 (88%)
Gasoline	17 (4%)	17 (12%)
Total	424	145

A: Electrolytic hydrogen and imported coal

B: Imported coal only

*: US$ early 1979

8   CONCLUSION

For further clarification the main findings of the study group will be summarized in this section:

1. Technically there is nothing which prevents the production of hydrogen with electrolysis in Iceland. Hydrogen can be burnt on a large scale and can also be used to power engines. The production and combustion technologies seem to be available. The same can on the other hand not be said for the storage and distribution of hydrogen. An economical method for handling hydrogen does not exist and probably won't in the near future. Hydrogen will hardly be used as a fuel in Iceland during this century.

2. The production cost of electrolytic hydrogen decreases more rapidly with increased plant size than was thought to begin with. A plan for four hydrogen plants 3-13 times larger than the State Fertilizer Plant was worked out. In the largest plant the cost of energy is about 2/3 of the production cost. In the coming years a 25% decrease in the production cost of hydrogen can be expected due to improvements in methods of electrolysis.

3. The study group cannot, at this stage, recommend the use of methanol as a fuel in Iceland. The combustion technology is still in the development stages and it seems clear that methanol has few advantages over synthetic gasoline. To use methanol as a fuel engines must be altered and a twofold storage and distribution system set up. The heating value of methanol is only half that of gasoline. Synthetic gasoline costs only 15% more than methanol, giving the same energy.

4. Synthetic gasoline can be produced in Iceland from electrolytic hydrogen and imported coal. The production cost of gasoline in a 110,000 tonnes/year plant is estimated at 507-622 $/tonne (US$ in January 1979) given electricity prices in the name 15-20m$/kWh and coal prices 45-75 $/ tonne. The gasoline production would require a power plant of 298 MW, a 202 MW hydrogen plant and a 266,200 tonnes/year methanol plant in addition to a plant which converts methanol to gasoline. The estimated capital cost is 424 M$ and the import of fuels could be reduced by 29 M$ using 350 $/tonne gasoline and 60 $/tonne coal. On the other hand it is possible to produce synthetic gasoline in Iceland from imported coal only and the estimated production cost in a 110,000 tonnes/year plant is then 390-513 $/tonne, if the coal costs 45-75 $/tonne.

5. Along with increasing oil and coal prices and improved electrolysis technologies it is to be expected that price developments will be favourable for domestic fuel production. Prices in the next few years could also be favourable for other energy use alternatives. All ideas about domestic fuel production must hence be evaluated on grounds of economic feasibility and in comparison with alternative uses of electrical energy.

9   RECOMMENDATIONS

The main recommendations of the study group to the General Director of
the National Energy Authority are the following:

1. Development in the technologies of electrolysis and
   production of synthetic fuels should be followed closely.

2. Cooperation with nations considering the production of
   synthetic gasoline should be established.

3. Research into alternative uses of Icelandic energy resources
   should be amplified to enable their comparison with domestic
   fuel production.

4. Icelandic peat resources should be investigated with respect
   to the possible use of peat in the production of liquid fuels
   in Iceland.

5. The National Energy Authority should coordinate further
   investigations into domestic fuel production.

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