# THE ENERGY SITUATION IN ICELAND AND THE UTILIZATION OF SURPLUS ENERGY RESOURCES

Prepared by The State Electricity Authority
Reykjavík, Iceland March, 1958

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## I. The Energy Resources of Iceland

### A. Hydro-power

Iceland's hydro-power resources are estimated at over $25 \times 10^9$ kWh a year, might even reach $38 \times 10^9$ kWh a year. Both figures refer to technically exploitable power, a substantial part of which, it is realized, will not be fit for economic utilization under present conditions.

Investigations into the hydro-resources and their possible development is yet in the initial stage in Iceland. This is due to the fact, that, in regard of the country's low population, comprehensive investigations into the waterpower resources would represent a heavy financial burden. Therefore, at present very little can be said as to how much water-power it may eventually be economically justified to develop. However, a part of the resources is so well known that it can be ascertained that it may be developed at a competitive price for industrial and other purposes.

Within the scope of this review, only the biggest and best known power sited in the country need be mentioned. In Table I there are enumerated 14 sites with their technically available power in GWh per year, the load being assumed uniform throughout the year. The last column shows the part of this power which, at the present stage of the investigations, is considered economically exploitable. However, it is expected that further investigations will show a substantial part of the technically available power to be fit for economic utilization. Sites nos 11 and 12 (Dettifoss and Réttarfoss) may perhaps be developed in a single site and no. 14 (Sog) will be fully developed within a few years.

Hydro-electric Power Sites in Iceland with Estimated Technically Exploitable Power in Excess of 500 GWh a year and their Technically and Economically Available Power.

TABLE I

| No. | Name of Site | Exploitable Power, GWh/year | |
|---|---|---|---|
| | | Technically | At present considered economical |
| 1 | Skaftá I | 700 | - |
| 2 | Thórisvatn | 4500 | 1500 |
| 3 | Sultartangi | 2800 | 2500 |
| 4 | Hjálp | 800 | 700 |
| 5 | Skard | 1500 | 1200 |
| 6 | Urridafoss | 800 | 600 |
| 7 | Bláfell | 700 | 700 |
| 8 | Gullfoss | 900 | 900 |
| 9 | Blanda | 800 | - |
| 10 | Laxá | 800 | 800 |
| 11 | Dettifoss | 1900 | 1000 |
| 12 | Réttarfoss | 2200 | 1100 |
| 13 | Jökulsá á Brú | 2000 | - |
| 14 | Sog | 600 | 600 |
| | Total | 21000 | 11600 |

Two sites, with about 700 and 900 GWh/year respectively, which may eventually prove to be technically harnessable, are not included in the table. The geographical distribution of the power is shown in fig. 1.

## B. Geothermal Heat

The main part of the geothermal heat resources of Iceland is found in twelve so-called natural-steam fields the geographical position of which is shown in fig. 2. These steam-fields have not yet been subject to much investigations, but Mr. G. Bodvarsson, Chief Engineer of the Geothermal Department of the State Electricity Authority has endeavoured to estimate the heat flow through the surface of these steam fields, on the basis of their temperature increase with depth ( thermal gradient ). His results are shown in Table II and fig. 2. Besides the steady heat flow, the bedrock in the steam-fields constitutes a vast heat-reservoir which might be tapped at an arbitrary rate ( depending upon the amount of drilling ), e.g. a tapping at a uniform rate for 50 years would give approximately the same amount of heat annually as the present natural heat flow to the surface.

Natural-Steam Fields in Iceland

TABLE II

| Name of steam field | Elevation m | Area Sq. km | Steady flow in t/h of steam at 3 ata, 132°C | Bedrock heat reservoir in millions of tons of steam |
|---|---|---|---|---|
| 1. Reykjanes | 15 | 1 | 60 | 26 |
| 2. Trölladyngja | 120 | 0.5 | 40 | 13 |
| 3. Krísuvík | 150 | 3 | 100 | 65 |
| 4. Hengill | 30-600 | 50 | 400 | 260 |
| 5. Kerlingarfjöll | 900 | 5 | 500 | 130 |
| 6. Torfajökull | 900 | 100 | 1500 | 880 |
| 7. Vonarskarð | 1000 | unknown | unknown | unknown |
| 8. Kverkfjöll | 1500 | 70 | unknown | unknown |
| 9. Askja | 1050 | unknown | unknown | unknown |
| 10. Námafjall | 350 | 2.5 | 150 | 65 |
| 11. Krafla | 450 | 0.5 | 40 | 13 |
| 12. Theystareykir | 330 | 2.5 | 100 | 65 |
| Total | - | - | 2890 | 1517 |

The total heat dissipated by the natural steam fields has been estimated at around $2.5 \times 10^9$ kcal/h.

Besides these steam fields, hot water springs are found in about 250 locations in Iceland. The temperature varies from 15°C to 100°C and the flow from a small fraction up to 250 litres per second, the total integrated flow being about 1500 litres per second and the total heat dissipated $4 \times 10^8$ kcal/h, which gives a mean temperature of around 75°C. The total heat dissipated by the hot water springs is thus about 1/6 of that of the natural steam fields.

## C. Peat

According to investigations carried out by the University of Iceland Research Institute, the peat deposits in Iceland amount to 3000 $km^2$ of 2.5 m thickness, which can yield approximately 2000 millions metric tons of air dry peat with 20% moisture content. The heat value of the peat varies from 4900 to 6300 kcal/kg, the average being 5700 kcal/kg. The ash content is usually high, up to 40% of dry matter, although a substantial part has an ash content of 10% or less. The most usual figure is 20-25% of dry matter. At present, the peat is not utilized. Icelandic peat bogs should be well suited for large scale mechanical mining, but it is rather unlikely that the peat will be competitive as an energy source, either to water power or geothermal heat.

## Energy Consumption in Iceland in 1955

TABLE III

| Consumption classes | PRIMARY ENERGY | | | | | | | | SECONDARY ENERGY | | | | | Total (9)+(14) GWh | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro electr. power GWh | Geo-thermal heat GWh | FUELS: COAL $10^3$ metric tons | COAL GWh | FUEL OIL $10^3$ metric tons | FUEL OIL GWh | Total (5)+(7) GWh | Total (2)+(3) +(8) GWh | GAS OIL $10^3$ metric tons | GAS OIL GWh | PETROL $10^3$ metric tons | PETROL GWh | Total (11)+(13) GWh | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| I | | | | | | | | | | | | | | | |
| Residential & commercial | | | | | | | | | | | | | | | |
| Space heating | 70 | 292 | 60 | 300 | - | - | 300 | 662 | 45 | 320 | - | - | 320 | 982 | 45.7 |
| Other residential & commercial uses | 135 | - | 1 | 4 | - | - | 4 | 139 | - | - | - | - | - | 139 | 6.5 |
| II | | | | | | | | | | | | | | | |
| Production: | | | | | | | | | | | | | | | |
| Agriculture | 1 | 58 | - | - | - | - | - | 59 | 1 | 3 | - | - | 3 | 62 | 2.9 |
| Fishing fleet | - | - | - | - | 80 | 230 | 230 | 230 | 35 | 105 | - | - | 105 | 335 | 15.6 |
| Chem. industry | 130 | - | - | - | - | - | - | 130 | - | - | - | - | - | 130 | 6.0 |
| Other industries | 55 | - | - | - | 20 | 92 | 92 | 147 | 31 | 150 | 2 | 8 | 158 | 305 | 14.2 |
| III | | | | | | | | | | | | | | | |
| Communications[1)] | | | | | | | | | | | | | | | |
| Motor vehicles | - | - | - | - | - | - | - | - | 1 | 2 | 35 | 85 | 87 | 87 | 4.0 |
| Merchant shipping | - | - | - | - | 3 | 11 | 11 | 11 | 21 | 90 | - | - | 90 | 101 | 4.7 |
| Aircraft | - | - | - | - | - | - | - | - | - | - | 4 | 9 | 9 | 9 | 0.4 |
| Total | 391 | 350 | 61 | 304 | 103 | 333 | 637 | 1378 | 134 | 670 | 41 | 102 | 772 | 2150 | 100.0 |
| % | 18.2 | 16.2 | | 14.1 | | 15.4 | 29.5 | 63.9 | | 31.1 | | 5.0 | 36.1 | 100.0 | |

1) There are no railways in Iceland

## Estimated Energy Consumption in Iceland in 1975

TABLE IV

| Comsumption classes | Primary energy: Hydro electric power GWh | Primary energy: Geo-thermal heat GWh | Primary energy: Prim-ary fuels GWh | Primary energy: Total (2)+(3)+(4) GWh | Sec-ond-ary fuels GWh | Total (5)+(6) GWh | % |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| I. Residential & commercial: | | | | | | | |
| Space heating | 160 | 770 | 220 | 1150 | 220 | 1370 | 28.1 |
| Other residential & commercial uses | 210 | - | - | 210 | - | 210 | 4.3 |
| II. Production: | | | | | | | |
| Agriculture | 35 | 155 | - | 190 | 20 | 210 | 4.3 |
| Fishing fleet | - | - | 220 | 220 | 220 | 440 | 9.0 |
| Chemical industry | 250 | 1650 | - | 1900 | - | 1900 | 39.2 |
| Other industries | 230 | 25 | 75 | 330 | 150 | 480 | 9.8 |
| III. Communications: | | | | | | | |
| Motor vehicles | - | - | - | - | 150 | 150 | 3.1 |
| Merchant shipping | - | - | 10 | 10 | 75 | 85 | 1.7 |
| Aircraft | - | - | - | - | 25 | 25 | 0.5 |
| Total | 885 | 2600 | 525 | 4010 | 860 | 4870 | 100.0 |
| % | 18.2 | 53.4 | 10.8 | 82.4 | 17.6 | 100.0 | |
| Possible large-scale industries (see Table VI) | 4000 | 5000 | | | | | |

## II. Present and Future Power Demands in Iceland

Table III shows the energy consumption in Iceland in 1955, by consumption classes and sources of energy, and table IV the estimated energy consumption in 1975. The estimate is based on an energy policy, the main features of which are:

a) Fuels, which all have to be imported, shall ultimately be replaced as far as practicable by the domestic sources of energy viz. hydropower and geothermal heat.

b) These two energy sources shall be made to contribute as much as possible to national economy by establishing energy-consuming industries, especially chemical, electrochemical, and electrometalurgical industries, and possibly by export of power.

Division of Energy Consumption Among Energy Sources in 1955 and 1975

TABLE V

| Consumption classes | 1955 Hydro-power % | 1955 Geo-thermal heat % | 1955 Fuels % | 1975 Hydro-power % | 1975 Geo-thermal heat % | 1975 Fuels % |
|---|---|---|---|---|---|---|
| Residential & commercial | 18.2 | 26.0 | 55.8 | 23 | 49 | 28 |
| Production, excl. chemical industry | 8 | 8 | 84 | 24 | 16 | 60 |
| Communications | - | - | 100 | - | - | 100 |

As far as the first item is concerned, viz. the replacement of fuels by hydropower and geothermal heat within the "conventional" consumption classes, Table V shows a comparison of the division of energy consumption among energy sources in 1955 and 1975.
In the residential and commercial consumption class, the main changes are that geothermal heat is supposed to replace fuels in space heating to such an extent that its share rises from 26% in 1955 to 49% in 1975, the fuel part to drop correspondingly, whereas the part played by hydro-power in this sector remains relatively constant. In the production, exclusive of chemical industry the evolution is characterized by an increase both of hydropower and geothermal heat in the consumption. The third class, communications, will continue to rely on imported fuels.

As to the item b), Table IV is based upon the assumption that the existing electrochemical industry will develop along present lines, but that some new plants, using geothermal heat, will be erected before 1975. However, a more ambitious program in this field is under consideration, and in Table IV is indicated the order of magnitude of the consumption that might arise from the realization of such projects. But owing to the uncertainity about the realization of such large-scale projects within the next decades, these figures are not included in the table proper.
Annex I shows the conversion factors used in compiling the tables.

## III. Utilization of surplus energy

A comparison of Tables I and IV shows that by 1975, about 7.6% of the hydro resources, that at present are considered economically exploitable might be utilized, and only 4.1% of the technically available power. For geothermal heat, the figure might be about 10% of the steady flow. It is to be emphasized, however, that this figure refers to the present natural steady flow; but as previously mentioned, this flow can be increased considerably by drilling.

It is evident, therefore, that very large surplus quantities of hydro electric power and geothermal heat will be available for a long time to come. In view of the fact that, aside from extensive grasslands, rich fishing grounds and the abundant hydro and geothermal potential, Iceland possesses very limited natural resources, the possible utilization of this surplus energy is of vital importance to the national economy of the country.

Principally, there are two ways of utilizing this surplus energy:

1. Direct export by submarine transmission of electricity
2. Indirect export by establishing energy-consuming industries in the country, and exporting their products.

These two possibilities will be discussed briefly below.

### 1. Submarine transmission of electricity:

The nearest industrial area for direct transfer is Scotland at a distance of approx. 800 km across the Atlantic. This distance by far exceeds anything yet covered by a submarine power cable. Only high voltage direct current ( HVDC ) would come into account. In the last decade, very considerable achievements have been made in this field, and the converter technique is rapidly developing. Eminent experts in this field are of the opinion that HVDC-transmission over such distances is already a technical possibility.
A very rough estimate has been made for such a transmission scheme, based on the assumption that a single-core cable with a voltage of 400-500 kV to ground and a current-carrying capacity of 1000-1200 amperes be laid out. The power transmitted would thus be 400-500 MW and the energy 3.5-5 TWh ( $10^3$ GWh) per year.

The cost estimate is reproduced below:

| | |
|---|---|
| Investment cost: | |
| Submarine cable | US $ 40 Millions |
| Converters and other end equipment | US $ 16 " |
| Total | US $ 56 Millions |

Taking annual cost as 10% of investment cost, and allowing for 10% transmission losses, the transmission cost per unit will be approx.

$$\frac{\text{US \$ } 0.1 \times 56 \times 10^{6}}{0.90 \times 5 \times 10^{9} \text{ kWh}} = \text{US \$ } 1.24 \times 10^{-3}$$

$$= \underline{1.24 \text{ US mills per kWh}}$$

Of course, as the power demand in Iceland grows, the amount of power available for export will ultimately be reduced, but it seems evident in view of the great hydro resources compared to the inland consumption in the foreseeable future that sufficient time will elapse to allow the transmission equipment to be amortized at a reasonable rate before such a reduction occur. But even when the firm power available for export has been somewhat reduced, a to-way power transmission seems possible, similar to that already existing in other parts of Europe between countries with abundant hydro resources and countries with mainly thermal power. In this connection it might be mentioned, that a part of the technically available power which at present is not considered economical might become so if a substantial market was available for the non-firm summer energy.

It is technically quite feasible to use geothermal heat to generate electricity for export, but such power would probably not be competitive to hydro-electricity, and this possibility is therefore left out of account here.

## 2. Indirect export, by exporting the products of energy-consuming industries established within the country

The types of industry most likely to fulfill the conditions imposed upon them in this connection are the chemical, electrochemical and electrometallurgical industries. The possibilities of establishing such industries in Iceland have been studied for a few years.

In Table VI, an indication is given of some possible industrial projects with their energy requirements. The studies have not yet reached such a stage as to allow definite conclusions about the economic feasibility of these projects to be drawn, but it is felt that they deserve further investigations.

Potentially Possible Energy-consuming Industrial Projects in Iceland

TABLE VI

| Process | Probable annual Plant Capacity Thousands of metric tons | Energy requirements GWh/year | |
|---|---|---|---|
| | | Hydroelectric power | Geothermal energy |
| 1. Processing of Diatomacous Earth | 10-50 | negligible | 100-400 |
| 2. Heavy Water Recovery | 0.1-0.5 | 100-400 | 1000-1500 |
| 3. Salt Manufacture from Seawater | 60 | negligible | 900 |
| 4. Alumina Manufacture | 300 | negligible | 2400 |
| 5. Aluminium Manufacture | 100-150 | 3000 | negligible |
| 6. Chlorine Manufacture | 30 | 150 | " |
| 7. Phosphorus Manufacture | 20 | 250 | " |
| Total | - | 3500-4000 | 4000-5000 |

## IV. Conclusions

The contemplated consumption of hydropower and geothermal energy for the three purposes mentioned above, viz. 1) inland consumption within the present pattern, 2) direct electric power export and 3) potentially possible industrial projects within the country, might therefore be approximately as follows ( in TWh or $10^3$ GWh per year ) :

| | Hydro-power | Geothermal energy |
|---|---|---|
| 1. Inland consumption by 1975 within the present pattern | 0.9 | 2.6 |
| 2. Direct export of electric power | 3.5-5 | - |
| 3. Industrial projects within the country | 3.5-4 | 4-5 |
| Total | 8 - 10 | 7-8 |

Comparing these figures to the estimated energy resources ( Tables I and II), and bearing in mind, that most of the 21 TWh/year of technically exploitable hydro-power may, upon further investigations, prove to be economical, it seems safe to say, that both ways of utilizing the country's surplus energy resources may be adopted simultaneously for a long time to come without any fear of power shortage either to each of them or to the country's own growing needs within the present consumption pattern.

## ANNEX I

### Conversion Factors

In compiling the tables, the following conversion factors have been used:

1. Hydro power is expressed directly in GWh

2. Geothermal heat:

   a) Natural hot-water for space heating and agricultural use:
   35 kcal or 0,0407 kWh per litre or about
   25.000 $m^3$ per GWh

   b) Natural-steam for space heating and industrial purposes:
   0.6 Gcal or 698 kWh per metric ton of steam,
   or 1440 metric tons per GWh

3. Fuels:

   a) Net Calorific values:

| | | | | | | |
|---|---|---|---|---|---|---|
| Coal | 7200 | kcal | or | 8.35 | kWh | per kg |
| Fuel oil | 9900 | " | " | 11.5 | " | " " |
| Gas oil | 10500 | " | " | 12.2 | " | " " |
| Petrol | 10400 | " | " | 12.1 | " | " " |

   b) Average efficiencies (by which the above heat values are multiplied).

| | |
|---|---|
| Residential & commercial uses | 60 percent |
| Agriculture and fishing fleet | 25 " |
| Other industries | 40 " |
| Motor vehicles and aircraft | 20 " |
| Merchant shipping | 35 " |

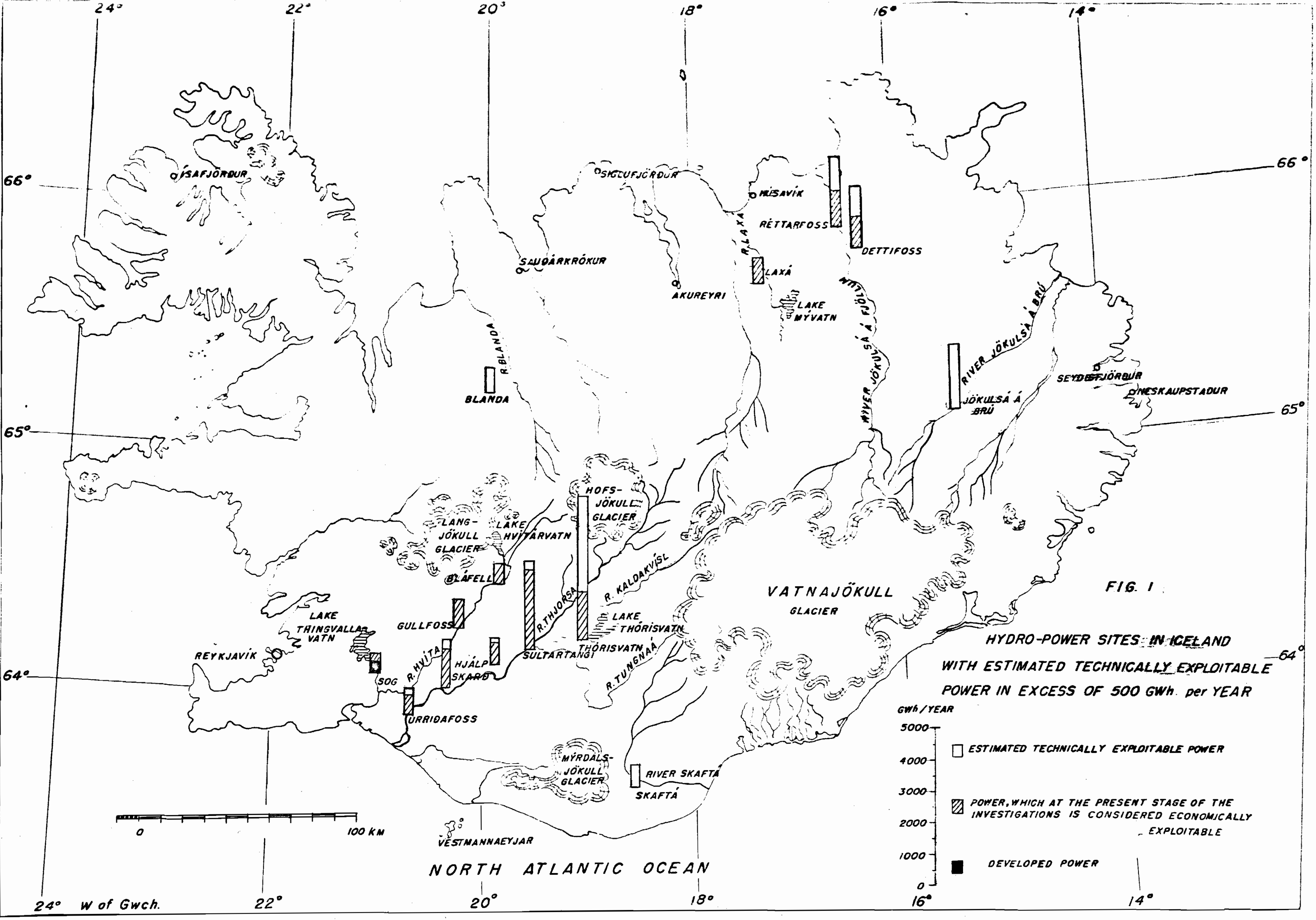



FIG. I

HYDRO-POWER SITES IN ICELAND WITH ESTIMATED TECHNICALLY EXPLOITABLE POWER IN EXCESS OF 500 GWh. per YEAR

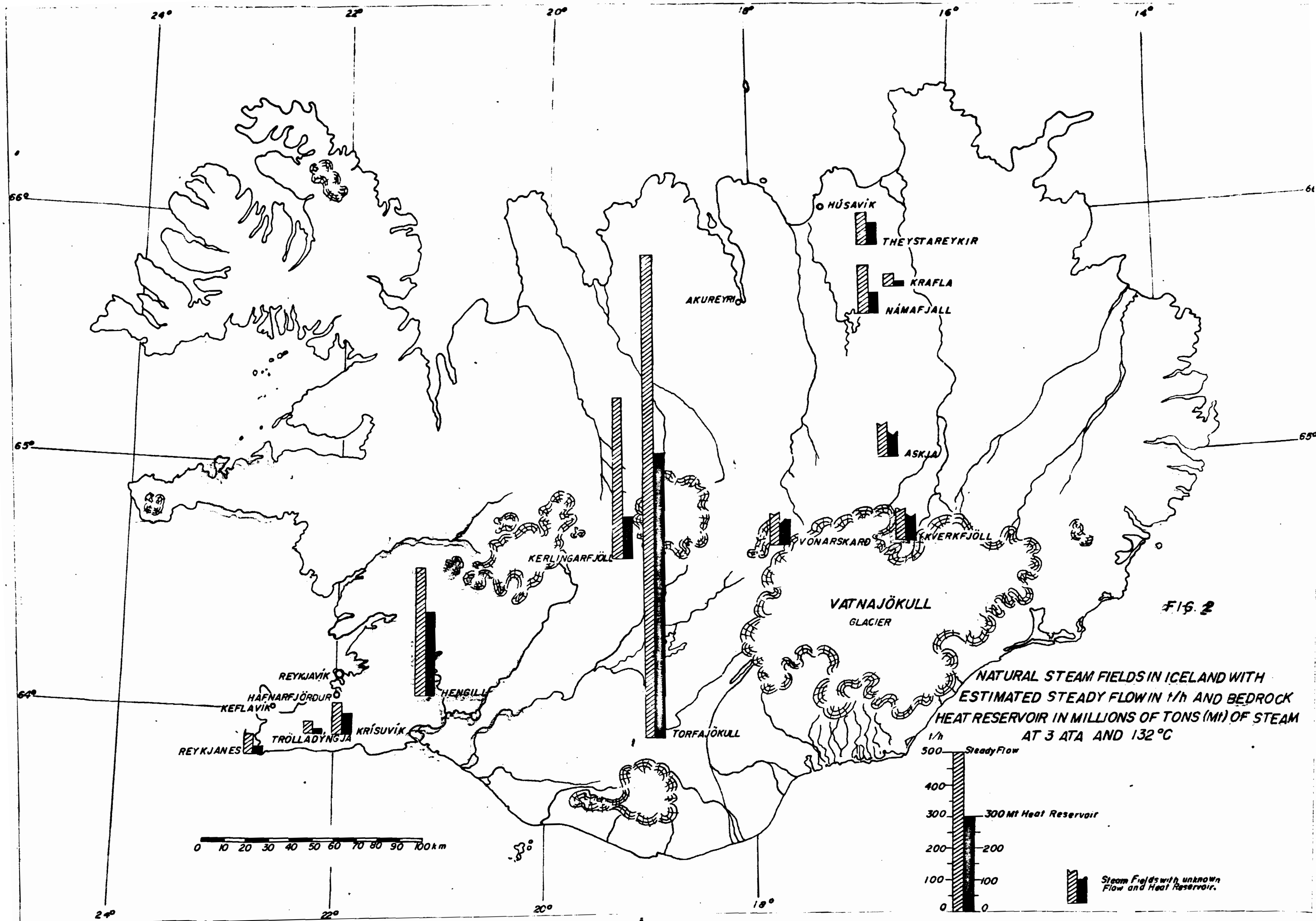


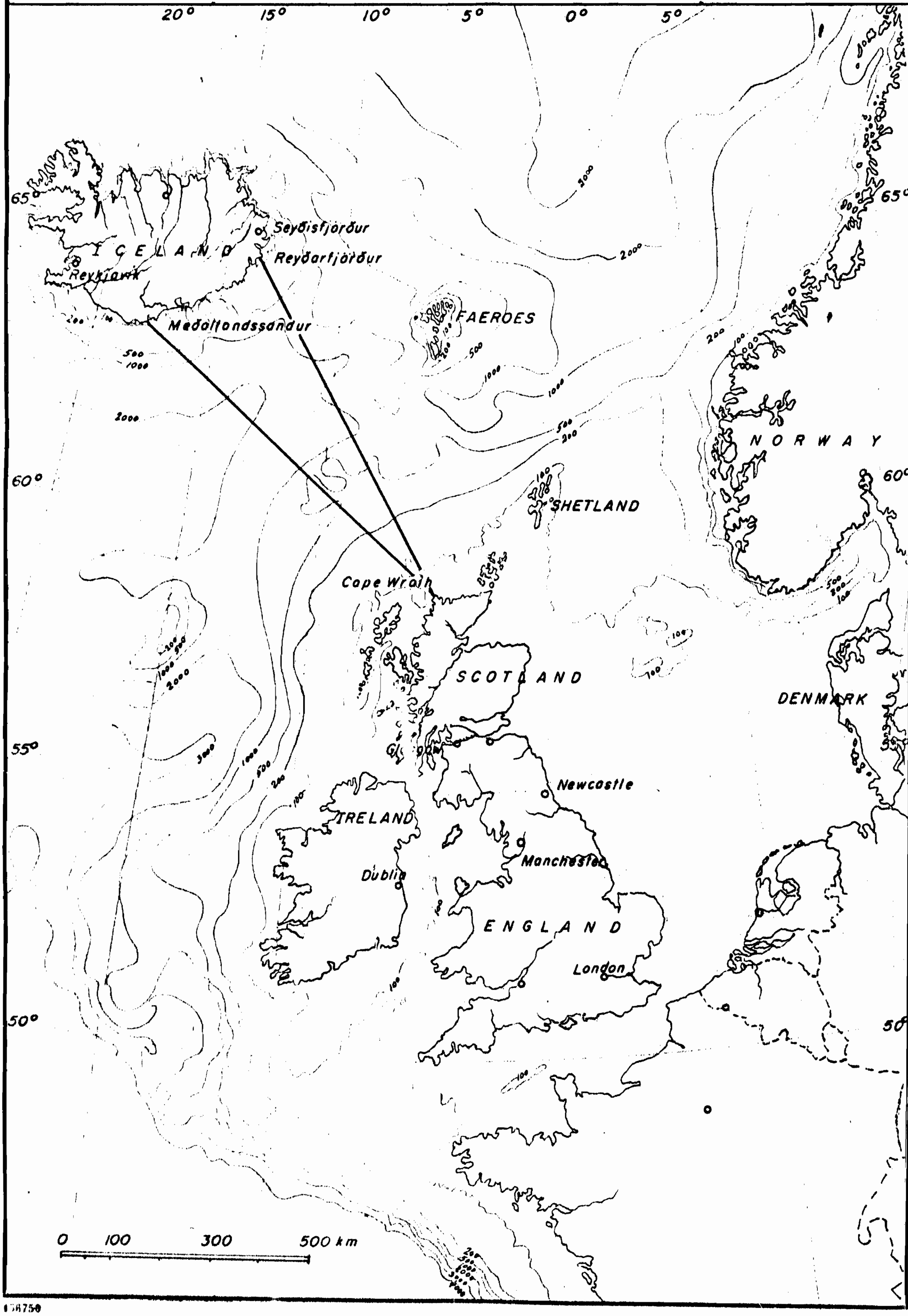

FIG. 2

NATURAL STEAM FIELDS IN ICELAND WITH ESTIMATED STEADY FLOW IN t/h AND BEDROCK HEAT RESERVOIR IN MILLIONS OF TONS (Mt) OF STEAM AT 3 ATA AND 132 °C

Scale 1:10 000 000

Possible Routes of a HVDC Submarine Power Cable Between Iceland and Scotland.

Fig 3

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