National Energy Authority,
Department of Natural Heat

A GEOTHERMAL POWER STATION

Preliminary project report on a 8 Mw, 12 Mw, 16 Mw and 55 Mw power station with regard to harnessing the Námafjall or Krafla thermal areas.

Sept. 1973

Summary and Conclusions.

This report is a direct continuation of a report titled "Geothermal Power Station, Preliminary Project Report on a Power Station with regard to Development at Námafjall or Krafla", published by the National Energy Authority in June, 1972. The reader is referred to that report for all specific technical data and assumptions on which the cost estimate is based. Prices on imported material are based on information obtained from "Toshiba", Japan, and "GIE Franco Tosi", Italy.

Geothermal prospecting has not been completed in the Krafla thermal area, but if the drilling of one or two exploratory wells there is successful then both areas, Krafla and Námaskarð, can be considered of equal suitability for harnessing. On grounds of waste water, however, it is considered unsuitable to construct a power plant to the west of Námafjall. Environmentally the waste water would probably cause similar pollution whether a power plant would be erected east of Námafjall or at Krafla, as in both cases the waste water would flow towards the edge of the Búrfellshraun lava. A considerable column of steam is associated with a power plant of this kind, but it is considered harmless to the environment and aesthetic considerations would be of major importance in deciding which locality would be more suitable on these grounds. The Krafla area is further away from inhabited areas.

The initial cost is estimated at 394 Mkr*, 464 Mkr, 555 Mkr and 1246 Mkr and the annual running cost at 53 Mkr,

* Mkr = million icelandic krónur

61 Mkr, 72 Mkr and 158 Mkr for power plants producing 8 Mw, 12 Mw, 16 Mw and 55 Mw respectively. The initial cost of one kw is therefore 49.000 kr, 39.000 kr, 35.000 kr and 23.000 kr for a plant capacity of 8 Mw, 12 Mw, 16 Mw and 55 Mw respectively.

A computerised simulation model has been made for the simultaneous operation of a thermal power plant and other power plants (hydropower) producing for the same network. The following results were obtained for the annual production of the thermal power plant in such a joint operation:

8 Mw power plant	55 Gwh/year
12 " " "	83 "
16 " " "	110 "
55 " " "	405 "

The production price based on these results and the estimated annual running cost would be:

8 Mw power plant	0,96 kr/kwh
12 " " "	0,73 "
16 " " "	0,65 "
55 " " "	0,39 "

Introduction.

This report is a direct continuation of a report titled "Geothermal Power Station, Preliminary Project Report on a Power Station with regard to Development at Námafjall and Krafla", published by the National Energy Authority in June, 1972.

All cost estimates for 8, 12 and 16 Mw power stations are recalculated in this report with regard to price changes and a cost estimate for a 55 Mw plant is added. Prices are based on the following rates of exchange:

100 yen	32,85	icelandic	krónur
100 liras	15,39	"	"
1 $	87,00	"	"

We refer to the previous report for technical arrangement in the power plants, but it should be emphasised that in all cases we assume that each plant will be run with a single turbine-unit. Additional information is presented on the steam plant at Mývatn and possible plant sites at Krafla and Námafjall are considered especially with regard to environmental implications. The price estimate is, however, made as if the plant were constructed at Krafla, but the plant would be slightly less expensive, if it were constructed in the eastern part of the Námafjall area. This report is, like the previous one, written by Karl Ragnars, mechanical engineer, Kristján Sæmundsson, geologist, and Stefán Arnórsson, geologist, of the Department of Natural Heat of the National Energy Authority, and Jónas Matthíasson, mechanical engineer, of the Guðmundur and Kristján Consultant Engineers.

The Steam Plant at Mývatn.

The steam plant at Mývatn is operated with six production wells (no. 4, 5, 6, 7, 8 and 9) and accompanying steam separators and steam pipelines. The Kísiliðjan diatomite plant uses 40 tn/hour of steam at 10-11 kg/cm^2 pressure, but 60 tn/hour at 8-9 kg/cm^2 pressure are used at the 3.2 Mw back-pressure steam power plant of the Laxárvirkjun Power Company. Drill holes number 4, 5 and 9 belong to the electricity plant and the holes number 6, 7 and 8 to the diatomite plant. The two systems are, however, interconnected and about one third of the steam used by the power plant comes from holes 6, 7 and 8, which yield considerably more than holes 4, 5 and 9.

Drillholes 4 and 5 were sunk in 1968, holes 6 and 7 in 1969 and holes 8 and 9 in 1970. The construction and finish of the wells in the Námafjall thermal area is not quite satisfactory as the drilling rig (Norðurbor) used was not powerful enough and well enough equiped for wells of this depth. As previously stated the diatomite plant and the power plant utilize about 100 tn/hour at present. Water is dissociated from the steam at each well head by steam separators at 8-12 kg/cm^2 pressure. The amount of thermal water in the wells is about 110 l/sec (400 tn/hour), but with the drop of pressure from separator pressure to atmospheric pressure a part of the water is converted to steam so that about 80 tn/hour of steam and 90 l/sec (320 tn/hour) of water at 100^o are disposed of at the separators into the environment. The steam for the diatomite plant is condensed within the steam dryers, which operate at 10 kg/cm^2 pressure, and the water is again converted to steam where the pressure drops to atmospheric pressure in the same way as in the steam separators. The steam for the power plant is not condensed (back-pressure turbine) and the steam is released from the station into the environment at 100°C. The plant has been operating under these conditions since 1969 and there have been no signs of thermal or chemical pollution in the surroundings, caused by the steam, but precipitation of silica from the thermal water has diminished the permeability of the lava into which the water is directed. The water thus flows considerable distances in search of new and new swallow holes. This problem is not considered serious at the present stage, as the permeable lava field is fairly extensive, but the problem will, of course, increase with time and similarly if drilling will increase.

At a few localities in foreign countries, where the only feasible drainage of the thermal water from projected power plants would be into irrigation systems, experiments have been made with reinjecting the thermal water under pressure into drillholes so that the dissolved silica cannot precipitate. This method has nowhere been used to any large extent as yet, and because of the cost involved it should only be considered an emergency procedure in Iceland.

Estimations of the extents to which thermal areas are utilized are commonly based on how much electricity can be produced in condensing power stations of the type discussed in this report. The present ejection of steam at Námafjall (Bjarnarflag) corresponds to 12-13 Mw production, according to this estimation method.

A Geothermal Power Plant at Námafjall or Krafla.

The disposal of steam and water from a 55 Mw condensing power station is illustrated in Fig.1. The smaller plants discussed in this report would eject less, linearly in relation to their size. The figure illustrates that 500 kg/sec of thermal water and 550 tn/hour of steam, are released into the environment. The thermal water, which contains much more dissolved chemicals than the ground water, produces a considerable stream from the plant, and it is certain that the dissolved silica will precipitate in the stream bed. The stream bed can be on the surface, or the stream may drain into the lava and mix with the ground water. The steam is ejected into the atmosphere where it disintegrates in a fairly limited area.

As a power plant of this kind pollutes its surroundings, it is self evident that environmental considerations will be a big factor in the selection of a plant site.

There are two thermal areas under consideration, i.e. Krafla and eastern Námafjall. The power station would be constructed in the eastern slope of Námafjall hill and on the plain below, but at Krafla the station would be constructed south of Víti crater and Mt. Krafla, at the head of Hlíðardalur valley. The geographical locations are illustrated in Fig.2. The illustrations show a 55 Mw plant.

A 55 Mw plant would, as stated previously, release 500 kg/sec of thermal water into the environment. In a plant at Námafjall this water would be directed eastwards, downslope from Hveraröndn, to the edge of the Búrfellshraun lava, which is about 1 km away from the potential plant site. The waste water at Krafla would be directed into a stream that runs southwards from the thermal area along Hlíðardalur valley. This stream drains into the lava at the western edge of the Búrfellshraun lava field, south of the main road at the same locality as where the waste water from the potential plant in Námafjall drains. The distance from the potential sites to the edge of the Búrfellshraun lava is 7 km and 1 km for Krafla and Námafjall respectively. A considerable precipitation of silica can be expected in the stream from Krafla. The stream bed along Hlíðardalur valley is rather impermeable, as it is sealed by clay from the thermal area and mud like tephra which was produced in the 1724 eruption of Víti volcano.

It is almost certain that silica precipitation from the waste water will change the scenery somewhat, but the precipitates are harmless. Thermal water in deep wells east of Námafjall is expected to have a similar chemical composition to the water presently obtained from the wells at Bjarnarflag. A similar composition is also expected in the Krafla area, although the water there would be more enriched in F and Cl, if perculated through acid volcanics.

The concentration of most of the dissolved chemicals in the waste water is so low that the chemicals would neither endanger vegetation near streams or canals along which the water would flow nor life in lake Mývatn. These chemicals are SiO_2, Na, K, Ca, Mg, Co_2, SO_4, Cl and F. There is no doubt, however, that H_2S (20-40 ppm in the waste water) might cause some pollution. It should be relatively easy to diminish the H_2S concentration at least 50% by air stripping the waste water. It is not certain whether the high concentration of H_2S would be harmful in some way to living organisms in lake Mývatn, although vegetation close to waste water streams might be harmed.

It is, however, considered very unlikely when the distance from Mývatn is taken into account and, even more important, in view of the very extensive ground water drainage system into which the waste water is mixed. H_2S is slowly broken down by oxidation into S and SO_4 when mixed with fresh water, due to the effects of oxygen in the fresh ground water. The pollution danger far away from the power plants is significantly increased if the waste water follows a well defined path at depth. It should be mentioned that there must be a considerable amount of thermal water and gases mixed with the local groundwater systems naturally in the Námafjall and Krafla thermal areas. By utilizing these areas sensibly, i.e. by avoiding overexploiting the areas, the amount of thermal water mixing with the groundwater should not increase significantly but mainly change in character from the natural situation.

It is considered likely that trace elements such as B and As are near the danger limit in the waste water, according to the tolerance limits of WHO and USPHS, but the tolerance limits are given with respect to vegetation and living organisms in lakes. The possibility of some plant species near the waste water channels being damaged can therefore not be excluded. This danger will, however, decrease with distance from the power plants as the waste water is diluted by fresh water. Because of hydrolisation As will also precipitate easily. There is higher concentration of SO_4 in thermal water than fresh water and the mixing of the thermal water with groundwater may stimulate plant growth.

It is assumed that 15 drill holes will be needed for a 55 Mw power plant, irrespective of which area would be selected. The distance between drill holes will be of the order of 100 m. The holes will be sunk within the thermal areas and the edges of the areas avoided. This implies that wells in Námafjall will be sunk on the top of Námafjall hill and in its eastern slopes down to Hveraröndd, but rather not further east on the lava plain. At Krafla the wells would be sunk at the foot of the hill at the head of Hlíðardalür valley, in the slopes southwest of mount Krafla, in the gulleys running northwards to Víti, on the flat ground between the gulleys and west of the westernmost gulley.

The Víti crater, and the small craters associated with it. will be protected and not disturbed.

The power plant at Námafjall will be built on the lava field east of Hveraröndd. This lava was erupted in the fissure of Þrengslaborgir about 2000 years ago. The lava extends all the way to the main road, where it is very thin. It is necessary to investigate its thickness and the nature and bearing capacity of the layer below it, which may be of clay. At Krafla the station will be built at the head of Hlíðardalur valley. The plain is made of lavas, but the slopes are of hyaloclastites and pillow lavas. Both the lavas and the hyaloclastites are covered by tephra, mainly originating from the crater Víti. The tephra layer is generally 1-2 m thick, but thicker on the plain where streams have made thick deposits on top of the lavas. It would be necessary to investigate the depth to bed rock by drilling or digging.

Gravel would be needed for constructing roads, drill platforms, foundations for pipelines and for building houses at both plant sites. If the Námafjall site were chosen, gravel could be obtained in Sandfell or Námaskarð, but gravel for road building is presently mined at both localities. There is also a gravel pit in a crater by the main road east of Hverarönd. The most promising gravel pit sites for a plant in Krafla would be in the spur of a hill in eastern Sandabotnafjall, about 1 km south of the potential plant site. Less amounts of construction material, both volcanic cinders and gravel, could be obtained in the slopes of Hlíðardalur valley.

It would be necessary to construct a main road, as free of snow as possible. from the inhabited area at Reykjahlíð to the Krafla power plant. It would apparently be preferable to construct the road west of Mt. Dalfjall than along the Hlíðardalur valley. The road could lie from the present power plant at Námafjall or the Kísiliðjan diatomite plant and directly towards Hlíðarfjall. This route is mostly covered by a relatively flat aa lava and is apparently suitable for road building. The road could lead east of Hlíðarfjall towards Leirhnjúkur and from there down to the plant site. The road could similarly be constructed on a flat pahoehoe lava through a relatively broad pass north of Þríhyrningur, and from there down to the plain at the head of Hlíðardalur. Electricity power lines would probably follow the same route as the road. The possibilities of snow blocking on this route have not been investigated as yet, but it should be relatively free of snow as the land is open and with no small hills or gulleys.

Table 1

Initial cost

Geothermal power station at Krafla/Námafjall

Items	8 Mw Mkr	12 Mw Mkr	16 Mw Mkr	55 Mw Mkr
1. Drill holes (4-4-5-15 holes)	62.0	62.0	77.0	227.0
2. Steam transmission pipelines	22.4	22.6	26.6	80.0
3. Turbine, generator, condenser	102.7	136.4	167.0	338.2
4. Cooling tower, pumps, pipes for cooling water	23.4	35.2	47.2	143.8
5. Electrical system	28.9	31.4	34.5	94.9
6. Power house, pump house	39.7	46.3	52.9	59.2
7. Cranes in power and pump houses	6.5	7.1	7.8	14.1
8. Flats for staff	15.3	15.3	15.3	15.3
9. Roads	10.5	10.5	10.5	10.5
Basic cost	311.4	366.8	438.0	983.0
10. Unforeseen cost 15%	46.7	55.0	65.6	147.4
Direct cost	358.1	421.8	504.6	1130.4
11. Engineering and supervision 10%	35.8	42.2	50.5	113.1
Initial cost	393.9	464.0	555.1	1243.5

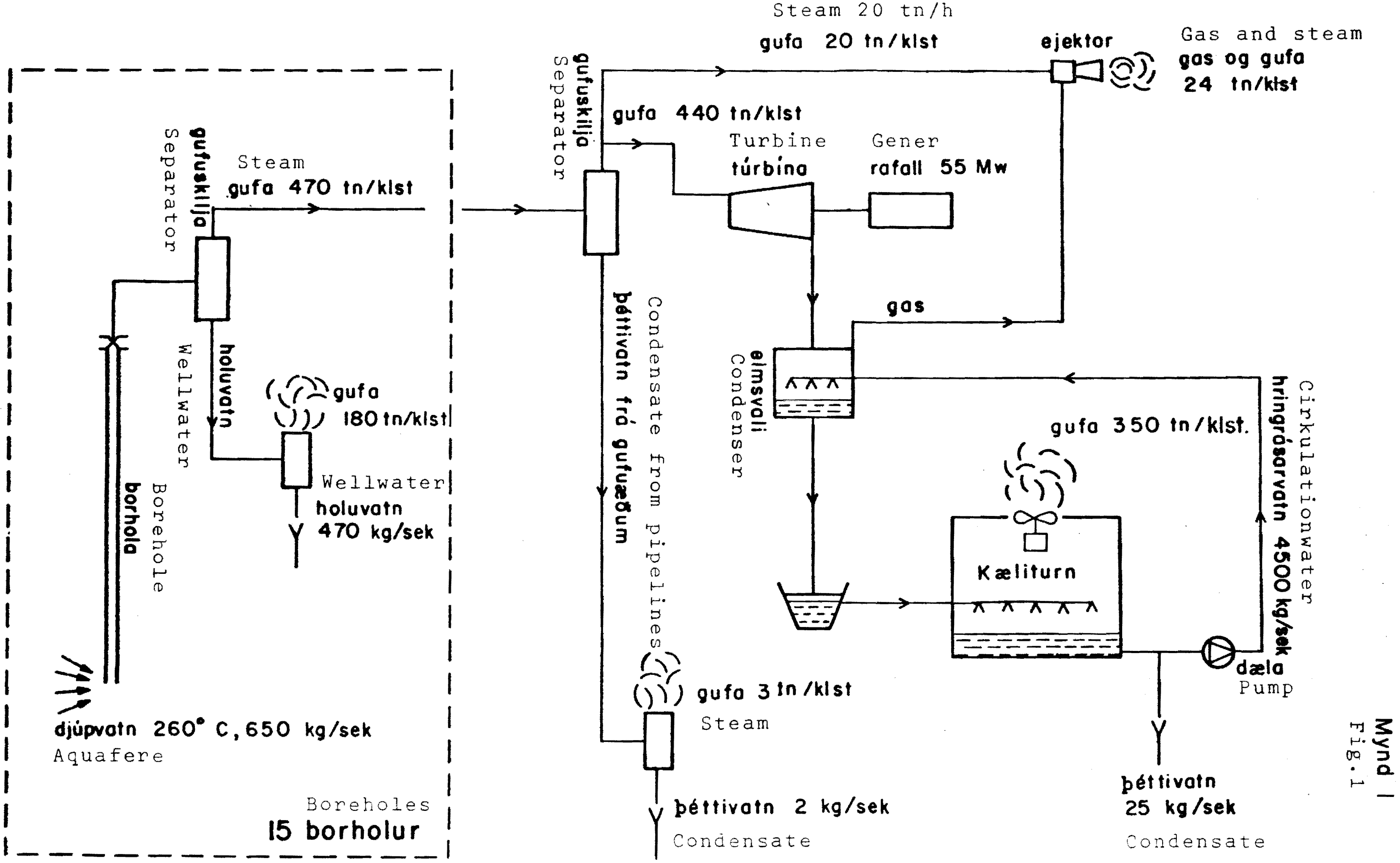
Table 2

Annual operating cost

Geothermal power station at Krafla/Námafjall

Items	8 Mw Mkr	12 Mw Mkr	16 Mw Mkr	55 Mw Mkr
Capital cost (25 years, 8%):				
1. Drill holes	7.3	7.3	9.1	26.9
2. Steam transmission pipelines	2.6	2.6	3.2	9.5
3. Turbine, generator, condenser	12.1	16.2	19.7	40.1
4. Cooling tower, pumps, pipes for cooling water	2.8	4.2	5.6	17.1
5. Electrical system	3.4	3.7	4.0	11.2
6. Power house, pump house	4.7	5.4	6.2	7.1
7. Cranes in power and pump houses	0.8	0.9	0.9	1.6
8. Flats for staff	1.8	1.8	1.8	1.8
9. Roads	1.3	1.3	1.3	1.3
Cost of maintenance:				
1. Drill holes (1%)*	0.8	0.8	1.0	2.9
2. Steam pipelines (2%)*	0.6	0.6	0.8	2.0
3. Turbine, generator, condenser (1.5%)*	1.9	2.5	3.2	6.5
4. Cooling tower, pumps (1.5%)*	0.5	0.5	0.9	2.8
5. Electrical system (1.5%)*	0.5	0.6	0.6	1.8
6. Station house, pump house (0.14%)*	0.2	0.2	0.2	0.2
7. Cranes in station and pump houses	0.1	0.1	0.1	0.1
8. Flats for staff (0.14%)*	0.2	0.2	0.2	0.2
9. Roads (3%)*	0.4	0.4	0.4	0.4
10. Maintenance drill holes (5.5%)*	4.3	4.3	5.3	15.8
Other cost:				
Salaries of staff	5.0	5.0	5.0	5.0
Administration	1.0	1.0	1.0	1.0
Bank reserves	0.6	0.8	1.0	2.5
Operating cost	52.9	60.4	71.5	157.8

* % of initial cost



Mynd 1
Fig. 1

ORKUSTOFNUN
Jarðhitadeild

Systems of steam and water for
Gufu og vatnskerfi
55 MW jarðgufuaflstöðvar með eimsvala
55 MW Geothermal powerstation with condenser

13.9.1973 KR/HO
Tnr. 393
J-Ým.
Fnr. 11430

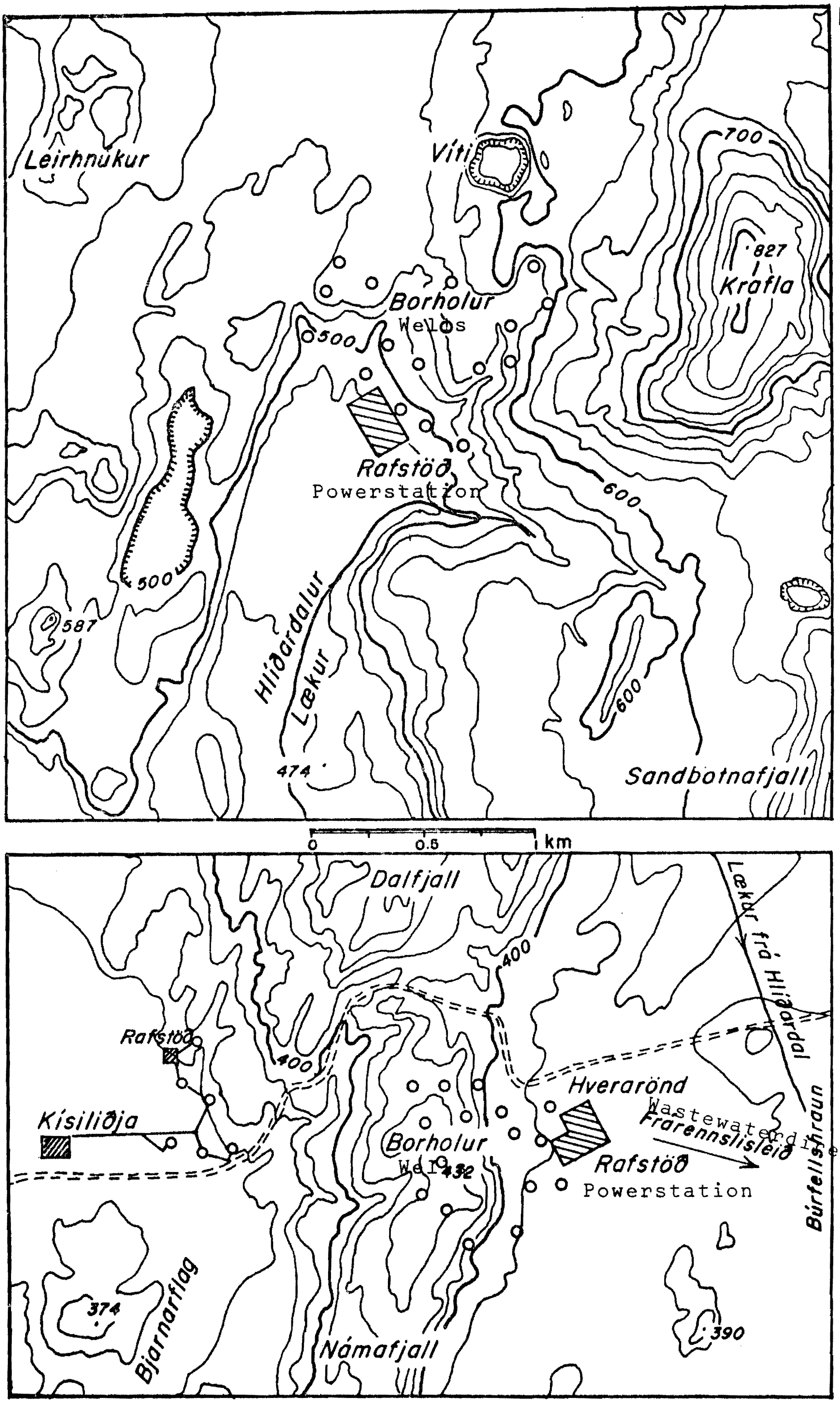
OS **ORKUSTOFNUN**
Jarðhitadeild

19.9.1973 KR/Gyða	
Tnf. 396	
J-Ým.	
Fnr. 11434	

Jarðhitasvæði við Kröflu og Námafjall

Geothermal areas at Krafla and Námafjall

Mynd 2
Fig.2



	ORKUSTOFNUN Jarðhitadeild Cost of electricity	16.9. 1973 KR / HO
	Raforkukostnaður	Tnr. 394
		J-Ým.
	jarðgufuaflstöð með undirliggjandi eimsvala Geothermal powerstation with condenser	Fnr. 11431