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Icelandic experience with direct use of geothermal energy

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Energy Resources and Energy Use in Iceland

Of the aggregate energy use in Iceland today, imported oil accounts for roughly 47% and domestic sources for 52%; the breakdown of the second component is 22% hydro and 30% geothermal. Everyone familiar with Iceland at all knows that it has a vast energy potential, both hydro and geothermal, at any rate in the context of a national population that is well under the quarter-million mark.

In assessing hydro resources, it is customary to estimate the theoretical potential on the basis of total surface drainage and the average drop of the flow to sea level. Applied to Iceland, that formula gives an aggregate of some 180 TWh annually. The truly harnessable proportion of that is determined by several factors, including environmental considerations and cost in relation to energy from alternative sources. By listing the likely hydro sites and adding up their potential, one finds that Iceland has an exploitable power resource anywhere between 30 and 50 TWh annually. The present hydro generation of electricity in Iceland is only around 2.8 TWh annually, or equal to just 5-8% of the exploitable potential. By way of explanation, one might add that the total annual electricity consumption in France is some 200 Twh, or four times Iceland's harnessable hydro potential.

It is more difficult to assesss the geothermal potential of Iceland. One can estimate the theoretical total by using a simple method where the following factors are taken into account:

- the volume of the country above a depth of 3 km,
- the thermal gradients established for different regions,
- the specific heat of rock and water and their likely proportion in the cited mass,
- a reject temperature of 40°C
- and the assumption of no new heat transfer from below 3 km.

According to the method, Iceland has a geothermal potential of 3,000 TWh annually for one century. Obviously, that estimate tells nothing about how much geothermal energy can actually be tapped. Instead, it expresses the upper limit of the resource and suggests that the harnessable total typically be increased by a factor of 10 to 20 if the water level in drillholes is lowered and pumps installed. If the average temperature of the retrieved water is assumed to be 100°C, the flow increased tenfold from the natural flow and the reject temperature set at 40°C, the harnessable potential of the low-temperature sources is 32 TWh annually. The total use each year of geothermal water in Iceland stands at about 54 million tonnes (Mtn) at average temperature of 85-90°C, which is equivalent to 2.9 TWh.

Table 1 shows a breakdown of the harnessable potential of Icelandic energy sources annually.

TABLE 1

Energy use:	Space Heating, Industry	Power Generation
Hydro sources:		30 -50 TWh
High-temp. sites:	160 TWh (>40°C) or	16 TWh (>130°C)
Low-temp. sites:	32 TWh (>40°C)	

Table 2 presents energy production and energy use in Iceland. The dual tabulation is necessary for a comparison of the current energy output and the total domestic potential, as also for demonstrating how and to what extent relatively cheap energy can be substituted for more expensive supplies. The table shows that space heating is the largest category of energy use in Iceland or 42.5% of the total. But while 67% of the national population have the benefit of geothermal heating, the cost of all that is just 35% of the total energy bill for heating. On the other hand, the 20% of the inhabitants who depend on heating oil account for 47% of the total outlay for the purpose. Compared to oil heating the cost of geothermal heating is only 22%.

Heating and Industrial Use of Geothermal Energy

As Table 2 makes clear, the overwhelming bulk of geothermal energy used now in Iceland is for space heating - which is a very basic requirement, given the northerly latitude of the country and the need for heating buildings most days of the year. Generally speaking, however, the energy use for that purpose during the coldest season is three times the level of the warmest months.

TABLE 2

Energy production and energy consumption in Iceland in 1979

- Production: hydro power - geoth. energy at wellhead - use of oil products
- Consumption: power sales - geoth. sales - oil utilization

	Energy prod.	%	Efficiency	Energy consumption	%
Gen. use (power, hydro)	395 GWh		0,86	340 GWh	
" " (" geoth.)	514 "		0,07	36 "	
" " (" oil 13 ktn)	162 "		0,36	58 "	
	1071 GWh	8,2%		434 GWh	5,1%
Space heating (hydro power)	561 GWh		0,86	482 GWh	
" " (hot water 54 mtn)	2936 "		0,85	2496 "	
" " (geoth. steam)	244 "		0,68	166 "	
" " (fuel oil 86 ktn)	1049 "		0,65	681 "	
	4790 GWh	36,7%		3825 GWh	45,2%
Energy intensive industry* (hydro power)	1483 GWh		0,94	1394 GWh	
	1483 GWh	11,4%		1394 GWh	16,5%
Other industrial use (hydro power)	379 GWh		0,86	326 GWh	
" " " (geoth. steam)	320 "		0,40	128 "	
" " " (fuel oil 20 ktn)	244 "		0,70	170 "	
" " " (light fuel oil 27 ktn)	310 "		0,85	263 "	
	1253 GWh	9,6%		887 GWh	10,5%
Fish processing (light fuel oil 104 ktn)	1195 GWh		0,85	1016 GWh	
	1195 GWh	9,1%		1016 GWh	12,0%
Vehicles (petrol 88 ktn)	1063 GWh		0,20	212 GWh	
" (diesel oil 25 ktn)	304 "		0,30	92 "	
	1367 GWh	10,5%		304 GWh	3,6%
Fishing fleet (diesel oil 121 ktn)	1476 GWh		0,36	487 GWh	
" " (light fuel oil 30 ktn)	345 "		0,30	103 "	
	1821 GWh	13,9%		590 GWh	7,0%
Domestic aviation (jet fuel 6 ktn)	73 GWh		0,20	14 GWh	
	73 GWh	0,6%		14 GWh	0,1%
	13053 GWh	100,0%		8464 GWh	100,0%

* Incl. Keflavik Airport (ca. 3%)

Breakdown of energy production and consumption in Iceland in 1979

	Hydro power	Geoth. power	Oil
Production:	21,6%	30,7%	47,7%
Consumption:	30,0%	33,4%	36,6%

The first steps toward systematic utilization of geothermal energy for space heating and related purposes were taken in Iceland during the early decades of this century, both in Reykjavik and other places where sufficient natural flow from hot springs was available. Geothermal drilling started relatively soon, but the first large-scale harnessing project was during World War II, when wells were sunk and a pipeline from them laid for a distance of 15 km to Reykjavik for a municipal heating system. In Iceland generally, however, geothermal heating did not become common for a time, and the benefits of the Reykjavik installation were largely restricted early on to the central part of town. The city grew very fast while further geothermal development was slow. The reason for that lag, it seems, was that the cost advantage of natural hot water over fuel oil was minor.

But progress in the exploitation of geothermal resources became fast after 1960, when a newly acquired rig that could drill to a depth of 2 km was used to tap two sites inside Reykjavik. Developments in pumping technology were being made at the same time; by placing pumps at a depth of 120 m, it proved feasible to increase the natural flow from geothermal wells. In the 1960's, the Reykjavik municipal heating system was extended throughout the city, and in the 1970's to three communities in the vicinity. Meanwhile, existing geothermal installations elsewhere in the country were enlarged and new projects started. Understandably, the effort became intense in the wake of the 1973 oil crisis, with the result that 67% of Icelanders today live in geothermally heated dwellings.

Some 20 installations provide the bulk of that service. Most of them tap low-temperature sites, using water of from 60 to 130°C, and are of relatively simple design. Typically, the water is piped from the wells to pumping stations, where it is degassed and then pumped on to distribution systems, for direct use in homes for heating and other purposes. As a rule, the temperature at the consumers' hookups is not higher than 80°C, while the waste water goes into sewers at 30-40°C. There are exceptions when the wellhead temperature is above 90-100°C; in such cases, part of the system is normally a dual one, in that spent water from houses is returned for diluting what comes direct from the source.

When high-temperature areas are harnessed for space heating, a more complex application is usually dictated by high concentrations of dissolved substances and gases in the water; the first may cause scaling in the system, while the second will make the water unsuitable for laundering and human consumption. In such circumstances, heat-exchanger technology is called for - where the heat energy is transferred to fresh water. But that procedure is inevitably more expensive than direct use of geothermal water, and the overall efficiency suffers because water must be rejected at two points: the wellhead and after circulation through single systems in homes.

At some sites tapped for heating installations, there is enough hydrostatic pressure for a sufficient spontaneous flow from natural springs or drillholes. More often, however, the water level in the holes is lowered through pumping - which, as mentioned before, generally makes it possible to multiply the natural flow. Used for that purpose are so-called deep-well pumps; the first such device was installed in a Reykjavik drillhole in 1960, and development in that sphere has been extensive since that time. The pumps used today in Iceland have closed impellers and sealed water-lubricated lineshafts; so far, the maximum depth of operational placement is 130 m, with maximum temperature at 130°C. These are no definite limits, but stem from the present pump design, specifically from differential expansion between pipe column and lineshaft during startup. The increasing pumping cost with depth is a criterion in selecting the level where the devices are installed. Currently, the cost of electricity for pumping of the Reykjavik district heating system is 6-8% of the proceeds from the sale of geothermal water.

The supply pipelines are of various types depending on local circumstances, especially the distance from source to distribution system and the size of the market. The most common basic designs of transmission lines from wells or pumping stations are:

1) steel pipe insulated with rockwool in concrete duct,
2) steel pipe above surface, insulated with rockwool and encased in sheet metal,
3) asbestos-cement pipe covered with earth,
4) steel pipe with polyurethane insulation and plastic casing,
5) plastic pipe insulated with rockwool.

Because the concrete duct is very expensive, type 1 is used only when the pipeline must pass through built-up areas, across roadways or where there is risk of damage. The only geothermal transmission line in Iceland that is completely in a concrete duct is the one from Reykir to Reykjavik, a distance of 12 km. Pipelines of types 2 and 3 are commonly used for towns and factories, while types 4 and 5 are more or less the rule in systems for villages or farms, and in hookups from supply lines. The cost of the different transmission-line types varies greatly; so does the distance that is possible without unacceptable heat loss.

Figure 1 shows transmission cost per kWh of geothermal water as a function of the volume, and also the maximum pipeline length, based on temperature drop of 20°C, as a function of volume. The transmission cost per unit of water decreases fast with increasing flow, and larger volume makes a longer line possible. According to Figure 1, some representative figure is:

a) Insulated steel pipe with plastic casing:
3.4 l/sec - 10 km - 10 kr/kWh

b) Insulated steel pipe with sheetmetal casing:
100 l/sec - 100 km - 10 kr/kWh

c) Same pipe as in b):
1,000 l/sec - 460 km - 10 kr/kWh

With 67% of the Icelandic population already enjoying geothermal heating, and with more than half of that figure accounted for by Reykjavik and neighbouring urban areas, it is clear that the most cost-efficient district systems have been completed. Conditions in localities still without geothermal heating are less favourable because of distance from sources, their scarcity or the smallness of the market. That goes especially for rural districts, where the goal is to replace fuel oil with heating from hydro power.

In the harnessing of geothermal sources thus far, the prime emphasis has been on space heating - a very basic need in a country with Iceland's latitude. But there has also been considerable use of natural hot water for swimming pools and greenhouse cultivation of vegetables and flowers. The traditional exploitation of geothermal energy has progressed close to the point of diminishing returns in comparison with electric heating. Additional uses of natural hot water are thus called for if geothermal developments are to continue.

One thing that comes to mind is extracting heat energy from waste water, which now goes into sewer systems at some 30°C. There will also be good justification for finding new uses of water coming direct from geothermal

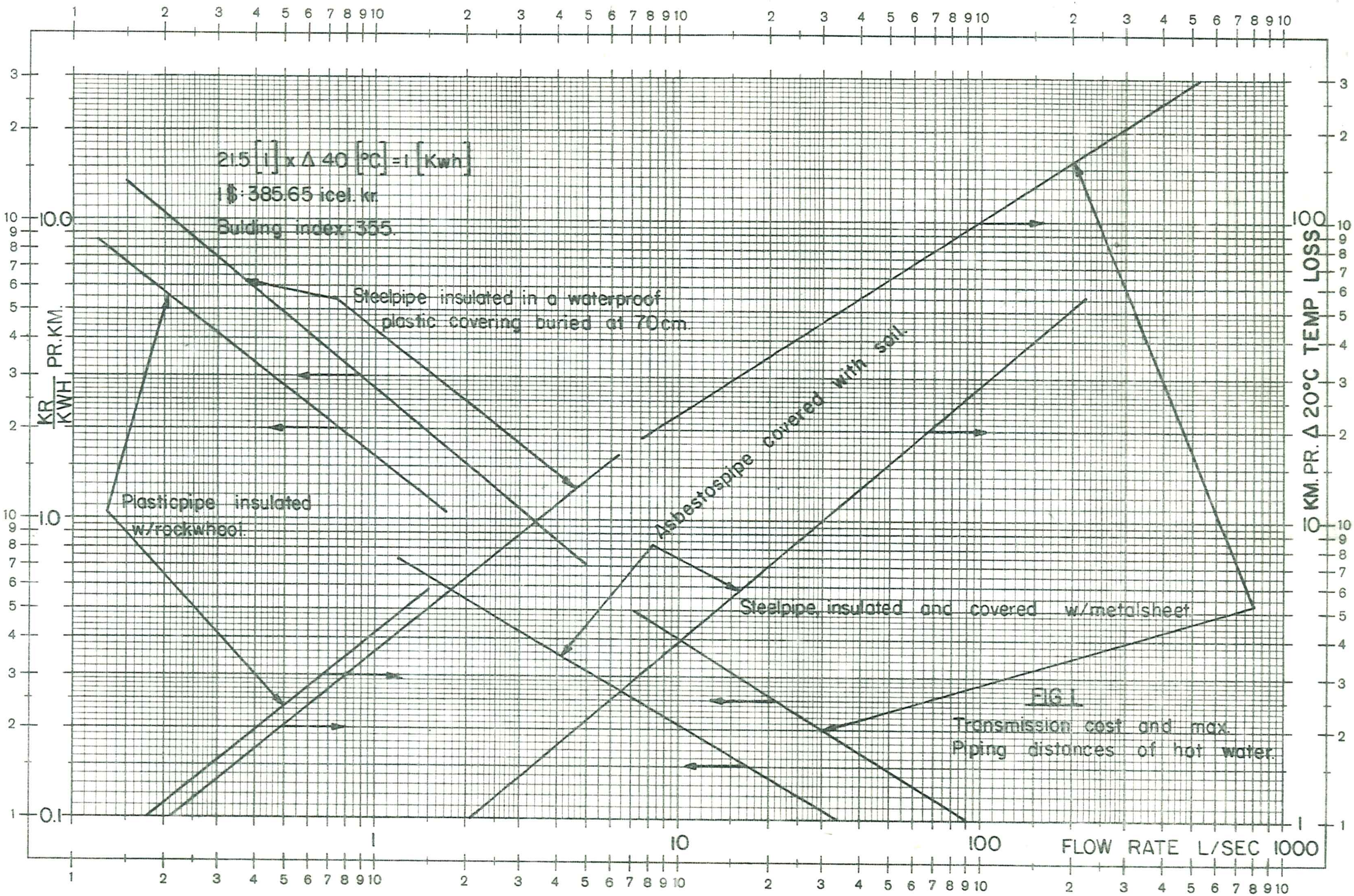

FIG. I.
Transmission cost and max. Piping distances of hot water.

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sources, as the capacity of existing installation can often be boosted at little cost. Some utilization of reject water is in evidence already, for melting snow off driveways and sidewalks, as also for soil heating in gardens. In recent years, large numbers of Icelanders have gone on vacation tours to sunny climes, and that has led to interest in somehow making use of geothermal water to create lushly vegetated outdoor spots, perhaps in conjunction with swimming pools.

There is interest in developing spas, too. One health resort with mud-baths, of a type popular in Japan, has operated in Iceland for a long time. Further greenhouse developments hold out a great promise - and with regard to geothermal heating of soil in agriculture, the surface has hardly been scratched yet. It is an intriguing possibility because the cool and short Icelandic summer makes for limited growth of produce; experiments along that line have demonstrated that crops can be increased by up to one third when a simple heating grid from plastic tubing is laid in the ground.

Still another potential use of geothermal water concerns fish farming - a procedure that has been tried on a small scale for a lengthy period. In that context, the emphasis has been on raising salmon to the smolt stage for release into rivers; the ideal water temperature at the hatchery is 10-15°C, and this is where geothermal energy enters the picture. A prerequisite in any such effort is plenty of fresh water, and few places have more of that than Iceland. Most of the salmon take in Iceland has been the catch of game fishermen, but there is growing interest in developing a commercial salmon industry through more stocking of rivers and perhaps raising of the fish to maturity.

There has been industrial use of geothermal energy in Iceland for some time, chiefly for drying and lately also for distillation. The largest operation in the field is a diatomite plant at Lake Myvatn in the North, whose feedstock is diatomaceous earth dredged from the bottom of the lake. That material is pumped, as 5% solids in water, for a distance of 3 km to settling ponds by the factory. From there it is pumped into the plant, first over vacuum filters and then into steam-tube driers. The geothermal heat energy comes from drillholes at a nearby site called Namafjall that has base temperature of some 280°C. Steam from separators there goes at 180°C and pressure of 10 atg to the plant. The geothermal steam plays a vital role in the drying process and is used additionally for heating the structures, and for melting ice off the settling ponds in winter - an important function as temperatures as low as -30°C occur in that season. The total cost of the heat energy for the plant is just 10% compared with oil.

Geothermal energy is used in a similar way for drying by a W-Iceland sea-weed industry - while at a high-temperature site in the southwest region, common salt is being produced experimentally with such energy, from geo-thermal brine tapped from permeable strata. There has been a preliminary study of the feasibility of using geothermal heat to refine sugar for domestic consumption from imported molasses. The lastly cited processes are highly energy-intensive, and projects of the type would be out of the question in Iceland if imported oil had to be used.

Even so, it is known that energy costs are not a large part of total expen-ditures in such production; moreover, cheap solar energy in warm climes is a rival source. On the other hand, Iceland has an export industry that is energy-intensive and strictly its own - namely, the fish factories. As Table 1 shows, their annual operation requires 1,016 GWh provided by oil, equal to no less than a quarter of the total energy used for space-heating purposes, the largest single category of energy consumption in Iceland. Some of these plants are so located that geothermal water or steam for them might be a possibility, despite considerable distances in certain cases - especially as it is a question of large and concentrated markets. But, sadly, research and planning in this domain is not far along - a neglect in part explainable in terms of relatively short peak seasons in many instances. It is conceivable, however, that a conversion to geothermal energy in this in-dustry might come to rank second only to savings from that domestic source in space heating.