HISTORICAL ASPECTS OF GEOTHERMAL UTILIZATION IN ICELAND

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ABSTRACT

Volcanoes and hot springs were probably the only natural phenomena completely new to the first settlers when they came to Iceland in the 9th century A.D., as these were unknown in northern Europe. The distribution of hot springs did not affect the location of farmhouses during the Age of Settlement, but the hot springs were gradually taken into **use** for washing and bathing. Numerous localities were named after the geothermal manifestations, most notably Reykjavik - Smoky Bay. Geothermal springs first became of national interest in the year 1000 when the Icelanders decided by parliamentary decree to adopt Christianity, and the then-pagans refused to he baptized except in warm water. The oldest known geothermal pipeline (a covered duct made of stone slabs) dates back to the 13th century. It is proposed that pilgrims brought this technology from Italy. Space heating with geothermal water was, however, not started until 1908 in Iceland. For several centuries, sulphur mined in geothermal fields was one of the main export products of Iceland. Hot springs were used at one locality for extracting salt from sea water (average production of 53 tonneslyear) during 1773-1793.

1. LOCATION OF FARMS AND HOT SPRINGS

Warm springs and steaming ground have probably been amongst the natural phenomena that were most surprising to the first settlers when they came to Iceland in the 9th century A.D. It is unlikely that any of the settlers had seen hot springs or active volcanoes before. The novelty of the hot springs is reflected in the numerous place names including reyk (smoke), **laug** (hot spring), and hver (boiling spring), such as Reykir, Reykjavik, Reykjadalur, Laugaland, Laugarvatn, Laugardalur, Hveravellir, and Hveradalir. It **is** likely that the settlers were suspicious of the hot springs and steam to begin with. But many of them were Vikings who claimed to fear nothing, and one can assume that they soon started using the hot springs for bathing and washing.

There are more than 250 separate thermal areas with **over** 600 main hot springs in Iceland. The majority of these are in lowland areas in the southern, western, and northern pans of the island. The distribution of the hot springs does not appear to have had any significant influence on the location of farmhouses during the Age of Settlements (874-930). In Landnáma (the Book of Settlements), which was written in the 12th century and covers the entire island, there are told stories of some 430 principal settlers, whereof about 100 obtained land within the lands of earlier settlers (commonly kinsmen of the first settlers). Stories are told of the land claims of each settler, his farmstead, his ancestors in the old country, and his descendants in the new. Researchers have tried to locate exactly the position of individual farmhouses from the text of Landnáma. In many cases, there is little doubt about the location of the farmhouses. A comparison of **a** map of the settlement farms in the edition of Hið islenska fornritafélag, (Landnámabók, 1968) and maps with the location of the hot springs of Iceland **does** not at **all** indicate that the first settlers wanted to build their farmhouses near the hot springs. On the contrary, Ingólfur Arnarson (considered to be the first Norse settler in Iceland), built his farmhouses about **3,5** km from the hot springs in Reykjavik. Apparently, he preferred to have his farm close to a good beach for landing boats rather than at hot springs suitable for washing clothes and bathing. Why not? The women would take care of the washing anyway!

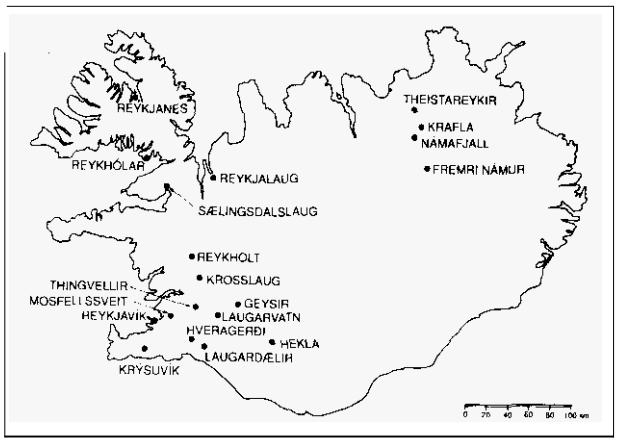

Figure 1. The main geothermal localities discussed in the text

2 USE OF HOT SPRINGS THROUGH THE AGES

It is not know with any certainty when the hot springs had been taken into general use for washing and bathing. Reference is frequently made to bathing in hot springs in the sagas which were written in the 12th-13th century A.D. Fig. 1 shows the main geothermal localities discussed in the paper. There are several romantic descriptions in the sagas of people bathing in the hot springs, in particular in Laxdæla Saga (Islendingasögur, 1981) where the beautiful hut strong minded Guðrún Ósvífursdóttir meets her hero Kjartan Ólafsson in the Sælingsdalslaug (hot pool) in the twilight. In addition to washing and bathing, the hot springs were also used widely for bending wood and bones, and for softening materials. Apart from the elaborate bathing pool **of** the saga writer Snorri Sturluson, which will be described in a separate chapter, the bathing pools seem to have been rather primitive. Commonly people would take a bath in brooks where hot water from the often boiling springs would be mixed with cold water. Eggert Ólafsson and Bjarni Pálsson (Ólafsson and Pálsson, 1943) in their travel book from 1752-1757 describe the bathing pools in Laugarnes (now the site of the main swimming pool of Reykjavik), where the people of Reykjavik brought clothes for washing and sailors and workers came in large groups on Saturday and Sunday nights for bathing.

Boiling food (meat, fish, eggs, milk) and baking bread was also

common in the hot springs. Ólafsson and Pálsson (1943) also mention that people used the hot clay from mud pools in Ölfus (probably in the geothermal field of the present day Hveragerði hot spring village) to make wood barrels for storing food airtight. They also mention dry-baths or steam-baths (saunas) in Thingeyjarsýsla in N-Iceland and in Árnessýsla in S-Iceland. Thorvaldur Thoroddsen who was travelling in Iceland a century later (1882-1892) mentions a dry-bath at Sturlureykir near Snorri's Reykholt in W-Iceland. He also mentions that people divert hot water into fields where they grow potatoes and cabbage. This increased the vegetable yield significantly. Here we have the first documented examples of soil heating in Iceland. Sulphur mining in geothermal areas was of significant interest from the 13th to the late 18th century. Geothermal springs were used for salt extraction from seawater during 1776-1792. These activities are described in separate chapters.

3. HOT SPRINGS OF NATIONAL INTEREST

The first time that geothermal energy was of national significance in the history of Iceland was associated with the adoption of Christianity as the formal religion of Iceland around the year of 1000 A.D. After a decree by an arbitrator, the Parliament decided that the people should give up the pagan gods of the Vikings and become Christians. This was accepted with some grunting. But when it came to the ceremony of baptism, which involved every individual being submerged in water, real trouble arose. The people at the Parliament absolutely refused to be baptized in cold water. According to Kristni Saga (Islendingasogur, 1981), the Saga of Christianity, originally written in the 12th century, the people from northern and southern Iceland were baptized in a hot spring named Reykjalaug (later called Vígðalaug=the consecrated spring) at Laugarvatn some 20 km east of the Parliament site at Thingvellir. The people from the western parts were baptized in Reykjalaug in Lundarreykjadalur (later called Krosslaug=the spring of the cross) some 30 km north of Thingvellir. Both springs were considered to have healing powers after this.

4. SNORRIS BATH AND CONDUITS FOR WATER AND STEAM

The only man-made bath still remaining in Iceland from the past centuries is Snorralaug (Snorri's bath), the bath of the famous historian and saga writer Snorri Sturluson (1178-1241) in Reykholt in W-Iceland (Fig. 2). It is in fact one of the most remarkable archaeological monuments in Iceland. The pool is circular in shape, slightly under 4 m in diameter, about 0.9 m deep, and made of hewn blocks of stone (silica sinter, which can be found about 2 km from Reykholt) which fit each other in the most exact manner (Fig. 3). The floor is paved by the same stone, and a stone bench, capable of seating some 30 people, surrounds the inside of the bath. It is filled by hot water led through an underground stone conduit from a boiling spring called Skrifla about 120 m away. In the old days, it is said that the temperature of the water could be altered by the addition of cold water from a brook that now is dried up. Archaeological excavations have revealed three conduits from the vicinity of Skrifla (Grimsson and Ólafsson, 1987). Two of these lead to Snorralaug (Snorri's bath), and are considered to have been used for transporting water to the bath. The third goes from the morass of Skrifla up a slope to the farm site. This pipe is considered to have been used to transport steam from Skrifla to a place near the farm. It is not known whether the steam was used for a steam bath or for cooking and baking, or possibly for warming up a house. The three conduits are built in such a way that ditches have been dug through the soil and humus layer (1-2 m deep), a narrow channel has been made into the underlying clay at the bottom and slabs of rock have been used to cover the channel. In some cases, small slabs of rock have been lined along the sides of the channel to give support to the larger slabs of rock used to cover the channel. The ditches have then been filled with soil.

According to Landnámabók (the Book of Settlements), describing the situation late in the 10th century, there was no farm at Reykholt but only sheep sheds belonging to the settlement farm Breiðabólsstaður, and a bath. As Tungu-Oddur

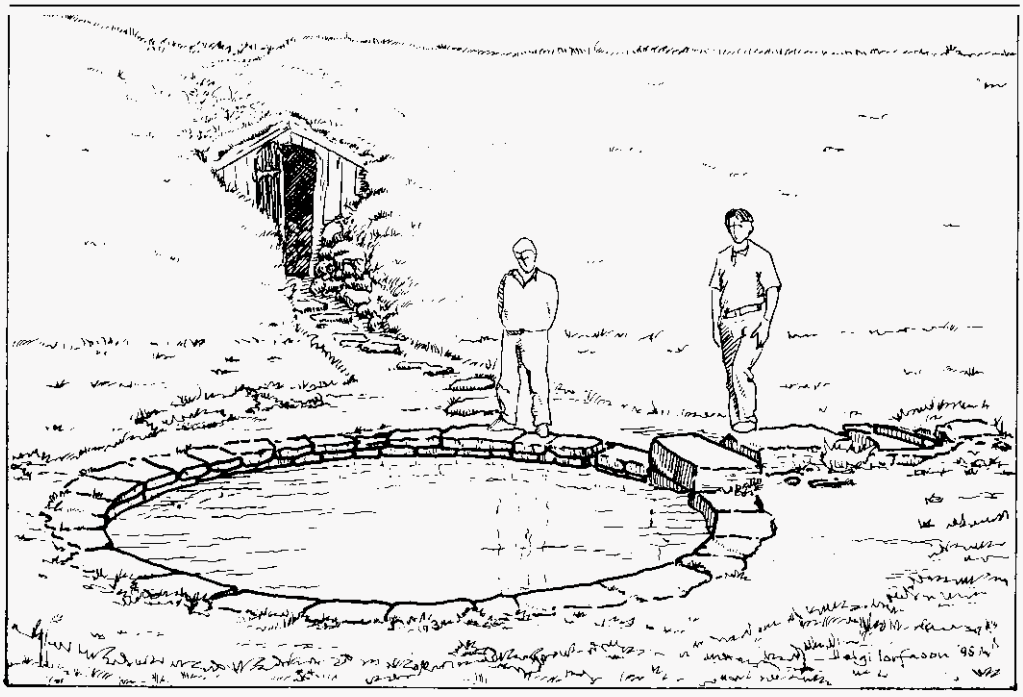

Figure 2. Snorralaug in Reykholt. The hot water conduit is on the right: the entrance of a tunnel from the both to the farmhouse is in the background (drawing by Helgi Torfason)

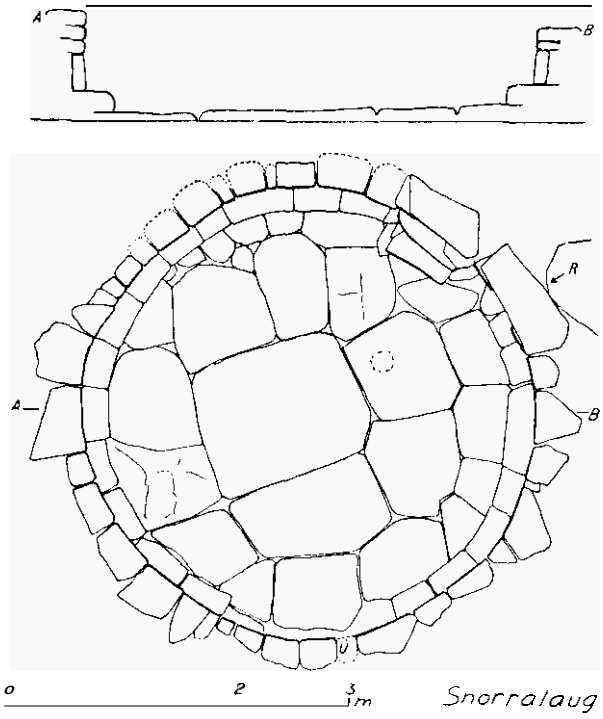

Figure 3. Plan and cross section of **Snorralaug** (Snorri's bath) before the restoration in 1959. R: Inflow of water from a 120 m long underground conduit; Ú: Outlet for water (from Grimsson, 1960)

took a bath there, this must have been before 960 A.D. Nothing is said about the position or nature of the bath, but this original bath in Reykholt must have been fed with hot water from either of the two boiling springs Skrifla or Dynkur (Grimsson, 1960). Both springs are situated in a morass and exposed lo winds on all sides. Both are far too hot for direct bathing. It is not known exactly when a ditch **was** first dug from Skrifla to bring the thermal water to the dry, solid ground in shelter from the northerly winds at the foot of the hill which later became the Reykholt farm site. One can imagine that this happened in **stages.** The distance from the hot spring to Snorralaug is about 120 m.

In the latter part of the 12th century, Reykholt had become a rich church farm. Snorri Sturluson, **a** scholar and a powerful chieftain, moved there in 1206. According to Sturlunga Saga, he had a defence wall built around his dwellings. Reference is made to two gates on this wall. One on the north side towards the church, the other **was** the doorway of a corridor or a tunnel leading to the bath. This bath is mentioned several times in Sturlunga Saga (*Íslendingasögur, 1981*), including **a** narration of an event in 1228 picturing Snorri himself in the bath one evening, chatting with friends. But no information is given on its age, size or structure. The bath in Reykholt is mentioned in several books from the 18th century, including the travel book of Eggert Ólafsson and Bjarni Pálsson (Ólafsson and PQlsson, 1943) who visited Reykholt in 1757. Snorralaug (Snorri's Bath) was rebuilt in 1858 (Thorsteinsson, 1971) and again in 1959 (Grimsson, 1960). The walls of the underground **passage nearest** to Snorri's bath were also restored.

Although there is no absolute proof, it is considered very likely that the pool and the pipelines were built by Snorri Sturluson. At **least** the pool existed during Snorri's time. Snorri **was** not only the most remarkable writer and historian **known** in Iceland's history. He was also an ambitious builder, as reflected by the defence wall around his farmhouse described in Sturlunga Saga. The model for the construction of the defence wall around the farm could easily have been sought in Norway, where Snorri was a frequent visitor. But where did he get the idea of piping the geothermal water? During the 11th and 12th centuries, pilgrims went frequently from Iceland to Rome. It is even known that a young couple, who had recently inherited Reykholt, died on the pilgrimage to Rome in the late 12th century. It is tempting to speculate that some scholar visiting Snorri Sturluson returning from a pilgrimage has told him how people in Italy constructed subterranean conduits to transport hot and cold water. Perhaps this is the first transfer of technology from Italy to Iceland on the use of geothermal energy. The sad fact is that this technology of piping hot water and steam seems not to have spread from Reykholt to other parts of Iceland. For seven hundred years people at farms with boiling springs continued to suffer in their cold, unheated houses.

5. HOT SPRINGS AS BAROMETERS

Eggert Ólafsson and Bjarni Pálsson who travelled around Iceland in the mid 18th century mention that hot springs have through the centuries been considered good indicators of changes in the weather (Ólafsson and PQlsson, 1943). Reykjalaug in Miðfjörður in N-Iceland can be taken as an example. When the temperature in the spring **rose,** people said that rain would be coming soon, even if the sky was blue and cloudless. They also reported that people in the vicinity of the Great Geysir in Haukadalur in S-Iceland could foresee rain and storm from the height of the water column in the eruptions of Geysir. When the water column goes as high as Laugafell in the background, then it is certain that a rainstorm is coming. With modern meteorology people realize that this is controlled by the air pressure. When a low depression goes over the country, the pressure on the surface of hot springs is reduced, and thus the hot aquifer pressure becomes relatively high. And depressions sweeping in from the ocean normally bring rain and storms. Our forefathers did not know this. Therefore it is understandable that people found the hot springs mysterious and even magical.

6. THE NUISANCE OF HOT SPRINGS

The romantic aspect of the use of the hot springs reflected in the sagas appears to have dwindled with time, at least when it came to counting the perks of farms for the tax-man. In Jarðabók Árna Magnússonar and Páls Vídalíns, written in 1703-1714, a description is given of every substantial farm in Iceland and the benefits and disadvantages associated with each farm listed (Magnússon and Vidalin, 1982). For all the farms with known geothermal activity that the present author looked up in the Jarðabók, the hot springs are considered a nuisance and a disadvantage. One must keep in mind, however, that the farmers describing the quality of their farmlands to the learned gentlemen at the beginning of the 18th century, probably had in mind that the descriptions might be used for assessing the taxation value of their farms.

It says of Laugardælir farm in S-Iceland: "A part of the hay field is spoiled by a hot secretion which is caused by a nearby hot spring, and from this warm broth the grassroots are eaten up resulting in patches with no vegetation". This description was written on 27th July 1709. Presently this "hot secretion" area is the main production field of Hitaveita Selfoss (District Heating Service of Selfoss), with an installed capacity of 21 MW-thermal. In the description of Hlaðgerðarkot in Mosfellssveit, which is a part of the main production field of Hitaveita Reykjavíkur (Reykjavik District Heating Service) it says: 'The possibility of cutting turf (as building material) is limited. Peat resources for cooking-fuel are both of bad quality and limited. The meadows are spoiled by scree. The land is small in size. Storms are fierce so that both houses and haystacks are in danger. The water is warm". There is a certain crescendo in this description, as the

musicians would say. After describing **all** the had qualities of the farmland, it is stated that even the water is not drinkable as it is warm. At present, this area is to the Icelanders as an oil field to the Arabs. In 1908, a farmhouse at Reykir near Hlaðgerðarkot was the first in Iceland to he heated with geothermal water.

7. SULPHUR MINING

Although the Icelanders did not make much use of the geothermal energy, at least not when asked by the tax-man, the King of Denmark certainly made a lot of money during the middle ages from the mining of sulphur in Iceland. Sulphur deposits are common in the high temperature fields of the country. The main sulphur mines were in Krýsuvík in SW-Iceland and in Námafjall, Krafla, Fremri-Námur and Theistareykir in N-Iceland. Sulphur was exported from Iceland at an early stage as an expensive commodity.

Iceland lost its independence and came under the King of Norway in 1262, and together with Norway under the Queen of Denmark in 1388. Apparently the Archbishop of Niðarós (now Trondheim) in Norway acquired some kind of exclusive right to transport or buy sulphur from Iceland during the latter part of the 13th century. What the sulphur was used for is not known, as gun powder was not invented until about 1400. It has been suggested that perhaps the Catholic Church was exporting sulphur from Iceland so that people in churches in Europe could get acquainted with the smells of Hell (Lýður Bjornsson, 1994). Iceland's most famous volcano Hekla was **well** known in the Church in Europe as one of the gateways to Hell during the Middle Ages.

Later the exclusive right to export sulphur was taken by the Danish King, At the beginning of the 16th century, sulphur was exported from Iceland by merchants from Hamburg in Germany, and the King of Denmark had to buy sulphur for powder production at an extremely high price. In 1561 the King forbade the Icelanders to sell sulphur to foreigners and only to merchants appointed by the King. After this, the Danish government controlled the export of sulphur from Iceland through the 16th century (Sigurjónsson, 1967). The export of sulphur **was very** lucrative during this period and it **is** reported that the King earned some 6000 *rikisdalir* from a single shipload (equivalent to the price of 1500-2000 dairy cows which cost some 2-3 million USD in Iceland today). The sulphur export was at this time the main source of income to the Danish Crown in Iceland. At the heginning of the 17th century, there **was** a pricefall in sulphur on the European market and the Crown stopped its export of sulphur. The mining was much reduced during the 17th and 18th century, and the license for mining and export was sold to various individuals. The King finally **gave** the right to sulphur mining to the Icelanders as a part of an Industrialization Plan (Innréttingar) in the 1760's.

8. SALT PRODUCTION WITH GEOTHERMAL HEAT

The first experiments in producing salt from sea water by vaporization using geothermal heat were conducted by Eggert Ólafsson and Bjarni Pálsson in 1753 at Reykhdlar in W-Iceland (Ólafsson and PQlsson, 1943). In 1773, a team sent by the Danish Crown started an experiment in producing salt from Seawater using boiling geothermal springs on the beach at Reykjanes in NW-Iceland. The experiment resulted in commercial production of salt that lasted until 1793 (Bjornsson, 1978). In 1776, salt was produced using 32 pans, each about 126x126x32 cm in size, mostly made of lead. The salt was regarded of a reasonable quality and was used for salting fish and meat. The annual production was up to 298 *tunnur* (equivalent to nearly 90 tonnes). The total production during 1773-1793 was 3711 *tunnur* (equivalent to 1113tonnes), or about 53 tonneslyear. Commercial production continued until 1793, when it was stopped due to economic reasons. The salt did not sell **well,** as it was contaminated with lead from the drying pans and the lead gave dark colour to the fish. Experiments with salt production in a geothermal field in Iceland started again in the 1960's.

9. INITIAL GEOTHERMAL DRILLING

The first geothermal drilling occurred in Laugarnes in Reykjavík in 1755 and in Krýsuvík in SW-Iceland a year later. Eggert Ólafsson and Bjarni PQlsson brought a hand-driven drilling tool owned by the Danish Science Society to Iceland. They drilled some **4** m down to the bedrock in Laugarnes, but to about 10 m depth in the Krýsuvík high-temperature field. In the last drillhole in Krýsuvík, they got only to a depth of some 3 m, but according to the words of Eggert Ólafsson "at that stage the soil started moving and in spite of the narrow **well** around the drilling rod, a thin soup started squirting out of the **well** with great force. We were forced to stop and pulled the drill out. But at that stage the heat came out in full force and squirted a boiling mixture of water and clay 2-3 m into the air. In a short while this restlessness stopped and **we** expected that the heat had become quiet, But after a short while the heat force increased again and the well started erupting and boiling again. We saw then that we had created a **new** boiling spring with our operations". After this episode, geothermal drilling did not start again until in 1928, and at that time also in Laugarnes in Reykjavik.

10. DISCUSSION

In a country such as Iceland, with no **coal** deposits and very limited deposits of firewood and peat, the hot springs were of a significant potential value for washing wool and clothes, bathing, and boiling food at individual farms. But it is sad to think of all the thousands of people shivering in their houses for 10 centuries at farms with ample free flowing water most suitable to heat the houses. The mean annual temperature in Iceland is about 4°C and the average temperature of July (the warmest month) about 11°C. Some heating is needed in the houses almost around the year. At tens of farms it would have been very easy to heat the houses by constructing a simple pipeline such as at Reykholt under the farmhouses and thus provide floor heating.

The technique of piping the hot water hy all indications came tu Reykholt in the early 13th century. But it was not until in 1908 that **a** farmer at Reykir in Mosfellssveit, Stefán B. Jónsson (1861-1928), who had spent 12 years in the USA, constructed a 2.3 km pipeline (1 inch steel pipe) from a hot spring to heat radiators in his house (Thórðarson, 1993). The spring was at a higher elevation than the house and thus no pumping was required. The achievement of **the** farmer and self educated carpenter and blacksmith Erlendur Gunnarsson (1853-1919) was even greater. He lived at Sturlureykir in W-Iceland, 4 km west of Reykholt, and had a boiling spring by his farm but at a *6* m elevation below the farmhouse. After much experimenting, he invented a simple separator to separate the steam from the water. He piped the steam to his house in 1911 and used it there both for cooking and for heating the house. Initially, the radiators were heated by steam, but later the steam was used to heat water for the radiators in a closed system (Finnbogason, **1943).** It is an interesting coincidence, that the world's longest geothermal pipeline, 63 km in length and constructed in 1980, transports boiling water from the Deildartunga hot spring some 2 km west of Sturlureykir.

The historical aspects of geothermal development during the 20th century are outside the scope of this paper. The historical session of the World Geothermal Congress in Florence 1995 will mainly deal with developments until approximately the year 1900.

Hopefully, the history of development of geothermal resources after 1900 will be dealt with properly in the near future, as many of the pioneers of this development in the various countries are still alive. A few items of historical interest as regards Iceland will be mentioned here.

The first municipal district heating service using geothermal water, Hitaveita Reykjavikur, was established in 1930. At present, about 86% of the Icelandic population lives in geothermally heated houses, and geothermal energy provides 46% of the total primary energy supply of the nation. Most school centres and villages established after 1930 are located **near** hot springs.

The first greenhouse was heated with geothermal water in 1924 at Reykir in Mosfellssveit. Most of the pioneering work for multipurpose use of geothermal energy, however, started in the Hveragerði hot spring village (Thorhallsson, 1988), such as: 1930 the first dairy to pasteurize milk and produce cheese; 1938 hay drying experiments; 1939-1941 a plant to dry seaweed 1944 experimental production of electricity; 1946 a freezing plant for vegetables (using absorption refrigeration); 1947 commercial production of bread; 1947 a wood-drying kiln; 1955 a factory for curing concrete blocks and pipes; 1975 a **fish** drying plant; and 1979 a candy factory.

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