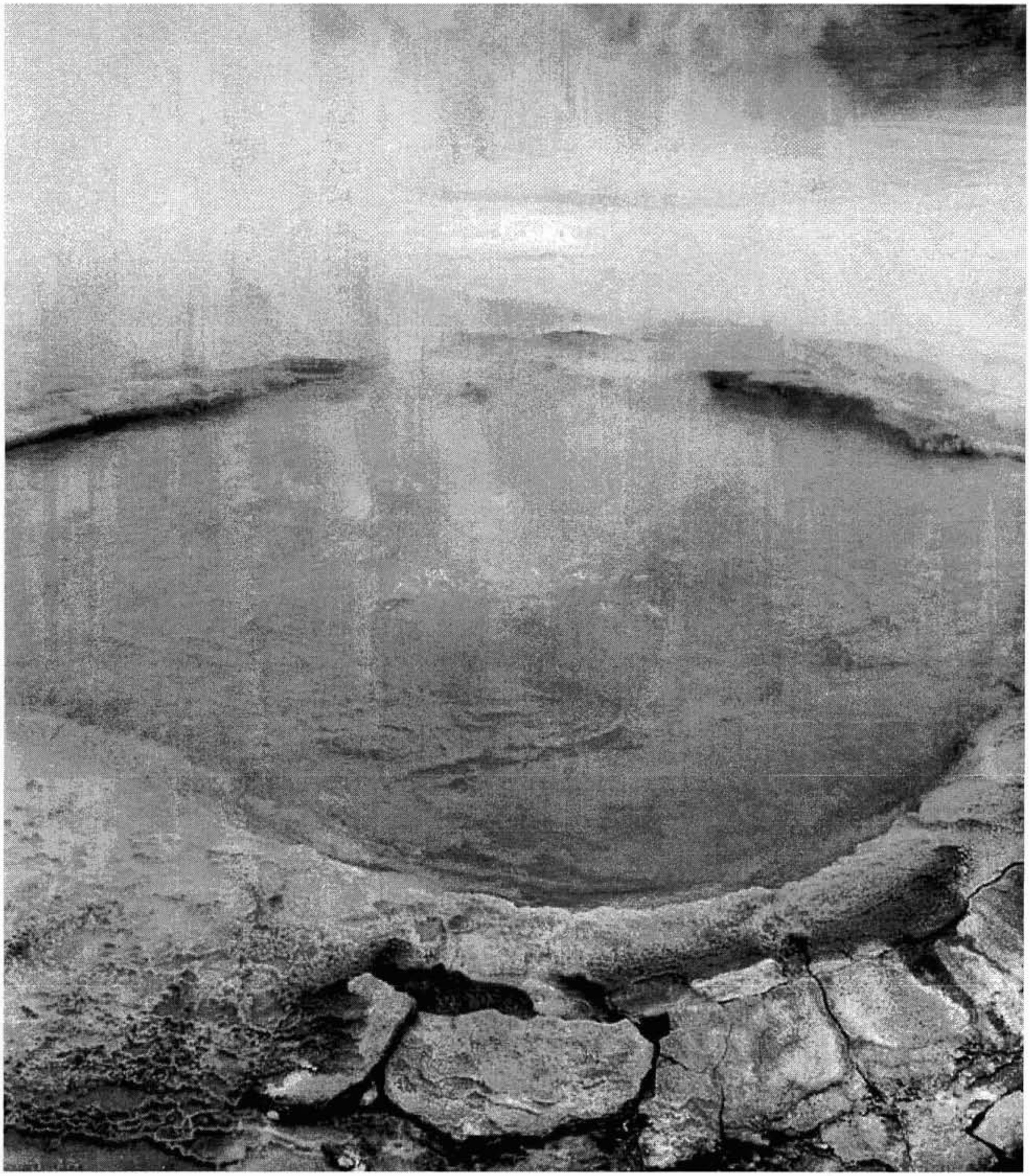
GEOTHERMAL DEVELOPMENT
AND RESEARCH IN ICELAND



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National Energy Authority and Ministries of Industry and Commerce
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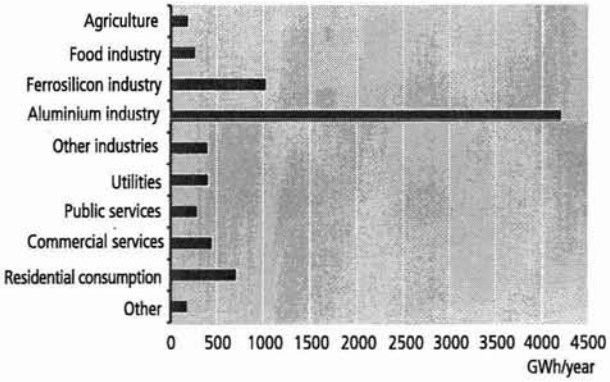
1. TABLE OF CONTENTS

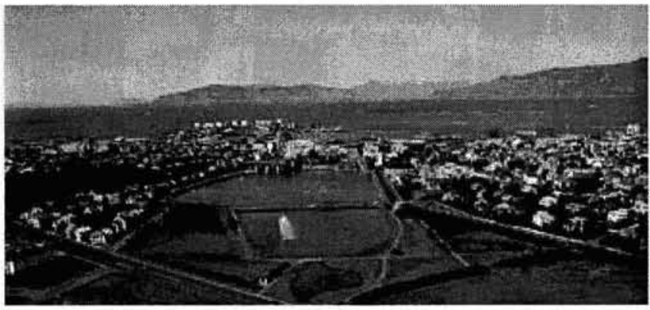
1. INTRODUCTION

Iceland is a country of 300,000 people, located on the mid-Atlantic ridge. It is mountainous and volcanic with much precipitation. The country's geographical peculiarities have endowed Iceland with an abundant supply of geothermal resources and hydropower. During the course of the 20th century, Iceland went from what was one of Europe's poorest countries, dependent upon heat and imported coal for its energy, to a country with a high standard of living where practically all stationary energy, and roughly 72% of primary energy, is derived from indigenous renewable sources (54% geothermal, 18% hydropower). The rest of Iceland's energy sources come from imported fossil fuel used for fishing and transportation. Iceland's energy use per capita is among the highest in the world, and the proportion of this provided by renewable energy sources exceeds most other countries. Nowhere else does geothermal energy play a greater role in proving a nation's energy supply. Almost three-quarters of the population live in the southwestern part of the country, where geothermal resources are abundant.

Fig. 1. **Electricity consumption 2004**



The current utilization of geothermal energy for heating and other direct uses is considered to be only a small fraction of what this resource can provide. The potential to generate electricity is more uncertain. Hydropower has been the main source of electricity, but in recent decades geothermal power plants have also won their share of the production. The increased demand for electric energy comes mainly from the energy intensive industry (fig. 1). In 2004, geothermal plants generated 17% of the total 8,618 GWh produced. In 2009, the total production is forecast to be about 15,000 GWh, 20% generated in geothermal plants. At the same time, 80% of the electricity will be used in the energy intensive industry.



From Reykjavík

Iceland possesses extensive untapped energy reserves. However, these reserves are not unlimited. Only rough estimates are available relating to the size of these energy reserves in relation to the generation of electricity. Therefore, there is considerable uncertainty when it comes to assessing to what extent they can be harnessed with regards to what is technically possible, cost-efficient, and environmentally desirable. For the potential generation of electricity, these energy reserves are estimated at roughly 50,000 GWh per year, some 60% coming from hydropower and 40% from geothermal resources. By 2009, the generation would amount to about 30% of that total potential. A master plan comparing the economic feasibility and the environmental impact of the proposed power development projects is being prepared. It is hoped that this comparison will aid in the selection of the most feasible projects to develop, considering both the economic and environmental impact of such decisions, like which rivers or geothermal fields should not be harnessed due to their value for natural heritage and recreation. Results from a first-phase study were presented in November 2003.

The evaluation compared 19 hydro projects, mostly glacial rivers located in Iceland's Highlands, and 24 geothermal projects centered in the high-temperature fields near the inhabited regions in the south, southwest and northeast Iceland. The hydro projects had an aggregated potential of 10,500 GWh/yr. Some of those projects, with a potential of 4,700 GWh/yr, were, however, found to have so severe an environmental impact that their development might not be accepted. The geothermal projects had a potential of 13,200 GWh/yr. Projects with a potential of 4,200 GWh/yr also fell into the severe environmental impact category. A second phase evaluation of projects with a potential of some 10,000 GWh/yr is now being prepared. Results are expected by 2009.

The following outline of geothermal research and development in Iceland is based on a number of references, which are listed in Chapter 6. The reader should refer to a series of papers, which were presented at the 2005 World Geothermal Congress in Antalya, Turkey. They can be accessed by logging on to www.os.is/wgc2005.

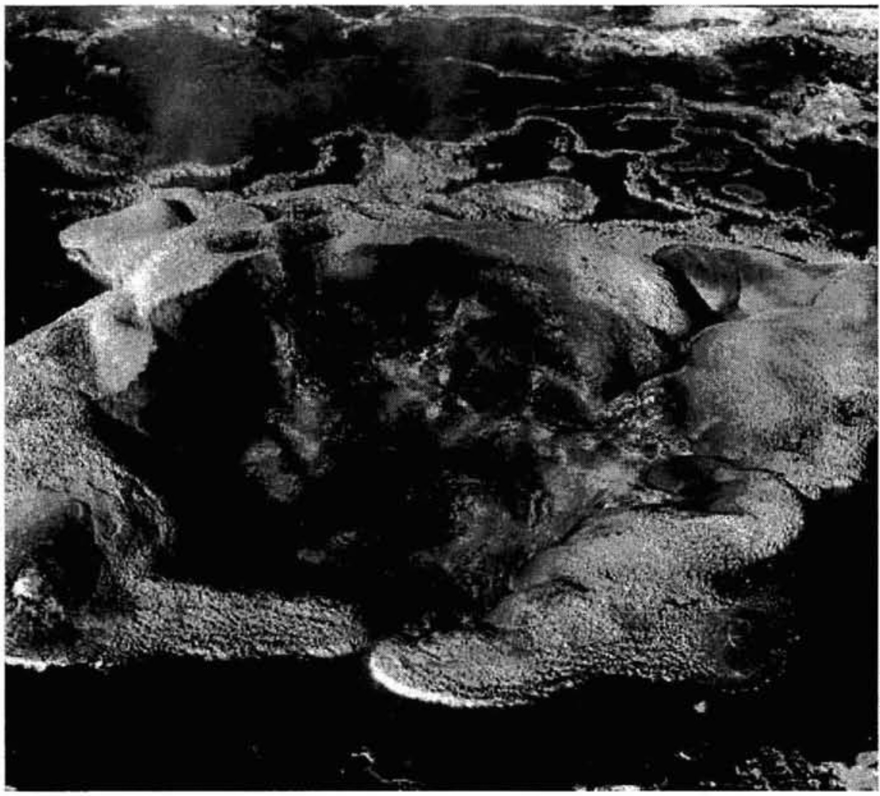
2. SUSTAINABLE UTILIZATION OF GEOTHERMAL RESOURCES

Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This definition is inherently vague, and is often understood in various ways. In an attempt to link sustainable development to the management of resources, the definitions of "renewable" and "sustainable" are often misused. One can use the terms renewable energy source and sustainable use of a resource. The term *renewable* describes a property of a resource, namely the ability of a resource to be replaced, whereas the term *sustainable* describes the mode of utilization of a resource. Geothermal energy is a renewable energy source that can be utilized in a sustainable or excessive manner. Excessive production from a geothermal field can only be maintained for a relatively short time, and can indicate overinvestment in wells and power plant equipment. After a period of prolonged over use, a field operator is forced to reduce the production to the level of maximum sustainable use. To avoid excessive production, "Stepwise development" is initiated.

Helga Barðadóttir

The Blue lagoon geothermal spa

Stepwise development of geothermal resources is a methodology that takes into consideration the individual conditions of each geothermal system, and minimizes the long-term production cost. The cost of drilling is a substantial component both in the exploration and the development of geothermal fields. With the stepwise development method, production from the field is initiated shortly after the first, successful wells have been drilled. The production and response history of the reservoir during the first development



The hot spring Eyvindarhver, in the Icelandic highlands

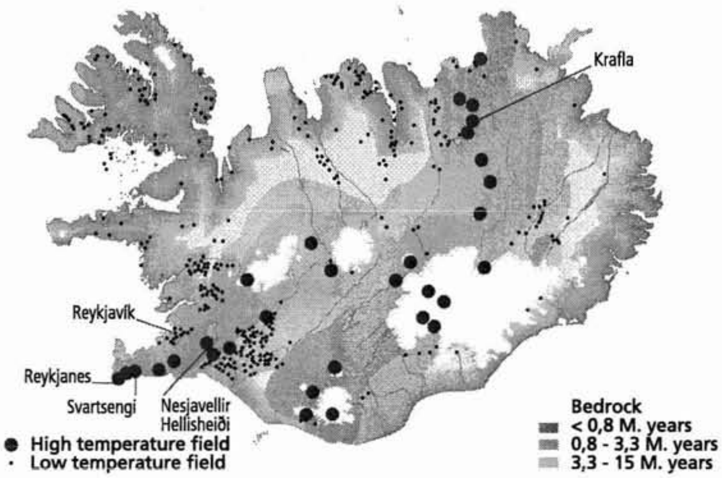
step is used to estimate the size of the next development step. In this way, favorable conditions are achieved for the timing of the investment in relation to the timing of revenue, resulting in lower long-term production costs than could be achieved by developing the field in one step. Merging the stepwise development method, with the concept of sustainable development of geothermal resources, results in an attractive and economical way to utilize geothermal energy resources.

3. THE NATURE OF GEOTHERMAL RESOURCES

3.1 Geological background

Iceland is a young country geologically. It lies on one of the earth's major fault lines, the mid-Atlantic ridge. This is the boundary between the North American and Eurasian tectonic plates, one of the few places on earth where one can see an active spreading ridge above sea level. The two plates are moving apart about 2 cm per year. As a result of its location, Iceland is one of the most tectonically active places on earth, resulting in a large number of volcanoes and hot springs. Earthquakes are frequent, but rarely cause serious damage. More than 200 volcanoes are located within the active volcanic zone running through the country from the southwest to the northeast, and at least 30 of them have erupted since the country was settled. In this volcanic zone there are at least 20 high-temperature areas containing steam fields with underground temperatures reaching 250°C within 1000 m depth. These areas are directly linked to the active volcanic systems. About 250 separate low-temperature areas with temperatures not exceeding 150°C in the uppermost 1000 m are mostly in the areas flanking the active zone. To date, over 600 hot springs (temperature over 20°C) have been located (Fig. 2).

Fig. 2. **Volcanic zones and geothermal areas in Iceland.**




Sigurður Sveinn Jónsson

Greenhouses in a low-temperature area at Laugaras, South Iceland

3. 2 The nature of low-temperature activity

Low-temperature systems are all located outside the volcanic zone passing through Iceland (see Fig. 2). The largest such systems are located in southwest Iceland on the flanks of the volcanic zone, but smaller systems can be found throughout the country. On the surface, low-temperature activity appears as hot or boiling springs, while some such systems have no surface manifestations. Flow rates range from almost zero to a maximum of 180 liters per second from a single spring. The heat-source for low-temperature activity is believed to be Iceland's abnormally hot crust, but faults and fractures, which are kept open by continuously ongoing tectonic activity, also play an essential role by providing channels for the water that circulates through the systems, and by mining the heat. The temperature of rocks in Iceland generally increases with depth. Outside the volcanic zone the rise in temperature varies from about 150°C/km near the margin to about 50°C/km farther away. The nature of low-temperature activity may be described as follows: Precipitation, mostly falling in the highlands, percolates down into the bedrock to a depth of one to three km, where it's heated by the hot rock, and ascends subsequently towards the surface, because of reduced density. Systems of this nature are often of great horizontal extent and constitute practically steady state phenomena. The most powerful systems are believed to be localized convection systems where the water undergoes vertical circulation in fractures several kilometers deep. The water then washes the heat out of the deep rocks at a much faster rate than it is renewed by conduction from the surroundings. These fields are therefore believed to be of transient nature, lasting some thousands of years.

3.3 The nature of high-temperature activity

High-temperature areas are located within the active volcanic belts or marginal to them. They are mostly on high ground. The rocks are geologically very young and permeable. As a result of the topography and high bedrock permeability, the groundwater table in the high-temperature areas is deep, and surface manifestations are largely steam vents. Hydrogen sulphide present in the steam tends to be oxidized at

Magnús Ólafsson

From Reykjadalir in the Torfajokull area

the surface by atmospheric oxygen, either into elemental sulphur, which is deposited around the vents, or into sulphuric acid, which leads to acid waters altering the soil and bedrock.

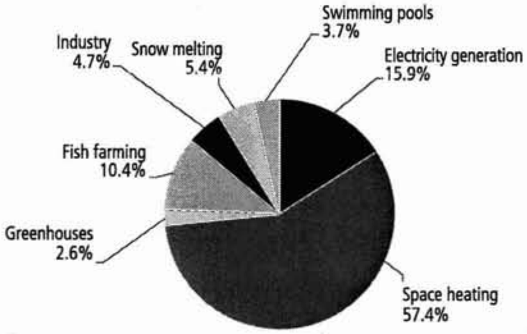
The internal structure of fossil high-temperature systems can be seen in Tertiary and Quaternary formations, where erosion has exposed rocks that were formerly at a depth of 1-3 kilometers. The system's heat source is generally shallow magma intrusions. In the case of high-temperature systems associated with central volcanic complexes the intrusions often create shallow magma chambers, but only dyke swarms are found where no central volcanoes have developed. It appears that intrusive rocks are most abundant in reservoirs associated with central complexes that have developed a caldera. The boiling point for water depends on the hydrostatic pressure. As the pressure increases with depth the temperature needed to let the water boil rises along a curve that is called the boiling point curve. Temperatures in active, high-temperature systems generally follow the boiling point curve. The highest recorded downhole temperature is 380°C. Hydrological considerations and permeability data imply that the groundwater in the reservoir is undergoing density driven vertical circulation. This groundwater is in most cases of meteoric origin. However, in three areas on the Reykjanes Peninsula it is largely or solely marine.

4. DEVELOPMENT OF UTILIZATION

As has previously been mentioned, geothermal sources account for just over half of Icelanders' primary energy needs. From the earliest times, geothermal energy has been used for bathing and washing. Late in the 19th century, people began experiments utilizing geothermal energy for outdoor gardening; and early in the 20th century geothermal sources were first used to heat greenhouses. Around the same time, people started using geothermal energy to heat swimming pools and buildings. Today, space heating is the largest component in the direct use of geothermal energy in Iceland. Figure 3 gives a breakdown of the utilization of geothermal energy for 2005. These percentages are for energy utilized rather than primary energy. In 2005, direct use of geothermal energy, for example heating, totaled around 27,690 terajoules (TJ), which corresponds to 7,608 GWh. In addition, electricity production amounted to 1,658 GWh. As Fig. 3 reveals, the 58% share of space heating was by far the greatest, followed by electricity production, accounting for 18%.

After its culmination in the 1980s, Iceland's development of geothermal energy for direct use was rather slow. Geothermal space heating is, however, slowly increasing. New industrial users that utilize geothermal energy on a large scale have not emerged, in spite of the high potential. Iceland's main geothermal development over the last few years has been with high-temperature geothermal exploration, and drilling with the aim of producing electricity for the further expansion of the country's aluminum industry.

Fig. 3. **Sectoral share of utilization of geothermal energy in Iceland in 2005**



4.1 Space Heating

Over the last 60 years, there has been considerable development in the use of energy for space heating in Iceland. After WW2, The National Energy Authority (Orkustofnun) and Iceland Geosurvey (and their predecessors) have carried out research and development, which has led to the use of geothermal resources for heating in 87% of all of Iceland's households. This achievement has enabled Iceland to import less fuel, and has resulted in lower heating prices.

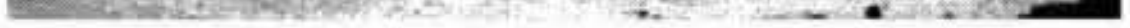
4.1.1 Fuel for heating houses

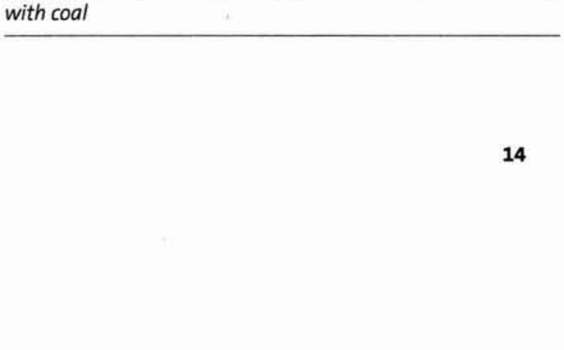
In a cold country like Iceland, home heating needs are greater than in most countries. From the time of settlement, Icelanders struggled to find the energy to heat their houses. In the early days they used open fires on the floor. On the roofs, there was an opening to let the smoke out and the light in. As wood became scarce, people were forced to survive on less heat, using cooking stoves, and the heat generated by house animals. This was not the case, however, for the wealthy, who had stoves for heating and chimneys to release the smoke. In the latter half of the 19th century, heating with cooking stoves became more common, and by the end of the century central heating using hot water, circulated throughout houses in closed circuit, was widely developed.

In earlier centuries, turf was commonly used for heating houses, as well as seaweed. This continued even after the importation of coal for space heating was initiated, after 1870. In the rural regions, the burning of sheep-dung was common, as the distribution of coal or turf was difficult due to the lack of roads. The use of coal for heating increased in the beginning of the 20th century, and was the dominating heat source until the end of WW2.

4.1.2 Oil comes into the picture

Iceland's dependence on oil began with the 20th century. At first oil was used for lights, in order to power small fishing boats and later gasoline for cars. Oil for heating purposes first became significant after WW1, but by 1950 about 20% of families used oil for heating, while 40% used coal. At that time about 25% enjoyed geothermal heating services. In the 1950s, the equipment to utilize oil for heating improved, obviously leading to increased consumption. As a result, coal was practically eliminated from space heating in Iceland around 1960. At the same time, control systems for central heating rapidly developed, and the first automatic temperature regulators for radiators became common.



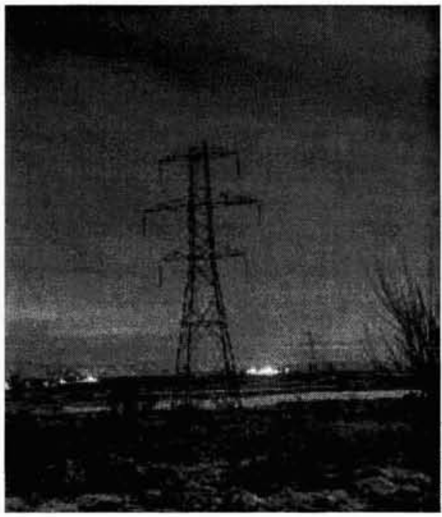


Reykjavik Energy

A black cloud of smoke over Reykjavik in 1940, due to heating with coal

4.1.3 Electric heating

Early in the last century, small hydro power plants were built in many regions. These plants were convenient for farmhouses, yielding electricity for lights, cooking and sometimes the heating of homes. Such private plants, owned by farmers, became widespread, but later electric distribution services were built to serve the rural public. Heating homes with electricity did not become common until larger electric power plants were erected in the 1930s and 1940s.


Oddur Sigurdsson

High-voltage transmission line

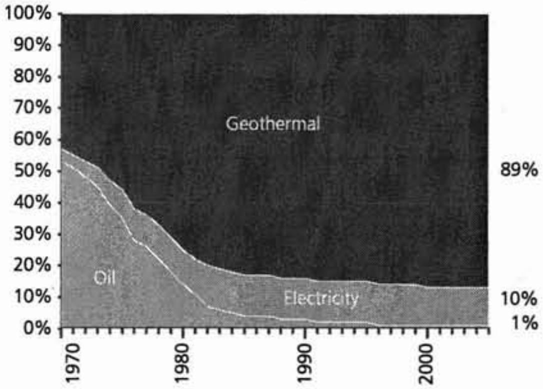
4.1.4 Initial use of geothermal heat

The first uses of geothermal energy to heat houses can be traced back to 1907. A farmer in west Iceland conveyed steam from a hot spring that ran below his farm, through a concrete pipe and into his house, which stood several meters above the hot spring. In 1909, a farmer near Reykjavik was the first to pipe water from a hot spring into his house for heating purposes. In Reykjavik, extensive distribution of hot water for heating homes began in 1930 when a 3 km long pipeline was built to transport hot water from the Washing Springs to two primary schools, a swimming hall, the main hospital and 60 family homes in the capital area. In 1943, a major step was reached when a new 18 km pipeline was put into use, and the Reykjavik District Heating Service began operating. By the end of 1945, there were 2,850 houses connected. The population of Reykjavik was just over 44,000. In addition to the development in the capital area, many communities around the country built their heating distribution systems in places where hot springs, or successful drilling, yielded suitable geothermal water. The largest of these systems were in Olafsfjordur (1944), Hveragerdi (1947), Selfoss (1948) and Saudarkrokur (1953). Community schools in the countryside were also preferably located close to supplies of geothermal water, which was available for heating and swimming.

4.1.5 Influence of the oil crisis on energy prices

When the oil crisis struck in the early 1970s, fuelled by the Arab-Israeli War, the world market price for crude oil rose by 70%. About the same time, roughly 90,000 people enjoyed geothermal heating in Iceland, around 43% of the nation. Heat from oil served over 50% of the population with the remaining population using electricity. In order to reduce the effect of rising oil prices, Iceland began subsidizing those who used oil for space heating. The oil crises in 1973 and 1979 (Iranian Revolution) caused Iceland to change its energy policy, deemphasizing oil, turning to domestic energy resources, hydropower and geothermal heat. This policy meant searching for new geothermal resources, and building new heating services across the country. It also meant constructing transmission pipelines (commonly 10-20 km) from

Fig. 4. **Relative share of energy resources in the heating of houses in Iceland**



geothermal fields to towns, villages and individual farms. This involved converting household heating systems from electricity or oil to geothermal heat. But despite reducing the use of oil in space heating from 45% to 18% from 1973 to 1979, the share of oil still remained about 50% to 60% of the total cost of heat. This was due to rising oil prices.

The relative share of energy resources used to heat households has developed since 1970 (see Fig. 4). The increase in geothermal energy is clearly seen, but after 1985 the change is relatively small. The use of geothermal energy is, however, still increasing, and over the long run could rise from its present rate of 89% to 92%. The share of oil for heating continues to decrease and is at present at about 1%. Electric heat has a share of about 10% but one third of that comes from heating plants where electricity is used to heat water that is then distributed through district-heating systems, to the various communities.

4.1.6 Benefits of using geothermal heat instead of oil.

The economic benefits of the government's policy to increase the utilization of geothermal energy can bee seen when the total payments for hot water used for space heating are compared to the consumer costs of oil.

Fig. 5. **Cost of hot water versus oil**

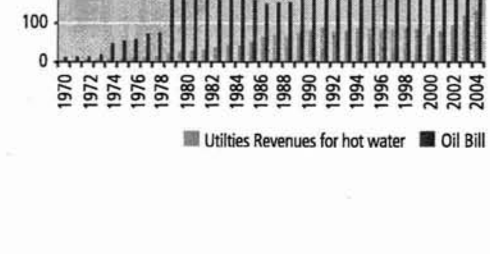


Fig. 5 compares the cost of hot water to what would have been spent on oil to yield the same energy for heating (1970 to 2005). All costs are priced in the corresponding year. Direct annual savings culminated from 1980 to 1983, and were about $200 million per year. They rose above $200 million in 2000, and savings continue to climb as oil prices increase. In 2000, the present value of the total savings between 1970 to 2000 was estimated at $8,200 million or more than three times Iceland's national budget in 2000. Opinion might be divided on the estimated savings of using geothermal energy rather than oil for heating purposes. Some might feel, for example, that sources other than oil could be used for heat. Also, heating energy could've been obtained through an increased generation of electricity through hydropower, as is done in Norway. Nevertheless, the economic savings garnished by using geothermal energy is substantial, and has contributed significantly to Iceland's prosperity.

Using geothermal energy for space heating has also benefited the environment. Both geothermal energy and hydropower have been classified as renewable energy resources, contrary to carbon fuels such as coal, oil and gas. Geothermal heat is also less damaging to the environment than carbon fuels in that it does not emit CO_2 into the atmosphere. Assuming that geothermal energy used for heating homes in 2003 was equivalent to the heat obtained from the burning of 646,000 tones of oil, the use of geothermal energy reduced the total release of CO_2 in the country by roughly 37%.

Besides the economic and environmental benefits, the development of geothermal resources has had a desirable impact on social life in Iceland. People have preferred to live in areas where geothermal heat was available, in the capital area and in rural villages where thermal springs can be exploited for heating dwellings and greenhouses, schools, swimming pools and other sport facilities, tourism and smaller industry. Statistics show improved health of the inhabitants of these regions.

4.1.7 Equalization of energy prices

Equalization of energy prices is a decades old Icelandic policy. This policy has been carried out in various ways, such as paying subsidies to those who heat their homes with oil. Families using electricity to heat their homes have also received government subsidies, since 1982 (Fig. 6). In 2002, a new Act on Subsidies was approved. These subsidies now amount to about $15 million per year, and a small part of that goes to lowering the cost of oil where no other means of heating homes are available. The cost of heating is not solely determined by energy prices. Houses differ in their condition, especially older houses, with regards to things like insulation and the control of heating systems. The needs and habits of the inhabitants differ. Therefore the cost of heating two homes of equal size in the same district might vary considerably. The solution for high heating bills might very well be home improvements, or implementing energy saving strategies. The government encourages such improvements to reduce subsidies.

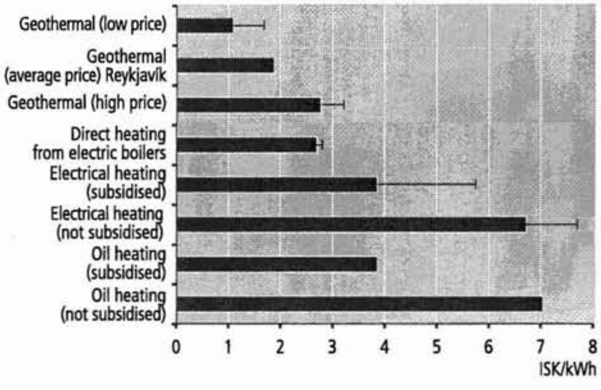


Fig. 6. **Comparison of energy prices for residential heating September 2005**

4.1.8 The government's role in developing geothermal energy

The government has encouraged the exploration for geothermal resources, as well as research into the various ways geothermal energy can be utilized. This work began in the 1940s at The State Electricity Authority, and was later, for decades, in the hands of its successor, The National Energy Authority (Orkustofnun), established in 1967. The aim has been to acquire general knowledge about geothermal resources and make the utilization of this resource profitable for the national economy. This work has led to great achievements, especially in finding alternative resources for heating homes. This progress has been possible thanks to the skilled scientists and researchers at the National Energy Authority. This research is now in the hands of a new state institute, Iceland GeoSurvey, which was born out of the National Energy Authority in 2003. New and effective exploration techniques have been developed to find geothermal resources. This has led to the development of geothermal heating services in regions that were thought not to contain suitable geothermal resources. Iceland's geothermal industry is so developed that the government can now play a smaller role. Successful power companies now take the lead in the exploration of geothermal resources, either geothermal fields that are already being utilized, or finding new fields.

The Icelandic government has also set up an Energy Fund to further increase the use of geothermal resources. This fund was established by merging the former Electricity Fund and the Geothermal Fund in 1967. Over the past few decades, it has granted numerous loans to companies for geothermal exploration and drilling. Where drilling failed to yield the expected results, loans were converted to grants. According to a new Energy Act in 2003, the Energy Fund is now under the National Energy Authority.

In recent years, the utilization of geothermal energy for space heating has increased mainly as a result of the population increase in the capital area. People have been moving from rural areas to the capital area. As the result of changing settlement patterns, and the discovery of geothermal sources in the so-called "cold" areas of Iceland, the share of geothermal energy in space heating is expected to increase to 92% over the next few decades.

The country's larger district heating services are owned by their respective municipalities. Some 200 smaller heating utilities have been established in rural areas. Recent changes in the ownership structure of many district-heating systems in Iceland have had their effect. The larger companies have either bought or merged with some of the smaller systems. Also it is getting increasingly common to run both district heating and electricity distribution in one municipally owned company. This development reflects increased competition in the energy market of the country.

4.1.9 Reykjavík District Heating

District heating in Reykjavik began in 1930 when a few official buildings and about 70 private houses received hot water from geothermal wells, located close to Reykjavik's old thermal hot springs. Reykjavik District Heating was formally established in 1943 when the production of hot water started in the Reykir field, 18 km from the city. Reykjavik Energy (Orkuveita Reykjavíkur) was established in 1999 through the merger of Reykjavik District Heating and Reykjavik Electricity. The company is responsible for the distribution and sale of hot water and electricity as well as the city's waterworks. The company has 492 employees with a turnover of $183 million in 2003. Reykjavik Energy is the largest of Iceland's 26 municipally owned geothermal district heating systems. It utilizes low-temperature areas within, and in, the vicinity of Reykjavik, as well as the high-temperature field at Nesjavellir, about 27 km away. At Nesjavellir, fresh water is heated in a cogeneration power plant. Today, Reykjavik Energy serves about 182,000 people, nearly the entire population of Reykjavik, plus the six neighboring communities (see Table 1).


Oddur Sigurdsson

Houses in Reykjavik

Table 1: **Reykjavik Energy – district-heating 2004**

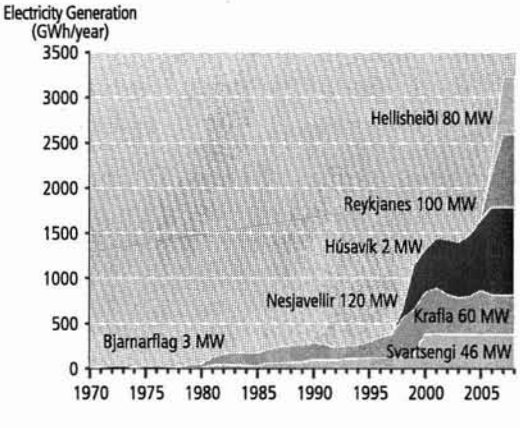
Number of people served	181.626	
Volume of houses served	52.685.307	m^3
Water temperature at user end	75	°C
Number of wells in use	80	
Installed capacity	1070	MWt
Peak load 2004	698	MW_t
Total pipe length	2233	km
Water delivered	65.096.971	m^3/yr

During the past few years Reykjavik Energy has been expanding by taking over several district-heating systems in the south and western parts of the country. Some are small systems in rural areas, but others are among the largest geothermal district heating systems in the country.

4.1.10 Sudurnes Regional Heating

Sudurnes Regional Heating (Hitaveita Suðurnesja) was a pioneer in building the cogeneration power plant at Svartsengi on the Reykjanes peninsula in 1977. The plant utilizes 240°C geothermal brine from the Svartsengi field to heat fresh water for district heating, and to generate electricity. The Keflavik airport and the NATO base, as well as four communities on the Reykjanes peninsula (pop. 17,000) utilize hot water and electricity from the plant. The plant also serves Hafnarfjordur (pop. 25,000), with electricity.

Fig. 7 **Generation of electricity using geothermal energy 1970 - 2008**

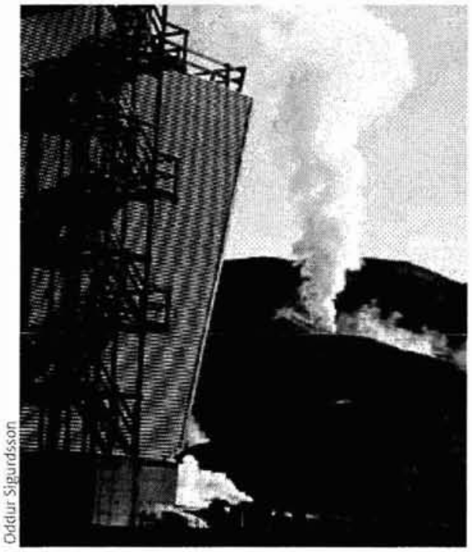


4.2 Electric Power Generation

Generating electricity with geothermal energy has increased significantly in recent years. As a result of a rapid expansion in Iceland's energy intensive industry, the demand for electricity has increased considerably. Fig. 7 shows the development from 1970-2005, and planned production up until 2008. The installed capacity of geothermal generating plants now totals some 200 MW_e. The total production in 2005 was 1,658 Gwh, which was 19.1% of the country's total electricity production. Enlargements of the existing power plants and two new plants will increase the installed capacity by 210 MW_e in 2006, bringing the total capacity up to 410 MW_e.

4.2.1 The Krafla Power Plant

The Krafla power plant in north Iceland has been operating since 1977. Two 30 MW_e double flash condensing turbine units were purchased when the plant started, but due to unexpected difficulties winning steam for the plant, Krafla was run with only one installed turbine for the first 20 years. The shortfall of steam was due to volcanic activity that injected volcanic gases into the most productive part of the geothermal reservoir. This contamination caused operational problems in some of the production wells, mostly in the form of rapid scaling of the complex iron silicates. It also caused wells to corrode. Repeated drilling in the area has shown that now, some 20 years after the eruptions, the concentration of magmatic gases in the steam has decreased drastically and now the reservoir can yield steam without problems with scaling or corrosion. The plant operated successfully with one turbine in spite of nine volcanic eruptions, the last one in September 1984. Initially the power generation was 8 MW_e, but reached 30 MW_e in 1982. The capacity of the Krafla power plant was expanded in 1997 from 30 to 60 MW_e, and preparations are underway to increase the plant's output by an additional 40


Oddur Sigurdsson

Krafla Power plant

MW_e. There are also plans to build a new plant in the Krafla area. The Krafla power plant is currently operated by the National Power Company (Landsvirkjun). The total electrical generation of the Krafla plant in 2005 was 483 GWh.

4.2.2 The Svartsengi Power Plant, the Blue Lagoon, and the Reykjanes Power Plant

The Svartsengi cogeneration power plant of Sudurnes Regional Heating exploits geothermal brine at 240°C with a salinity of about two thirds seawater. Geothermal heat is transferred to freshwater in several heat exchangers. After improvements and expansion in late 1999, the total installed capacity of the Svartsengi power plant increased to 200 MW_t for hot water production and 45 MW_e for electrical generation. Of that, 8.4 MW_e came from Ormat binary units using low-pressure waste steam. The total electrical generation of the Svartsengi power plant in 2005 was 368 GWh. The effluent brine spillover from Svartsengi is disposed into a surface pond called the Blue Lagoon. The Blue Lagoon has long been used by people suffering from psoriasis and other skin diseases like eczema. They have sought therapeutic effects from the silica-rich brine. The Blue Lagoon is Iceland's most popular tourist destination with about 170,000 annual visitors. In July 1999, the Blue Lagoon opened new facilities 800m from the previous site, which include indoor and outdoor bathing facilities, steam caves, mud pool and restaurants. The new facilities have gained international acclaim and the annual number of visitors is expected to increase.

Sudurnes Regional Heating is constructing a new power plant on the Reykjanes geothermal field. Two turbines of 50 MW_e each will be installed in the first stage. The plant will begin production in 2006, and a further expansion to 150 MW_e is expected in the future.

4.2.3 The Nesjavellir and Hellisheidi Power Plants

Reykjavik Energy has been operating a cogeneration power plant at the Nesjavellir high temperature field north of the Hengill volcano since 1990. The primary purpose of the plant is to provide hot water for the Reykjavik area, 27 km away. Freshwater is heated by geothermal steam and hot water in heat exchangers. The power plant started generating electricity in 1998 when two 30 MW_e steam turbines were put into operation. In 2001, a third turbine was installed and the plant enlarged to a capacity of 90 MW, and to 120 MW_e in 2005. The total electrical generation of the Nesjavellir power plant in 2004 was 674 GWh.

Reykjavik Energy is constructing a geothermal power plant at Hellisheidi in the southern part of the Hengill area, which is expected to start productionin in October 2006. In the first stage of operation, the plant's installed power will be 80 MW. The plant is expected to expand, and produce hot water for Reykjavík.

4.2.4 The Husavik Power Plant

At Husavik, in Northeast Iceland, the generation of electricity through geothermal energy began in mid-2000 when a Kalina binary-fluid 2 MW_e generator was put into service. It was one of the first of its kind in the world. The generator utilizes 120°C water as an energy source to heat a mixture of water and ammonia, which in closed circuit acts as a working fluid for heat exchangers and a turbine. The mixture has a lower boiling point than water, and can generate steam and gas pressure by boiling down to 80°C. The generated electricity accounts for about three-quarters of Husavik's electrical needs. The plant's hot water is used for the town's public heating, as well as the local swimming pool.

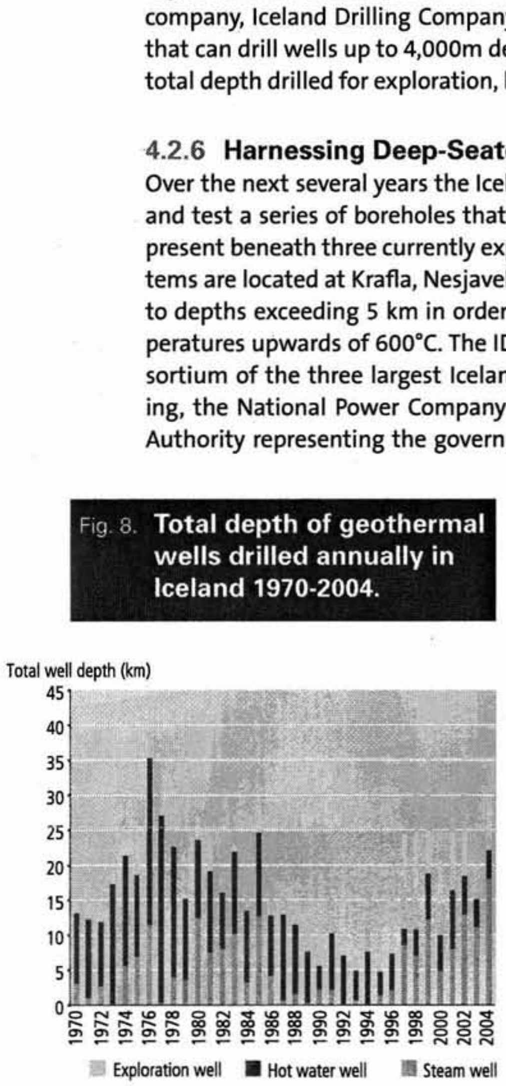
4.2.5 Geothermal Drilling

In order to meet the increasing demand for geothermal resources, considerable drilling has started to take place. Drilling is carried out by private contractors. The largest company, Iceland Drilling Company, recently invested in two advanced drilling rigs that can drill wells up to 4,000m deep into high temperature fields. Fig. 8 shows the total depth drilled for exploration, hot water and steam over the last 35 years.

4.2.6 Harnessing Deep-Seated Resources

Over the next several years the Iceland Deep Drilling Project, (IDDP), expects to drill and test a series of boreholes that will penetrate supercritical zones believed to be present beneath three currently exploited geothermal systems in Iceland. These systems are located at Krafla, Nesjavellir and Reykjanes (Fig. 2). This will require drilling to depths exceeding 5 km in order to produce hydrothermal fluids that reach temperatures upwards of 600°C. The IDDP was launched in 2000 by Deep Vision, a consortium of the three largest Icelandic energy companies: Sudurnes Regional Heating, the National Power Company and Reykjavik Energy with the National Energy Authority representing the government's share. The principal aim of this project is to enhance the economics of high temperature geothermal resources. A two-year long feasibility study dealing with geosciences and site selection, drilling techniques, and fluid handling and evaluation was completed in 2003. These reports are available on the IDDP website (www.iddp.is.). Based on the findings of this report, Deep Vision decided to proceed to the operational stage and seek international partners in November 2003. Deep Vision has been receptive to including scientific studies in the IDDP from the outset. An international advisory group, SAGA, has assisted Deep Vision with science and engineering planning of the IDDP, and was established in 2001 with financial support from the International Continental Scientific Drilling Program (ICDP). SAGA discussed the drilling and scientific issues associated with the IDDP at two international

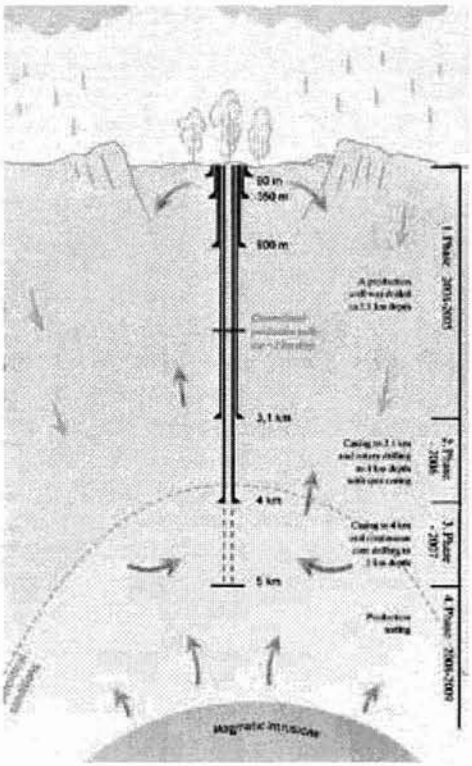
Fig. 8. **Total depth of geothermal wells drilled annually in Iceland 1970-2004.**



workshops held in 2002. Altogether, some 160 participants from 12 nations participated in the workshops. The recommendations to IDDP are described in SAGA reports, which are also available on the IDDP website. Modeling described in the feasibility report indicates that, relative to the output from conventional geothermal wells 2.5 km deep, a ten-fold increase in power output per well is likely if fluid is produced from reservoirs hotter than 450°C. This is because supercritical fluids have very low viscosity and density, and thus extremely high flow rates should be possible from such wells. A typical geothermal well in Iceland yields a power output equivalent to approximately 5 MW_e. An IDDP well tapping a supercritical reservoir with temperatures of 430 – 550°C and pressures of 23 – 26 MPa may be expected to yield 50 MW_e given the same volumetric inflow rate. However, to reach these conditions requires drilling deeper than 4 km (Fig. 9).

The feasibility study also concluded that an IDDP well 5 km deep could be drilled using available technology but such a deep production well would cost between $8-9 million. A full-scale exploratory IDDP well with extensive coring required by the science program could cost up to $15.5 million. Drilling deeper wells to test such an unconventional geothermal resource would also allow testing by injecting cold water into fractured rock to sweep heat from a very hot reservoir. Experiments in permeability enhancement could also be conducted.

Fig 9. **Conceptual model of a deep-seated resource**



In December 2003, a member of the Deep Vision consortium, Sudurnes Regional Heating, offered to allow IDDP to deepen one of their planned 2.7 km deep exploratory/production wells for scientific studies. It is located on the Reykjanes peninsula, where the mid-Atlantic ridge emerges from the ocean. It's ideally located for scientific studies of supercritical phenomena and the coupling of hydrothermal and magmatic systems on mid-ocean ridges. A comprehensive scientific program involving investigators from more than 12 different countries is planned to take advantage of this unparalleled research opportunity.

4.3 Other Utilization

4.3.1 Industrial Uses

- The diatomite plant at Lake Myvatn, near the Namafjall high temperature geothermal field, began operation in 1967, producing some 28,000 tones of diatomite filter for annual export. For environmental and marketing reasons, the plant was closed at the end of 2004. The plant employed about 50 people and was one of the world's largest industrial users of geothermal steam. The raw material was diatomaceous earth found on the bottom of Lake Myvatn. Each year the plant used some 230,000 tones of geothermal steam at 10-bar pressure (180°C), primarily for drying. This corresponds to an energy use of 444 TJ per year.
- The seaweed manufacturer Thorverk, located at Reykholar in West Iceland, uses geothermal heat directly in its production. The company harvests seaweed found in the waters of Breidafjordur in northwest Iceland using specially designed harvester crafts. Once landed, the seaweed is chopped and dried on a band dryer that uses large quantities of clean, dry air heated to 85°C by geothermal water in heat exchangers. The plant has been in operation since 1976, and produces between 2,000 to 4,000 tones of rockweed and kelp meal annually using 34 l/sec of 107°C water for drying. The product has been certified as organic. The plant's annual use of geothermal energy is about 150 TJ.
- A salt production plant was operated on the Reykjanes peninsula for a number of years. From geothermal brine and seawater, the plant produced salt for the domestic fishing industry, as well as low-sodium health salt for export. During the plant's final years of operation, production has been intermittent.
- Since 1986, a facility at Haedarendi in Grimsnes, south Iceland, has produced commercially liquid carbon dioxide (CO_2) from geothermal fluid. The Haedarendi geothermal field has an intermediate temperature (160°C) and very high gas content (1.4% by weight). The gas discharged by the well is nearly pure carbon dioxide with a hydrogen sulfide concentration of only about 300 ppm. Upon flashing, the fluid from the Haedarendi well produces large amounts of calcium carbonate scaling. Scaling in the well is avoided by a 250m long downhole heat exchanger made of two coaxial steel pipes. Cold water is pumped through the inner pipe and back up on the outside. Through this process, the geothermal fluid is cooled and the solubility of calcium carbon-

Helga Bardadottir

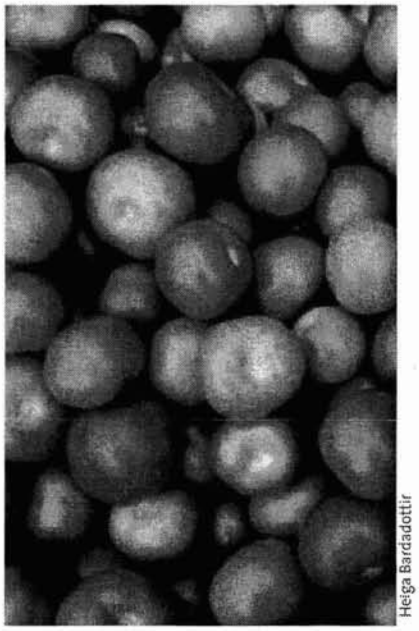
The CO2 plant at Haedarendi, South Iceland ate sufficiently increases to prevent scaling. The plant uses approximately 6 l/sec of fluid and produces some 2,000 tones annually. The production is used in greenhouses for manufacturing carbonated beverages, and in other food industries. It is sufficient for that market.

- Geothermal energy has been used in Iceland for drying fish for about 25 years. The main application has been the indoor drying of salted fish, cod heads, small fish, stockfish and other products. Until recently, cod heads were traditionally dried by hanging them on outdoor stock racks. Because of Iceland's variable weather conditions, indoor drying is preferred. The process is as follows: hot air is blown over the fish, and the moisture from the raw material removed. Today about 20 small companies dry cod heads indoors and 17 of them use geothermal hot water, and one uses geothermal steam. The annual export of dried cod heads is about 15,000 tones. The product is shipped mainly to Nigeria where it is used for human consumption. In 2001, about 2 million tones of geothermal water was used for drying fish, corresponding to about 550 TJ.
- In addition, drying pet food is a new and growing industry in Iceland with an annual production of about 500 tones. Examples of additional industrial uses of geothermal energy on a smaller scale are: re-treading car tires and wool washing in Hveragerdi, curing cement blocks at Myvatn, and baking bread with steam. Iceland's total amount of geothermal energy used to process heat for industrial purposes is estimated to be 1,600 TJ per year.

4.3.2 Greenhouses

Apart from space heating, one of Iceland's oldest and most important usages of geothermal energy is for heating greenhouses. For years, naturally warm soil has been used for growing potatoes and other vegetables. Heating greenhouses using geothermal energy began in Iceland in 1924. The majority of Iceland's greenhouses are located in the south, and most are enclosed in glass. It is common to use inert growing media (volcanic scoria, rhyolite) on concrete floors with individual plant watering. The increasing use of electric lighting in recent years has lengthened the growing season and improved greenhouse utilization. This development has been encouraged through governmental subsidies spent on electricity for lighting. CO_2 enrichment in greenhouses is also common, primarily though CO_2 produced in the geothermal plant at Haedarendi.

Greenhouse production is divided between different types of vegetables (tomatoes, cucumbers,



Helga Bardadottir

Tomato crop

paprika, etc.) and flowers for the domestic market (roses, potted plants, etc.). The total area under glass increased by 1.9% per year between 1990 and 2000. It was about 195,000 m^2 in 2002. Of this area, 55% is used for growing vegetables and 45% for flowers. It is expected that the total surface area of greenhouses will decrease despite of an increase in total production. This is due to increased competition with imported products, and an increased use of artificial lighting is expected to result in increased productivity in the greenhouse sector. Outdoor growing at several locations is enhanced by soil heating though geothermal water, especially during early spring. Soil heating enables growers to thaw the soil so vegetables can be brought to market sooner. It is estimated that about 105,000 m^2 of fields are heated this way. Soil heating is not a growing application, partly because similar results are commonly obtained at a lower cost by covering the plants with plastic sheets. The total geothermal energy used in Iceland's greenhouse sector is estimated to be 940 TJ per year.

4.3.3 Fish Farming

In the middle of the 1980s, Iceland saw an increase in the number of fish farms. For a period of time there were over 100 fish farms in operation, many of them quite small. The industry encountered early problems and almost collapsed. Since 1992, the production has been slowly increasing, totaling 4,000 tones in 2002 with about 50 plants. Salmon is the main species, accounting for about 70% of the production, but arctic char and trout have also increased.

Initially, Iceland's fish farming industry was mainly in shore-based plants. Geothermal water, commonly heated to 20-50°C, is used to heat fresh water in heat exchangers, typically from 5 to 12°C. This requires a large consumption of both freshwater and seawater, adding considerably to the operational cost. However, this process is still commonly used, especially when raising trout. The electrical consumption is reduced by injecting pure oxygen into the water and thus cutting down on water changes. Farming fish in cages floating along the shore is becoming more common and has proved to be more economical than shore-based plants that produce salmon. After many years of salmon produced by ocean ranching, the production method was not found to be profitable and has been on the decline. The total geothermal energy used in Iceland's fish-farming sector is estimated to be 1,680 TJ per year, of which about 65% is used for raising trout. Iceland's fish-farming production is expected to increase in the future. This means increased geothermal utilization, especially in smolt production (trout and salmon).


Broddi R. Hansen

Arctic char

4.3.4 Bathing

Until early in the last century, Iceland's geothermal energy was limited to bathing, washing clothes and cooking. These uses are still significant. After space heating, and electricity generation, heating of swimming pools is among the most important uses of geothermal energy. There are about 160 swimming pools operating in Iceland, 130 of which use geothermal heat. Based on their surface area, 89% of the pools are heated by geothermal sources, 7% by electricity, and 4% by burning oil.


Jónas Erlendsson

Swimming pool in Vik, South Iceland

Of the geothermally heated pools, about 100 are public and about 30 are pools located in schools and other institutions. The combined surface area is about 28,000 m². Most of the public pools are open-air pools used throughout the year. The pools serve recreational purposes and are also used for swimming lessons, which are compulsory in schools. Swimming is very popular in Iceland and pool attendance has increased in recent years. In 2002, Icelanders visited the pools on average 15 times. In the greater Reykjavik area alone there are ten public outdoor pools, and three indoor. The largest of these is Laugardalslaug with a surface area of 1,500 m² plus five hot tubs in which the water temperature ranges from 35 to 42°C. Other health uses for geothermal energy are the Blue Lagoon, and the Health Facility in Hveragerdi, comprised of geothermal clay baths and water treatments. The latest development in the water health sector is a bathing facility at Bjarnarflag that uses effluent geothermal water from wells.

Typically, about 220 m³ of water or 40,000 MJ of energy is needed annually for heating one m² pool surface area. This means that a new, middle-sized swimming pool uses as much hot water as is needed to heat 80-100 single-family dwellings. The total annual water consumption in geothermally heated swimming pools in Iceland is estimated to be 6,500,000 m³, which corresponds to an energy use of 1,200 TJ per year.

4.3.5 Snow Melting

To a limited extent, geothermal energy has been utilized to heat pavement and melt snow during the winter. Snow melting has increasing during the last two decades. Used water from the houses, at about 35°C, is commonly used for de-icing sidewalks and parking spaces. Most systems have the possibility to mix the spent water with hot water (80°C) when the load is high. In downtown Reykjavik, a snow-melting system has been installed under the sidewalks and streets, covering an area of 40,000 m². This system is designed for a heat output of 180 W per m^2 surface area. Iceland's total area of snow melting systems is around 740,000 m^2, of which about 550,000 m^2 is in Reykjavik. The annual energy consumption depends on the weather conditions, but the average is estimated to be 430 kWh/m^2. The total geothermal energy used for snow melting is estimated to be 1,150 TJ per year. Over half of this energy comes from return water from space heating systems.


Oddur Sigurðsson

Heated parking space at Perlan, Reykjavik


Oddur Sigurðsson

Pipe system for snow melting

4.3.6 Heat Pumps

Until recently, geothermal energy has been economically feasible only in areas where thermal water or steam is concentrated at depths less than 3 km in restricted volumes, analogous to oil in commercial oil reservoirs. The use of ground source heat pumps has changed the economic norms. In this case, the earth is the heat source for the heating and/or the heat sink for cooling, depending on the season. This has made it possible for people in all countries to use the earth's heat for heating and/or cooling. It should be stressed that heat pumps can be used basically anywhere. The significant fluctuations of oil prices caused by political unrest in key oil producing regions should encourage governments to focus on indigenous energy sources to meet their basic energy requirements. Recent developments in the deregulation of the electricity markets and integration of the electricity networks in Europe have destabilized consumer electricity prices. This makes ground source heat pumps a favorable alternative for base load heat sources in countries where electric heating is common.

Heat pumps have not found much use in Iceland, since sufficient cheap geothermal water for space heating is commonly available. However the Akureyri District Heating did install two 1.9 MW_t heat pumps between 1980 and 1984 to utilize the waste heat in return water from the distribution system while exploration for additional geothermal water was undertaken. It is considered likely that heat pumps will become competitive in the areas of the country where water above 50°C is not found. In these places, heat pumps can be used to raise the temperature of warm springs instead of direct electrical heating.

5. INSTITUTIONS AND COMPANIES

5.1 The National Energy Authority

The National Energy Authority (NEA) is a government agency under the Ministry of Industry and Commerce. Its main responsibilities have been to advise the Government of Iceland on energy issues and related topics, promote energy research and provide consulting services relating to energy development and utilization. The research facilities and the multidisciplinary research environment of NEA have given the institution a status for over three decades as one of the leading geothermal energy research institutions in the world. As already outlined in chapter 4, the NEA has been instrumental in the execution of government policy regarding exploration and development of geothermal resources, and in advising communities, companies and individuals about their utilization of these resources. Until 2003, the NEA was operated in four independent units: the Energy Management Division (energy resources, statistics and analyses), the UNU Geothermal Training Program (UNU-GTP), the Geoscience Division, and the Hydrological Service Division. NEA had about 110 employees, of which 77% are university graduates. In 2003, as a result of changes in Iceland's energy legislation, the Geoscience Division was separated from the NEA and a new government-owned institution was established under the name Iceland GeoSurvey (Islenskar Orkurannsoknir- ISOR).

Sigurður Sveinn Jónsson

Strokkur, in Haukadalur, South Iceland

5.2 Iceland GeoSurvey

Iceland GeoSurvey is a research institution providing specialist services to the Icelandic power industry, the Icelandic government and foreign companies with regard to the field of geothermal sciences and utilization. The staff is comprised of about 50 people, most of whom have academic degrees and varied experience in geothermal research and training. Geothermal exploration and exploitation involves several disciplines such as geology, geophysics, geochemistry, reservoir physics and engineering. Iceland GeoSurvey (ÍSOR) is a self-financed, non-profit government institution that operates on the free market like a private company. It gets no direct funding from the government but operates on a project and contract basis. The annual turnover is approximately $6 million. It is expected that about 20% of Iceland GeoSurvey's turnover will come from government contracts, and the remainder from contracts with various energy companies, utilities and municipalities. Each geothermal field is different from the others and exploration methods as well as modes of utilization need to be tailored to conditions at individual sites in order to get optimal information. Thus Iceland GeoSurvey specialists usually work in project teams covering all the expertise needed to perform the research as efficiently as possible. Groups of specialization include: computerized GIS mapping, geological mapping, hydrogeology, borehole geology, geophysical exploration, marine geology, geochemistry, corrosion and deposition, environmental sciences and monitoring, well design, well logging, well testing and stimulation, reinjection, reservoir modeling, resource management, drilling engineering and geothermal utilization. Iceland GeoSurvey sites exploration and production wells, and evaluates their geothermal characteristics and production capacity. The results are integrated into a conceptual model of the geothermal reservoir, which forms a basis for numerical modeling of the reservoir to assess the production capacity of the field. Iceland GeoSurvey has service contracts with electric utilities, and district heating services around the country. These involve monitoring of reservoirs and chemical composition of geothermal fluids. It also advises developers on cold water supplies and on disposal of effluent water. The company has specialized research equipment, laboratories and computer software developed for the processing and interpretation of various types of data. The staff takes an active part in international geothermal workshops and conferences, provides course work and lectures for specially tailored training seminars and the United Nations Geothermal Training Program. Iceland GeoSurvey has about 50 years experience in geothermal research, services and consultancy abroad. This includes most categories of geothermal research and utilization. Among the countries involved: Kenya, Uganda, Burundi, Ethiopia, Djibouti, Russia, Poland, Slovakia, Hungary, Romania, Georgia, Germany, Portugal, Guadeloupe, Greece, Turkey, USA, Indonesia, Philippines, El Salvador, Costa-Rica, Nicaragua and China.

5.3 The United Nations University Geothermal Training Program

The Geothermal Training Program of the United Nations University (UNU-GTP) was established in Iceland in 1978 when the National Energy Authority (NEA) became an Associated Institution of the UNU. Since 1979, a group of professional scientists and engineers from the developing and transitional countries have come to Iceland each spring to spend six months in highly specialized studies, research, and on-the-job training in geothermal science and engineering. All of them are university graduates with practical experience in geothermal work and permanent positions at energy agencies/utilities, research organizations or universities in their home countries.

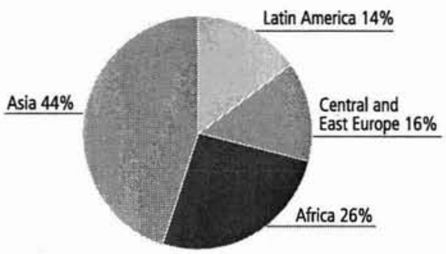
The UNU Fellows have full access to the research facilities and the multidisciplinary research environment of the NEA and the Iceland GeoSurvey. There is an excellent library specializing in energy research and development (in particular geothermal and hydropower) with some 12,000 titles and subscriptions to 140 journals. Most of the teaching and research supervision of the UNU-GTP has been conducted by geothermal specialists of the Geoscience Division of NEA. This division was separated from the NEA in 2003 to become a new government-owned institution, Iceland GeoSurvey. The integration of the UNU Fellows with the specialists and the research atmosphere will continue as in previous years. The UNU-GTP closely cooperates with the University of Iceland (UI). Staff members of the Faculty of Science and the Faculty of Engineering have been among the key lecturers and supervisors of the UNU Fellows. In May 2000, a cooperation agreement was signed between the UNU-GTP and the UI on MSc studies in geothermal science and engineering. This is designed for UNU Fellows who have already completed the traditional six-month courses at the UNU-GTP, which constitute 25% of the MSc program.

Specialized training is offered at the UNU-GTP in geological exploration, borehole geology, geophysical exploration, borehole geophysics, reservoir engineering, chemistry of thermal fluids, environmental studies, geothermal utilization, and drilling technology. The aim is to assist developing countries and Central and Eastern European countries with significant geothermal potential to build groups of specialists that cover most aspects of geothermal exploration and sustainable development. All trainees are selected by private interviews with UNU-GTP representatives as they visit the countries concerned to become acquainted with geothermal


Ingvar Birgir Friðleifsson

UNU-Fellows during field training

Fig. 10. **Distribution of UNU Fellows by continets 1979-2005.**



fields, research institutions and energy utilities of the home country of the prospective candidate. Participants are selected for training in the specialized fields that are considered most relevant to promote geothermal development in their respective countries. The trademark of the UNU-GTP is to give university graduates engaged in geothermal work intensive on-the-job training in their chosen fields of specialization. The trainees work side by side with Iceland's geothermal professionals. The training is tailored to the individual and the needs of his institution/country. The candidates must have a university degree in science or engineering, a minimum of one year practical experience in geothermal work, speak fluent English, have a permanent position at a public energy company/utility, research institution, or university, and be under 40 years old.

Participants from developing countries and most CEE countries (not EU members) normally receive scholarships, financed by Iceland and the UNU, that cover international travel, tuition fees and per diem in Iceland. The participants therefore do not need additional funds for their training.

From 1979-2005, 338 scientists and engineers from 39 countries completed the six-month specialized courses offered. Of these, 44% have come from Asia, 26% from Africa, 16% from Latin America, and 14% from Central and Eastern European (CEE) nations. The largest groups have come from China (62), Kenya (37), Philippines (29), Ethiopia (23), El Salvador (22), Indonesia (17), Poland (14), Iran (14), and Costa Rica (11). In all, there have been 53 women (16%). Eight have graduated from the MSc program (Fig 10 and 11).

In many countries, UNU-GTP graduates are among the leading specialists in geothermal research and development. They have also been very active internationally, as exemplified at the 2000 World Geothermal Congresses in Japan and in Turkey in 2005. In Turkey, 20% of the 705 refereed papers accepted were authored or coauthored by 104 former UNU fellows from 26 developing and transitional countries. The level of activity of the UNU fellows in the international geothermal community is well-reflected by the fact that a third of the 318 graduates of the UNU-GTP, from 1979- 2004, were authors of refereed papers at the congress.

Considerable expansion of the UNU-GTP's operations is planned over the next few years. The core activity, six month specialized courses in Iceland, will continue, but short courses will be added, first in Africa and later in Central America and Asia. In the next few years, it is expected that the UNU-GTP will have about 20 UNU Fellows per year for the six month courses, and that the MSc program will be expanded, admitting up to five former UNU Fellows per year to commence MSc studies in geothermal science and engineering in cooperation with the University of Iceland.

Fig. 11. **Geographical distribution of Fellows completing the six-month courses at the UNU-GTP in Iceland 1979-2005**

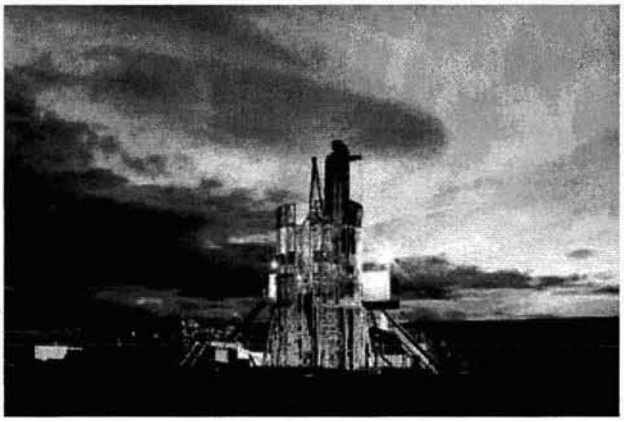
Iceland has secured core funding for the UNU-GTP to expand its capacity building activities by short courses in geothermal development in selected countries in Africa, Central America and Asia. This announcement was made at the International Conference for Renewable Energies held in Bonn (Germany) 1-4th June 2004. The short courses will be set up in cooperation with the energy agencies/utilities and earth science institutions responsible for the exploration, development and operation of geothermal energy power stations and utilities in the respective countries. The teaching will mostly be conducted by UNU-GTP graduates in their respective countries/regions, and the regular teachers of the UNU-GTP. The courses may in the future develop into sustainable regional geothermal training centers. The first annual short course for Africa was held in Kenya in 2005. The first course for Central America will be held in Costa Rica in 2006, and the first for Asia has tentatively been set for 2007.

5.4 International Development Aid

Iceland's government decided in April 2004 that official development assistance (ODA) as a proportion of Gross Domestic Product (GDP) should rise from 0.19% to 0.35% by 2009. When the target is achieved, this will represent a fourfold increase in ODA in ten years.

Sustainable development is one of the pillars of Iceland's development cooperation. Within that pillar, Iceland will increase its focus on sustainable development, emphasize the sustainable use of natural resources, particularly in regards to energy. Increased focus will be placed on geothermal energy and cooperation with countries with unexploited geothermal resources with the objective of assisting them to develop their renewable energy resources.

The Icelandic International Development Agency (ICEIDA) is an autonomous agency under the Ministry for Foreign Affairs. ICEIDA's role set by law is to execute and administer bi-lateral development assistance provided by Iceland. Presently, ICEIDA is engaged in development cooperation with six countries; Malawi, Mozambique, Namibia, Uganda, Sri Lanka and Nicaragua.



Iceland Drilling

The Geysir geothermal rig. Operated by Iceland Drilling.

In Uganda, ICEIDA supported a one-year geothermal project, which began in early 2004. The project was to complement previous geophysical and geological work carried out by the Ministry of Energy and Mineral Development in order to finalize a pre-feasibility study of three prospective geothermal sites in western Uganda. Because of the promising results, further technical assistance will be provided. In Nicaragua, ICEIDA has begun preparations for geothermal projects in cooperation with geothermal organizations in Iceland, such as the National Energy Authority, Icelandic GeoSurvey, the UNU Geothermal Training Program and the Icelandic Ministry of Industry.

ICEIDA has also participated in preparing a joint project with six states in northwestern Africa. The project is in cooperation with the UN Environment Program, the KfW Bank in Germany and the Global Environment Fund, along with other donors relating to the research and use of geothermal energy in the northern reaches of the East African Rift (ARGeo).

5.5 Enex

The Enex company was established to coordinate the ongoing efforts of the shareholding companies and institutions to export geothermal and hydropower technical know-how and experience in a more vigorous and integrated manner than before. The objectives set out in its charter are:

- Develop geothermal, direct use and electrical generation and hydropower plants.
- Participation on commercial basis in studying, building and the subsequent operation of geothermal developments as a Joint Venture partner or part owner / operator
- Offer on commercial basis hydrological, geoscientific and consulting services covering geothermal exploration and development, hydrological surveys and sedimentation studies, project financing, personnel training, sale and/or rental of tools and techniques specially developed and tested in Iceland
- Actively promote hydropower and geothermal energy as a sustainable and clean alternative resource through visits, exhibitions and training seminars.

Enex is owned by eight Icelandic companies and organizations that collectively have several decades of experience in the development of geothermal energy and hydropower, spanning a wide range of application and conditions. The shareholders are Reykjavik Energy, Sudurnes Regional Heating, Iceland Drilling Company, National Power Company, New Business Venture Fund, Iceland GeoSurvey, Akureyri Municipal Water and Power Company, and Virkir Engineering Group. Members of the owner group have pioneered the comprehensive and integrated utilization of geothermal energy, both internationally and domestically. Enex offers novel solutions applicable to geothermal resources of diverse types and properties, and hydropower resources where harsh weather conditions and nature prevail. It has affiliates in the United States, Germany and China. During the 35 years of operation, Enex has participated in numerous geothermal projects worldwide. Some of the recent projects and customers are:

- Hungary (MOL, the Hungarian Oil & Gas Company), evaluation of wells for generation of electricity.
- Galanta, Slovakia (NEFCO), replacing lignite heating with geothermal heating.
- Hungary (ALTENER II - EU), feasibility of small scale geothermal power plants.
- Zakopane, Poland (World Bank), restructures the Geotermia Phodhalanska geothermal power plant.
- Beijing, China, conceptual design for a geothermal heating system and reservoir simulation.
- Budapest, Hungary (Fötáv), replacing fossil fuel with geothermal heating.
- Tanggu, China (NIB & NDF), modify and expand the existing geothermal heating system.
- Tengchong, Yunnan, China, reservoir appraisal and feasibility studies for a geothermal power plant.

5.6 Export of Know-how

It is a moral obligation of the world's nations to reduce greenhouse gas emissions. Increased use of renewable energy could play a key role in this respect. Iceland is a world leader in terms of the share of renewable resources. Iceland is willing to share its experience with other nations, as can be seen from its development assistance in this field. In addition, several Icelandic companies export geothermal and hydropower know-how and experience:

Addresses of engineering and consulting companies as well as energy companies are found in the reference list.

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Stefansson, V., and Axelsson, G.: Sustainable Utilization of Geothermal Resources through Stepwise Development. Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005. (www.os/wgc2005).

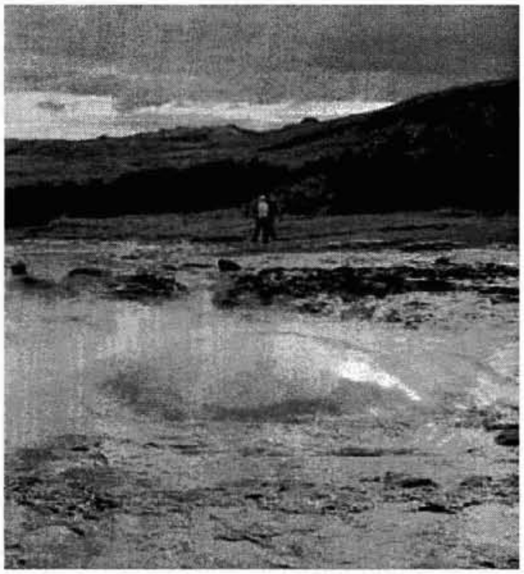
6.2. Home pages:

Ministries of Industry and Commerce: www.ivr.is
National Energy Authority: www.os.is
UNU Geothermal training programme: www.os.is/unugtp

Engineering and consulting companies:
Icelandic GeoSurvey: www.isor.is
Enex: www.enex.is
Linuhonnun: www.lh.is
Rafhonnun: www.rafhonnun.is
Rafteikning: www.rafteikning.is
Honnun: www.honnun.is
Afl: www.afl.is
Hnit: www.hnit.is
Fjarhitun: www.fjarhitun.is
VGK: www.vgk.is
VSO-radgjof: www.vso.is
Iceland Drilling: www.jardboranir.is

Energy companies:
Hitaveita Sudurnesja: www.hs.is
Husavik Energy: www.oh.is
Iceland State Electricity: www.rarik.is
Landsvirkjun: www.lv.is
Nordurorka: www.nordurorka.is
Reykjavik Energy: www.or.is
Westfjord Power Company: www.ov.is

6.3. List of figures and tables



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