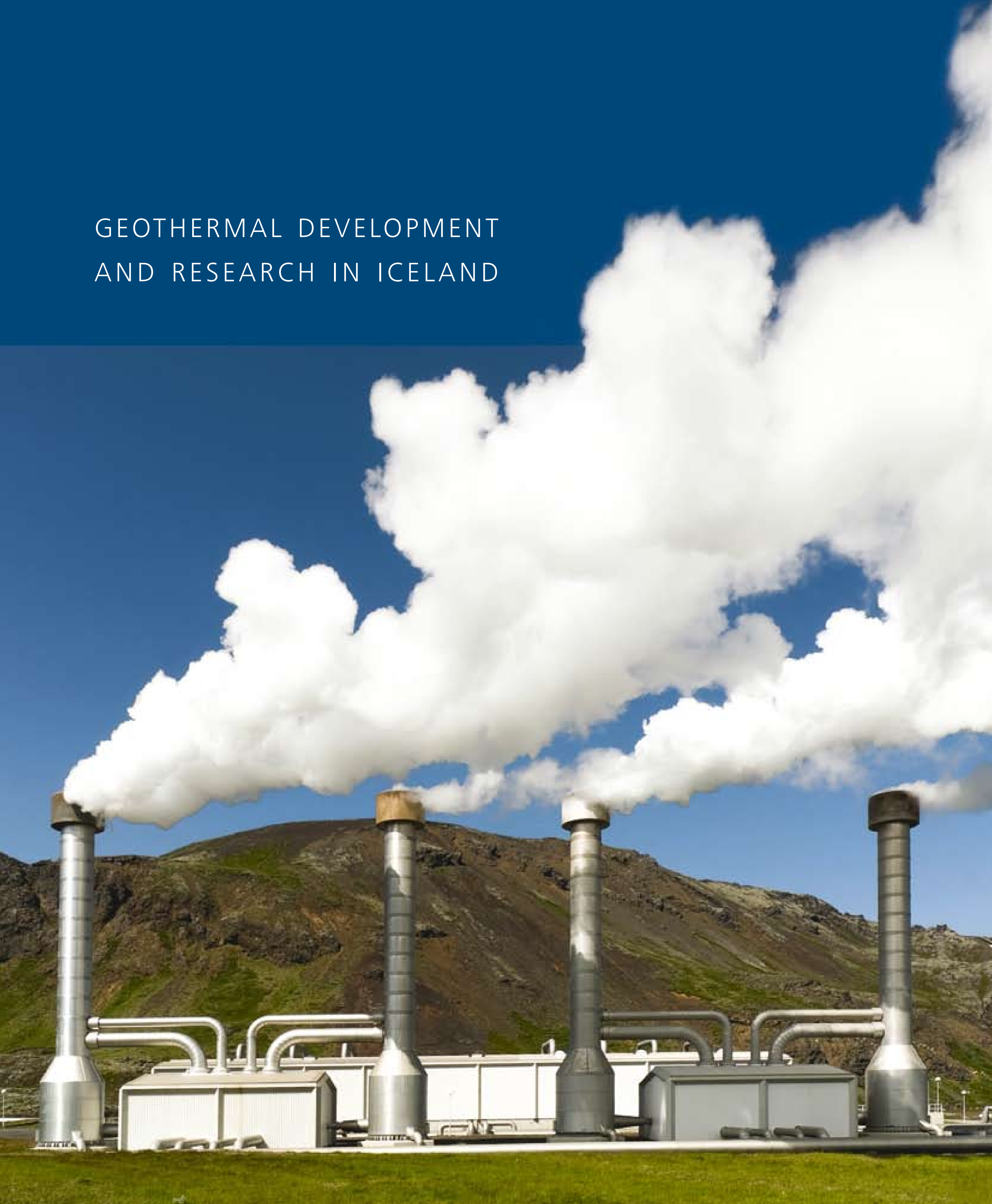
GEOTHERMAL DEVELOPMENT AND RESEARCH IN ICELAND



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Content

1. Introduction

Iceland is a country of 320,000 people, located on the mid-Atlantic ridge. It is mountainous and volcanic with ample precipitation. The country's geological characteristics have endowed Iceland with an abundant supply of geothermal resources and hydropower. During the 20th century, Iceland developed from what was one of Europe's poorest countries, dependent upon peat and imported coal for its energy, to a country with a high standard of living where practically all stationary energy, and in 2008 roughly 82% of primary energy, was derived from indigenous renewable sources (62% geothermal, 20% hydropower). The rest of Iceland's energy sources is 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 that of most other countries. Nowhere else does geothermal energy play a greater role in providing a nation's energy supply. Almost three-quarters of the population live in the southwestern part of the country, where geothermal resources are abundant.

Iceland derives 82% of its primary energy from indigenous renewable resources (62% geothermal, 20% hydropower).

Resources

The current utilisation of geothermal energy for heating and other direct uses is considered to be only a small fraction of what this resource can provide. The electricity generation potential is more uncertain. Hydropower has until now 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 is mainly from the energy intensive industry (Fig. 1). In 2008, geothermal plants generated 24.5% of the total 16,468 GWh produced, 78% used by the energy intensive industry. In 2009, the total production is forecast to be about 16,797 GWh, 27% generated with geothermal.

Electricity is totally generated from renewable resources, 75.5% hydro and 24.5% geothermal. Energy intensive industry consumes 78% of the electricity.

Reykjavik smokeless city.

Iceland possesses extensive untapped energy reserves. These reserves are however not unlimited. Only rough estimates are available regarding the extent of these energy reserves in relation to the total amount of electricity generated. Therefore, there is considerable uncertainty in the assessment of the extent to which they can be harnessed with regard to what is technically possible, cost-efficient, and environmentally desirable. For the potential generation of electricity, these energy reserves are estimated at roughly 50 TWh per year, some 60% from hydropower and 40% from geothermal resources. The potential is currently under re-evaluation.

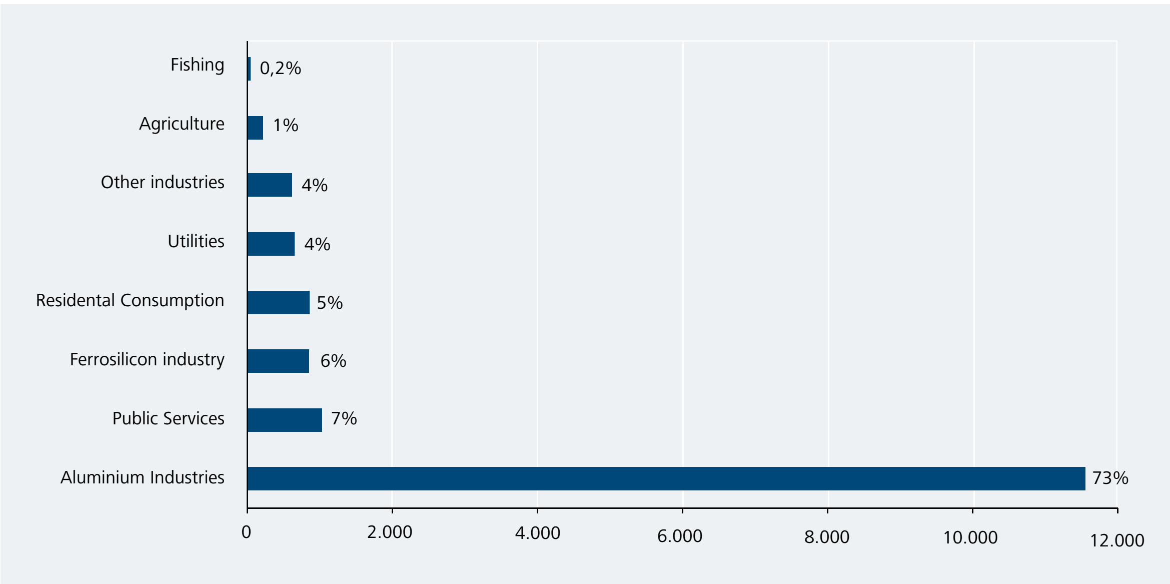

Fig. 1. Electricity Consumption, GWh/year 2008.

Master Plan

A Master Plan for Hydro and Geothermal Energy Resources is being prepared, which compares economic feasibility and the environmental impact of proposed power development projects. This comparison will aid in the selection of the most feasible projects to develop, considering both the economic and environmental impact of such decisions, such as which rivers or geothermal fields should not be harnessed due to their value as natural heritage and for recreation. Results of a first-phase study were presented in November 2003.

During the first-phase evaluation 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, were compared. The hydro projects had a combined potential of 10.5 TWh/yr. A number of these projects, with a combined potential of 4.7 TWh/yr, were, considered to have an environmental impact of such severity that their development might not be acceptable. The geothermal projects had a combined potential of 13.2 TWh/yr. Among those, projects with a total potential of 4.2 TWh/yr were also considered liable to cause severe environmental impact. A second phase evaluation of projects, comparing all projects in major high temperature geothermal fields, and new or revised hydro projects is now being prepared. Results are expected in 2010.

Seljalandsfoss.

Legal framework

The private ownership of resources within the ground is associated with the ownership of the land, while on public land underground resources are the property of the State of Iceland, unless others can prove their right of ownership. Even though the ownership of resources is based on the ownership of land, research and utilisation is subject to licensing according to the Act on Survey and Utilisation of Ground Resources, No. 57/1998 and the Electricity Act, No. 65/2003. Survey, utilisation and other development pursuant to these Acts are also subject to the Nature Conservation Act, Planning and Building Act and other acts relating to the survey and utilisation of land and land benefits.

The Act on Survey and Utilisation of Ground Resources, No. 57/1998, covers resources within the ground, at the bottom of rivers and lakes and at the bottom of the sea within netting limits. The Act also covers surveys of hydropower for the generation of electricity. The term resource applies to any element, compound and energy that can be extracted from the Earth, whether in solid, liquid or gaseous form, regardless of the temperature at which they may be found.

According to the Act the Minister of Industry is permitted to take the initiative in and/or give instructions on surveying and prospecting for resources in the ground anywhere in the country. In the same way, the Minister may permit others to survey or prospect, in which case a prospecting licence shall be issued to them. A prospecting licence confers the right to search for the resource in question within a specific area during the term of the licence, survey extent, quantity and potential yield and to observe in other respects the terms which are laid down in the Act and which the Minister considers necessary.

The utilisation of resources within the ground is subject to a licence from the Minister of Industry, Energy and Tourism.

The utilisation of resources within the ground is subject to a licence from the Minister of Industry, Energy and Tourism whether it involves utilisation on private land or public land, with the exceptions provided for in the Act. A landowner does not have a priority to a utilisation licence for resources on his or her land, unless such an owner has previously been issued a prospecting licence. A utilisation licence permits the licence holder to extract and use the resource in question during the term of the licence to the extent and on the terms laid down in the Act and regarded necessary by the Minister. Before the holder of a utilisation licence begins extraction on private land the holder needs to reach an agreement with the landowner on compensation for the resource or obtain permission for expropriation and request assessment. In the event of neither an agreement made on compensation nor expropriation requested within 60 days immediately following the date of issue of a utilisation licence, the licence shall be cancelled. The same applies if utilisation on the basis of the licence has not started within three years of the issuance of the licence. This also applies to the utilisation of resources inside public land.

The Minister of Industry, Energy and Tourism may revoke the above licences if their conditions are not fulfilled. If a licence holder does not comply with the conditions established in the licence or contracts relating to the licence, the Minister shall issue a written warning and provide time limits for rectification. Should the licence holder not comply with such a warning, the licence shall be revoked.

According to the Electricity Act, No. 65/2003, a licence issued by the Minister of Industry, Energy and Tourism is required to construct and operate an power plant. However, such a licence is not required for power plants with a rated capacity of under 1 MW, unless the energy produced is delivered into the distribution system or into the national transmission grid. The owners of power plants with a rated capacity of 30–1,000 kW shall submit technical details of the plant to the National Energy Authority. Also, the National Energy Authority shall be informed annually of the total generation of power plants with a rated capacity of over 100 kW.

The National Energy Authority is responsible for monitoring mineral prospecting or extraction areas and geothermal areas, as well as to regulate the compliance of companies operating under issued licences. The National Energy Authority will report to the Minister of Industry, Energy and Tourism on the conduct of exploration, prospecting, and extraction in accordance with further instructions issued by the Minister. The protection and monitoring of prospecting and extraction areas is also subject to the Nature Conservation Act.

Three major amendments have recently been made to the legal energy framework in Iceland:

1. The ownership of resources can no longer be sold by the state or municipalities although utilisation rights can be leased to a developer for up to 65 years with a possibility of extension. Royalties for the utilisation are determined by the Prime Minister.
2. Producers of electricity compete in an open market in Iceland. Therefore CHP power plants are obliged to keep separate accounts for heat and power production to prevent cross subsidisation of electricity.
3. The National Energy Authority can grant licenses on behalf of the Minster of Industry, Energy and Tourism, according to Act. No. 57/1998 and Act. No. 65/2003, effective as of 1. August 2008.

3. The References

The following outline of geothermal research and development in Iceland is based on a number of references, which are listed in Chapter 6.

2. Sustainable Utilisation 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 different 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 utilisation of a resource. Geothermal energy is a renewable energy source that can be utilised 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 overuse, a field operator is forced to reduce the production to the level of maximum sustainable use. To avoid excessive production, "stepwise development" is initiated.

Stepwise development of geothermal resources is a methodology that takes into consideration the individual conditions of each geothermal system, and minimises 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 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 utilise geothermal energy resources.

Merging stepwise development with sustainable development of geothermal resources, results in attractive and economical utilisation.

3. The Nature of Geothermal Resources

3.1 Geological background

Iceland is a hot spot of unusually great volcanic productivity on the diverging boundary of the North American and Eurasian tectonic plates.

Iceland is a young country geologically. It lies astride one of the Earth's major fault lines, the Mid-Atlantic ridge. This is the boundary between the North American and Eurasian tectonic plates. The two plates are moving apart at a rate of about 2 cm per year. Iceland is an anomalous part of the ridge where deep mantle material wells up and creates a hot spot of unusually great volcanic productivity. This makes Iceland one of the few places on Earth where one can see an active spreading ridge above sea level. 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 stretching 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 200°C within 1,000 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 1,000 m are found mostly in the areas flanking the active zone. To date, over 600 hot springs (temperature over 20°C) have been located (Fig. 2).

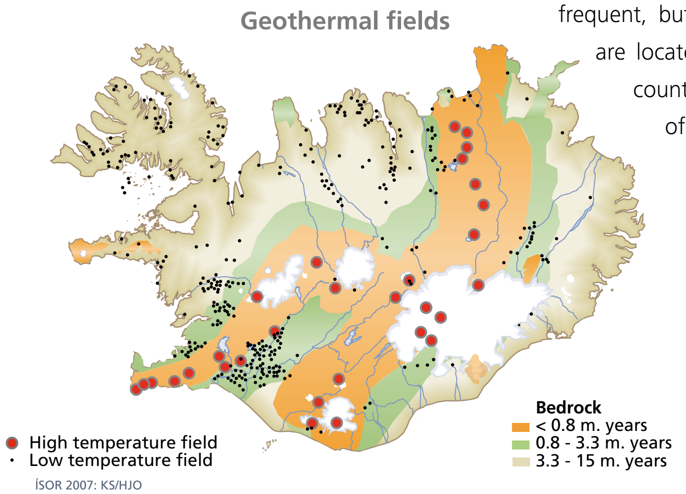

Fig.2 Volcanic zones and geothermal areas in Iceland.

3.2. Energy current and stored heat

The energy current from below Iceland has been estimated to be about 30 GW (1 GW = 10^9 W). About 24 GW are carried by flowing magma and 6 GW by heat conduction. This only considers land above sea-level, while considerable additional energy also flows up through the ocean floor around the island. Energy flows through the crust, which also stores great amounts of energy. Near the surface the energy current splits between; 7 GW by volcanic activity, 8 GW by water- and steam-flow in geothermal areas and 15 GW by heat conduction. The total energy stored in the crust of Iceland, from surface down to 10 km depth, amounts to about $12 \cdot 10^{14}$ GJ. Above 3 km depth the energy stored is only about $1 \cdot 10^{14}$ GJ. Again these results only apply to the crust directly below the section of the country above sea-level. The concentration of energy is greatest within the volcanic zone, in particular in the high-temperature systems. The thermal energy stored in five of the largest high-temperature systems is estimated to account for 70% of the total energy stored in all high-temperature systems in Iceland. Figure 3 presents a simple sketch of the energy current and stored heat, i.e. the components of the geothermal potential of Iceland.

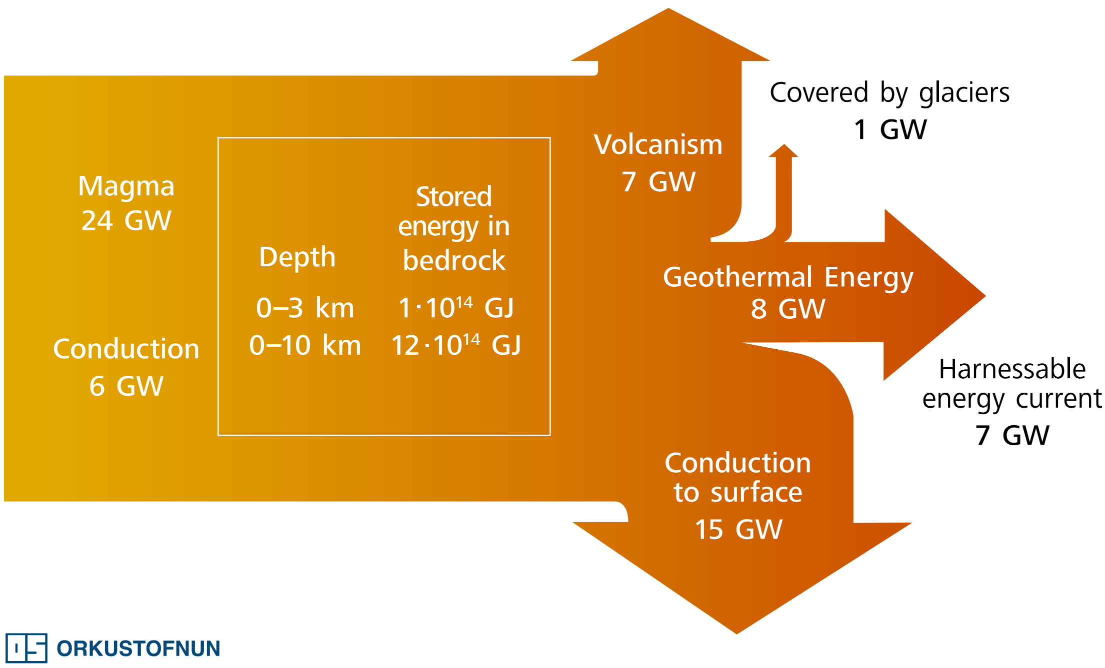

Fig. 3: Terrestrial energy current through the crust of Iceland and stored heat.

3.3 The nature of low-temperature activity

The heat-source for hot springs is believed to be Iceland's abnormally hot crust.

The low-temperature systems are all located outside the volcanic zone passing through Iceland (see Fig. 2). The largest of these systems are located in southwest Iceland on the flanks of the western volcanic zone, but smaller systems can be found throughout the country. On the surface, low-temperature activity is manifested in hot or boiling springs, while no surface manifestations are observed on top of some such systems. 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 mines the heat. The temperature of rocks in Iceland generally increases with depth. Outside the volcanic zones the temperature gradient 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 1 - 3 km, where the water is heated by the hot rock, and subsequently ascends 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 localised convection systems where the water circulates vertically in fractures of several kilometers of depth. The water then takes up the heat from 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.

Strokkur.

3.4 The nature of high-temperature activity

The heat source of the high temperature steam fields is generally shallow magma intrusions.

High-temperature areas are located within the active volcanic zones 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 generally deep, and surface manifestations are largely steam vents. Hydrogen sulphide present in the steam tends to be oxidised at 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 where no central volcanoes have developed only dyke swarms are found. Intrusive rocks appear to be most abundant in reservoirs associated with central complexes that have developed a caldera.

The boiling point of water depends on the hydrostatic pressure. As the pressure increases with depth the temperature needed for the water to 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 386°C. Hydrological considerations and permeability data imply that the groundwater in the reservoir is undergoing a density driven vertical circulation. This groundwater is in most cases of meteoric origin. However, in three areas on the Reykjanes Peninsula it is partly or solely ocean water.

4. Development of Utilisation

Geothermal resources account for 62% of Icelanders' primary energy needs. Half (47%) of the utilisation of geothermal resources is in space heating, 37% in generation of electricity

Geothermal sources account for over half of Icelanders' primary energy needs. From the earliest times, geothermal energy has been used for bathing and laundry. Late in the 19th century, people began experiments utilising geothermal energy for outdoor gardening; and early in the 20th century geothermal sources were first used to heat greenhouses. At about 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 4 gives a breakdown of the utilisation of geothermal energy for 2008. These percentages are for utilised energy rather than primary energy. In 2008, direct use of geothermal energy, for other uses than electrical generation, totaled around 25,0 PJ, which corresponds to 7000 GWh. In addition, electricity production amounts to 4,038 GWh. As Fig. 4 reveals, the 47% share of space heating is by far the greatest, followed by electricity generation, accounting for 37%.

After its culmination in the 1980s, Iceland's development of geothermal energy for direct use has been rather slow. Geothermal space heating has, however, continued to increase at a slow rate. New industrial users that utilise 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 in high-temperature geothermal exploration and drilling, with the aim of producing electricity for the further expansion of the country's aluminum industry.

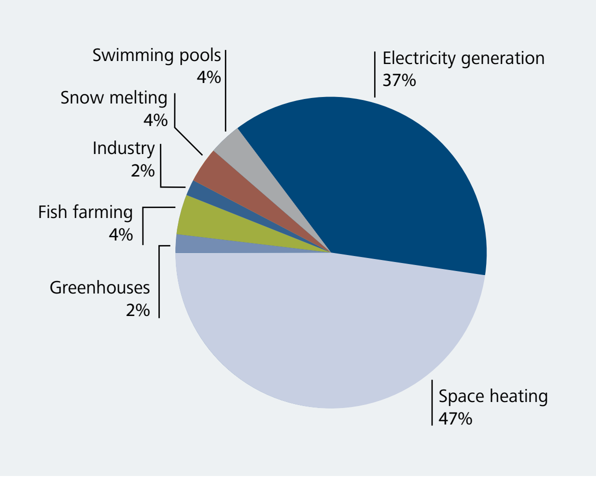

Fig. 4. Sectoral share of utilisation of geothermal energy in Iceland in 2008.

4.1 Space Heating

Geothermal resources provide heat to households of 89% of the population.

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 the households of 89% of the population. This achievement has enabled Iceland to import less fuel, and has resulted in lower heating prices.

4.1.1 Fuel for heating houses

In earlier centuries peat, sheep-dung and seaweed were burned for heating of houses. Coal became the dominant heat source in the beginning of the 20th century and remained until the end of WW2.

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 a closed circuit, was widely developed.

In earlier centuries, peat 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 peat 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 enters the picture

Oil practically eliminated coal from space heating around 1960.

Iceland's dependence on oil began with the 20th century. At first oil was used for lights, to power small fishing boats and later as 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 1950's, the equipment to utilise oil for heating was improved, obviously leading to increased consumption. As a result, coal was practically eliminated from space heating in Iceland in about 1960. At the same time, control systems for central heating rapidly developed, and the first automatic temperature regulators for radiators became common.

4.1.3 Electric heating

Heating homes with electricity did not become common until in the 1930s and 1940s.

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 1930's and 1940's.

4.1.4 Initial use of geothermal heat

The first uses of geothermal energy to heat houses can be traced back to 1908, when 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 Thvottalaugar (laundering 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 from Reykir, Mosfellssveit was put into use, and the Reykjavik District Heating Service began operating. By the end of 1945, 2,850 houses were 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 Ólafsfjordur (1944), Hveragerdi (1947), Selfoss (1948) and Saudárkrókur (1953). Community schools in the countryside were also preferably located close to supplies of geothermal water, which was available for heating and swimming.

In Reykjavik, extensive distribution of geothermal homes began in 1930. By the end of 1945, there were 2,850 houses connected.

4.1.5 Influence of the oil crises 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%. At about the same time, close to 90,000 people enjoyed geothermal heating in Iceland, about 43% of the nation. Heat from oil served over 50% of the population, the remainder using electricity. In order to reduce the effect of rising oil prices, Iceland began subsidising those who used oil for space heating. The oil crises in 1973 and 1979 (Iranian Revolution) caused Iceland to change its energy policy, reducing oil use and turning to domestic energy resources, hydropower and geothermal heat. This policy meant exploring for new geothermal resources, and building new heating utilities across the country. It also meant constructing transmission pipelines (commonly 10–20 km) from geothermal fields to towns, villages and individual farms. This involved converting household heating systems from electricity or oil to geothermal heat. But despite the reduction in the use of oil for space heating from 53% to 7% from 1970 to 1982, the share of oil still remained about 50% to 60% of the total heating cost due to rising oil prices.

The oil crises in 1973 and 1979 caused Iceland to deemphasise oil, and turn to domestic energy resources, hydropower and geothermal heat. By 1985 the share of oil in house heating had decreased to less than 3% and is now about 1%.

The relative share of energy resources used to heat households has changed since 1970 (Fig. 5). The increase in geothermal energy is clear, but after 1985 it has been relatively small. The proportion of the population using geothermal energy is, however, still increasing, and could in the long run rise from its present ratio of 89% to 92% of the population. The share of oil for heating continues to decrease and is at present at about 1%. The share of electric heating is about 10% but one third of that comes from heating plants where electricity is used to heat water for district-heating systems.

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

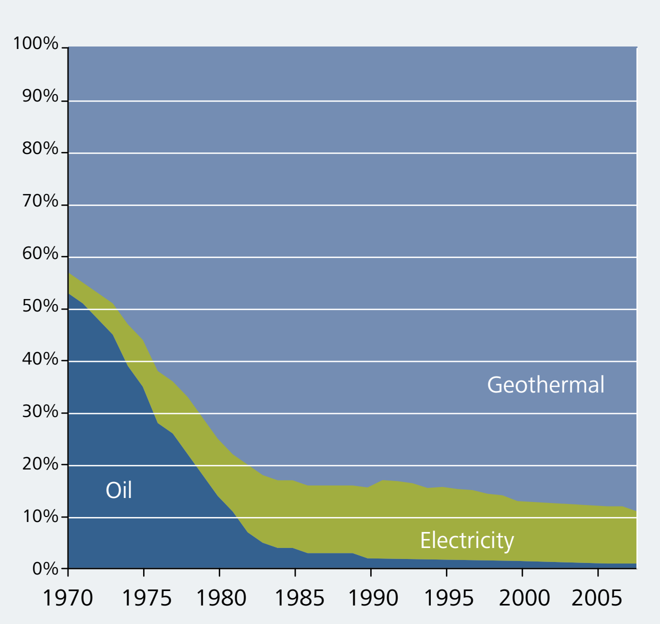

Fig. 5. Relative share of energy resources in the heating of houses in Iceland 1970–2008.

4.1.6 Benefits of using geothermal heat instead of oil

The economic benefits of the government's policy to increase the utilisation of geothermal energy can be seen when the total cost of hot water used for space heating is compared to the consumer cost of oil.

In Fig. 6 the cost of hot water is compared to that of oil to yield the same energy for heating. The cost of hot water is derived from the annual utilities revenues of hot water. Up to year 2000 the price of oil is the average for each year, but after that the midpoint of the January prices for two consecutive years is used to reflect the price over the winter months. In July 2009, the present value of the total savings between 1970 and 2008, using 2% real interest rate over the consumer price index, is estimated at roughly 160% of the total state expenditure in year 2008. In 2008 the estimated savings of that year amounted to about 91% of the total imports of refined oil products or 11% of the total state expenditure. While this estimate should only be taken as an indicative measure of the national savings, as it is conceivable that other sources of fuel could be used instead of oil, it is clear that the economic benefit is substantial. Another benefit is the relative stability of the price of geothermal energy over time compared to that of oil and the resulting cushioning effect against fluctuations in oil price and the currency exchange rate.

The use of geothermal energy for space heating and electricity generation has also benefited the environment. The benefit lies mainly in lesser CO_2 emissions compared to fossil fuel power plants. The use of oil to produce the heat provided by geothermal energy to heat houses in 2008 would have caused the emission of 2.1 Mt of CO_2 and increased the total anthropogenic release of CO_2 equivalents in Iceland from an estimated 4.9 Mt in 2008 to 7.0 Mt. The generation of the 4038 GWh of electricity produced in 2008 from geothermal energy caused the release of 185 kt of CO_2, which is

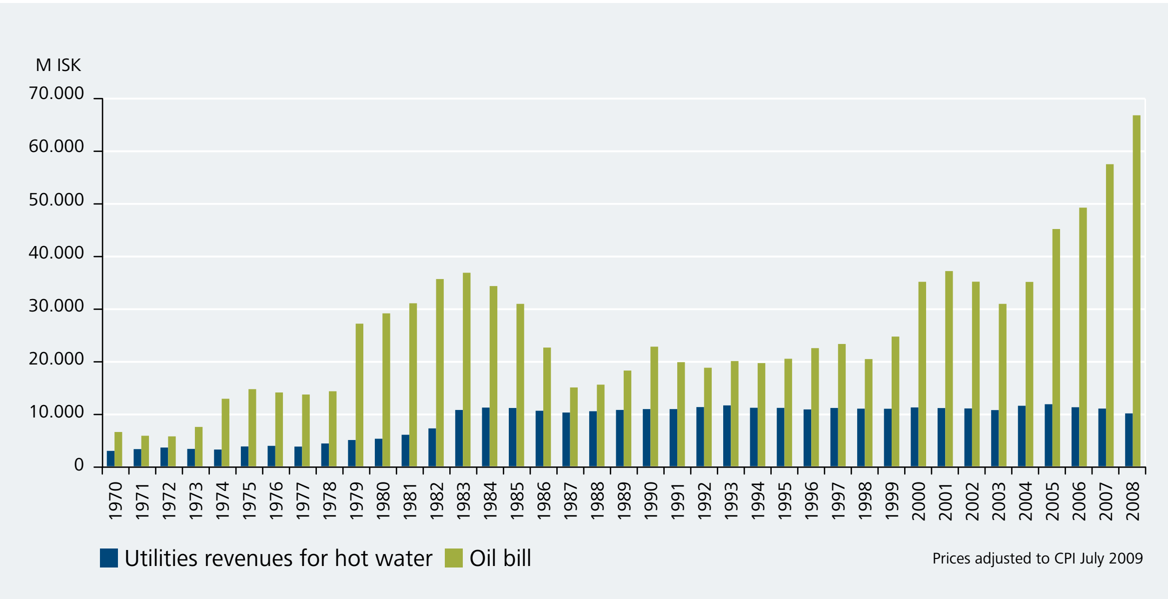

Fig. 6. Cost of geothermal space heating compared with the cost of oil heating.

approximately 5% of the emissions from oil fired power plants according to guidelines from the IEA. The total avoided emissions from using geothermal energy for house heating and power generation amounts to about 4.9 Mt of CO_2, which is nearly 170% of the total country emissions in 2008. This indicates that geothermal energy plays a significant role in minimising Iceland's contribution to global warming. Besides the economic and environmental benefits, the development of geothermal resources has had a desirable impact on social life in Iceland. The abundant supply of geothermal water for space heating and industry led to the formation of several new rural towns and improved the living conditions of a large part of the population. Better space heating improved comfort and health, and snow-melting of private property, parking lots, public spaces, and sports arenas has increased safety and expanded the potential of participation in outdoor sports over the winter time. Geothermal swimming pools have developed into social meeting places for all generations and provide playgrounds for youngsters as well as venues for elders to discuss current events. They have become engrained in the national image as cultural phenomena of their own and larger man-made water bodies in natural settings, such as the Blue Lagoon, have become an attraction for foreigners as well as locals. Horticulture has benefited considerably from geothermal resources, as the heating of greenhouses has increased production and lengthened the growing season. The drive to utilize Iceland's geothermal resources over the course of the 20th century has led to an expanding body of dedicated geothermal professionals that by the end of the century had grown into an established and well recognized community of scientists, engineers, academics, and O&M personnel with positive implications for society.

The development of geothermal resources has had a desirable impact on social life in Iceland. People prefer to live in areas where geothermal heat is available.

4.1.7 Equalisation of energy prices

Equalisation of energy prices is a decades old Icelandic policy. This policy has been carried out in various ways, such as by 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. 7). In 2002, a new Act on Subsidies was approved. These subsidies amounted to about 951 million ISK in 2008, and a small part of that contributes 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 regard to insulation and the control of heating systems. The needs and customs of the inhabitants differ. Therefore the cost of heating two homes of equal size in the same district might vary considerably. The solution to high heating bills might very well be home improvements, or the implementation of energy saving strategies. The government encourages such improvements to reduce subsidies.

Government subsidies are paid to equalize the cost of space heating for families that do not enjoy geothermal heat.

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 utilised. This work began in the 1940's 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 utilisation 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 was possible thanks to the skilled scientists and researchers at research divisions of the

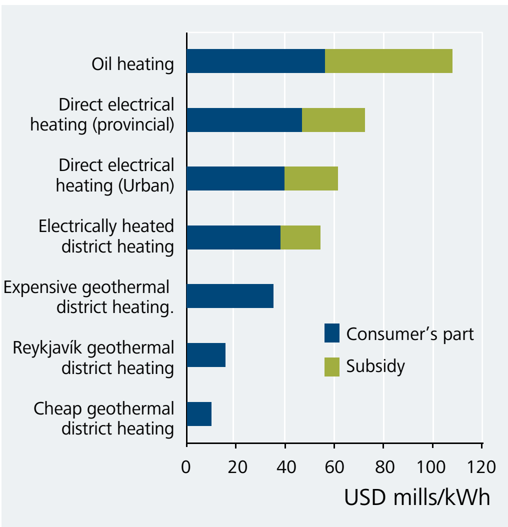

Fig. 7. Comparison of energy prices for residential heating in 2009.

The government has encouraged exploration for geothermal resources. New and effective exploration techniques have been developed. Successful power companies now take the lead in the exploration of geothermal resources.

National Energy Authority. The research activities have now been outsourced and are carried out mainly by a new state institute, Iceland GeoSurvey under contract with the Icelandic energy companies which have become substantial sponsors of geothermal surveying as well as the National Energy Authority administrating state sponsored exploration.

New and effective exploration techniques have been developed to discover geothermal resources. This has led to the development of geothermal heating services in regions that were thought not to enjoy suitable geothermal resources. Iceland's geothermal industry is now sufficiently developed for the government to play a smaller role than before.

The Icelandic government has also set up the 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 utilisation 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 a 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.

4.2 Drilling for geothermal water and steam

Wells drilled for hot water in Reykjavik in the years 1928–30 yielded significantly more flow than the natural hot springs.

First attempts to drill wells in geothermal areas in Iceland began as early as 1755 when exploration wells were drilled in search for sulphur near the Laugarnes hot springs in Reykjavík and in the high temperature field Krýsuvík on the Reykjanes Peninsula. In Krýsuvík the hole reached 10 m depth and erupted a mixture of steam and clay. Drilling with percussion rigs for potable water in Reykjavik shortly after 1900 was not successful but rumors that the boreholes had encountered traces of gold led to the purchase of a rotary core drilling rig which was nicknamed the "gold drilling rig". The Reykjavik Electricity Service became interested in drilling as they learned of successful drilling for steam in Lardarello in Italy to generate electricity. They bought the "gold drilling rig" and used it to drill 14 wells in the hot spring area of Laugarnes in Reykjavík 1928–30. The deepest well was 246 metres. No steam was found but the wells yielded significantly greater artesian flow of hot water than the hot springs prior to drilling. This success led to the first step in geothermal heating of houses in Reykjavik in 1930.

The "gold drilling rig" rotated small spheres of hardened steel (calyxies) under the load of the rim of a core barrel on the bottom of the hole. The spheres crushed the rock and cut the core free to enter the core barrel. These rigs progressed very slowly but were cheap to operate. A hole of several hundred metres depth could take over a year to drill. If steam entered the hole no countermeasures were available for the rig and the hole could not be drilled further. During the second world war new rotary drilling rigs for water and oil were imported. These rigs used tricone drillbits with hard teeth that rolled under a heavy load on the hole bottom. The bits were rotated by drilling string pipes that also circulated fluid to cool the drillbit and wash up the drill chips. This technology allowed drilling to depths of over

1000 metres in several weeks and opened up the possibility of casing off unwanted inflows of water or steam. A State Drilling Company was established in 1945 and the Reykjavik Heating Service also operated its own core barrel drilling rigs until 1965. The „gold drilling rig" is now stored in the Arbaer Museum of Reykjavik. In 1957 Reykjavik and the State founded a company to buy and operate a large rig capable of drilling more than 2000 metres deep boreholes in hot water and steam fields. The new drilling rig was first used in Reykjavik in the spring of 1958 and for exploration drilling in the high temperature fields north of Hveragerdi and in Krýsuvík. It was then used for extensive redrilling in the hot spring fields in Reykjavík and Mosfellssveit. The new rig's capability to drill wide boreholes made the cementing of casings to great depths much easier than before, thus facilitating the instalment of pumps in the wells. The first attempts to operate downhole pumps ran into difficulties as the bearings could not withstand the temperature and the chemistry of the hot water. After several years of testing the problems were solved by bearings made of teflon in the spring of 1967. The pumping multiplied the flow of hot water from each well and provided sufficient hot water to expand the Reykjavik District Heating Service to serve the whole population of the capital and the neighboring communities.

A modern drilling rig redrilled the hot spring fields serving Reykjavik. Downhole pumps were developed which greatly increased the flow from wells and provided sufficient hot water to expand the Reykjavik District Heating Service to serve the whole population of the capital and the neighboring communities.

Until 1986 nearly all drill rigs were operated by the State Drilling Company. The emphasis was on discovering hot water for space heating all over the country. The wells were located near hot springs and also in regions where exploratory surveys and drilling indicated a high geothermal gradient. Some drilling also took place in the high temperature fields. Exploratory wells were drilled in Reykjanes to provide hot brine for a sea chemicals factory. Drilling for cogeneration of hot water and electricity took place at Svartsengi and Nesjavellir and wells were drilled in Krafla to provide steam for the generation of electricity. There the drilling ran into difficulties because volcanic activity caused an influx of corrosive gases into the geothermal reservoir. The drilling company was privatised 1986 and now operates as Iceland Drilling Ltd (see 4.3.5) but several other smaller drilling companies have also been established. These smaller firms have overtaken most of the drilling in hot spring areas whereas Iceland Drilling has emphasised drilling boreholes in the high temperature fields.

Until 1986 nearly all drilling rigs were operated by the State Drilling Company. The company was then privatized. Several other smaller drilling companies have also been established.

Among recent innovations in drilling technology are downhole hydraulic turbines that are driven by the circulation fluid and can rotate the drillbit much faster than the rotating string. This technique yields a faster penetration rate and also allows for inclined directional drilling to intersect targets off the drilling platform. A cluster of wells can thus be drilled to different directions from the same drilling platform. Another novelty used in shallow holes is pneumatic hammers implanted with carbide balls

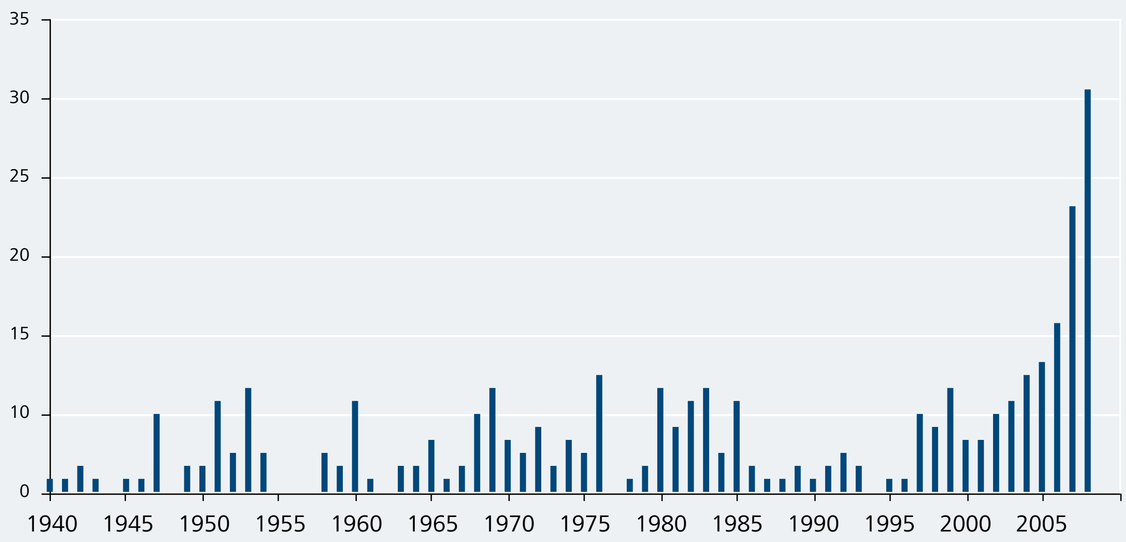

Fig. 8. Number of wells drilled in high temperature fields 1970–2008.

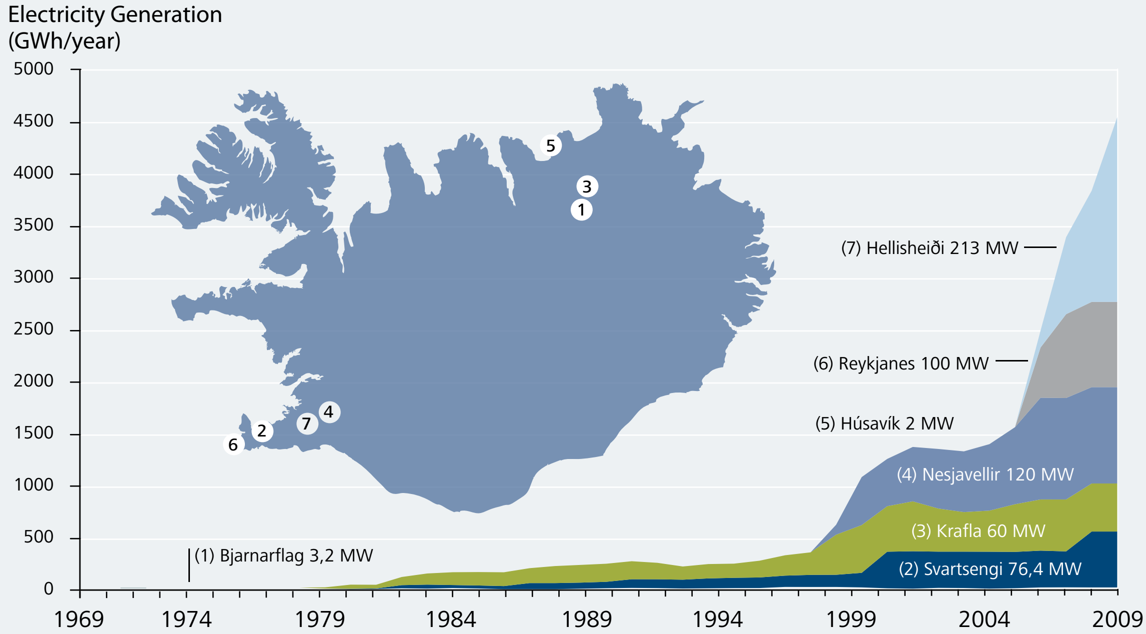

Fig. 9. Generation of electricity using geothermal energy 1969–2009.

that hammer the hole bottom several thousand times per minute and give a penetration rate of 10–30 m/hour.

More than 300 wells have been drilled in steam fields for production. Of those 208 are deeper than 500 m, 36 reach more than 2000 m and six beyond 3000 m. In hot water fields about 860 production wells have been drilled. Thereof 291 are deeper than 500 m, 19 reach more than 2000 m and one beyond 3000 m. Wells drilled in search of high temperature gradients are more than 2600. Most of them are shallower than 100 m but some exceed 1000 m in depth. These wells are rarely intended for production. Steam field drilling for generation of electricity has dominated in the last decade as can be seen in Fig. 8. In 2008 31 wells were drilled in six steam fields with a combined depth of 67 km.

4.3 Combined heat and power production

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 utilities. Also it is getting increasingly common for one municipality-owned company to run both district heating and electricity distribution. This development reflects the increased competition in the energy market of the country.

The use of geothermal energy to generate electricity 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. Figure 9 shows the development from 1969-2009. The installed generation capacity of geothermal power plants totalled 575 MW_e in 2008 and the production was 4,038 GWh, or 24.5% of the country's total electricity production. It is estimated that generation of electricity in year 2009 will increase to 4,556 GWh due to the enlargement of Hellisheidi geothermal power plant in year 2008 by 90 MW.

4.3.1 Reykjavik Energy

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 Reykjavik Water and Sewage Works.

District heating

Reykjavik Energy is the largest of Iceland's geothermal district heating systems. It utilises low-temperature areas within and in the vicinity of Reykjavik, as well as the high-temperature fields at Nesjavellir and Hellisheidi in the Hengill volcanic region, about 27 km away. Today, Reykjavik Energy serves about 204,000 people, or nearly the entire population of the capital area, Reykjavik and six neighboring communities. 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.

Today, Reykjavik Energy heats homes of some 204,000 people, nearly the entire population of the capital area, Reykjavik and six neighboring communities.

In the low-temperature fields in Reykjavík and its vicinity 52 wells deliver a total of 2,400 litres per second of 62–132°C hot water. The geothermal water from these areas is pumped to storage tanks on two hills in mid-Reykjavik, Öskjuhlíd and Grafarholt. A glass dome with a rotating restaurant, Perlan (the Pearl), has been mounted on the top of the storage tanks on Öskjuhlíd, giving a spectacular view of the city. Geothermal water from low-temperature areas contains a low concentration of dissolved solids and can therefore be supplied directly to consumers without any treatment.

Until 1990, the low-temperature areas could provide the entire capital area with hot water. However, due to the rapid population growth in the area, additional energy has had to be sought in the high-temperature field at Nesjavellir in the Hengill area. Because of the great quantity of dissolved solids in high-temperature water, it cannot be utilised directly. For this reason, the geothermal fluid at Nesjavellir is used to heat fresh water from five boreholes near Grámelur, near Lake Thingvallavatn. The fresh water is heated to about 80°C and a small amount of hydrogen sulphide added to it to prevent corrosion.

Between 40–45% of the capital area are at present supplied with heated groundwater from Nesjavellir. The rest of the area is supplied with geothermal water from the four low-temperature areas in Reykjavik and its vicinity. The geothermal district heating system in the capital area is the largest in the world, delivering about 75 million cubic metres per year of hot water to some 200,000 inhabitants. The population of the capital area is still rapidly growing, and therefore a new geothermal power plant,

Geothermal water tanks, with restaurant Perlan on top.

producing hot water, is being installed at Hellisheidi. It will start producing hot water in 2010–2011, with an expected capacity of 400 MW_{th} in addition to the present 1,100 MW_{th} installed capacity of the system.

Electricity generation

Installed generation capacity at Nesjavellir is 120 MW_e and at Hellisheidi 213 MW_e. A further expansion by 180 MW_e in the Hengill region is planned in 2010–2011.

Reykjavik Energy has been operating a cogeneration power plant at the Nesjavellir high temperature field north of the Hengill volcano since 1990. 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_e, and to 120 MW_e in 2005. The total electrical generation of the Nesjavellir power plant in 2008 was 976 GWh.

A second geothermal power plant in the Hengill region, Hellisheiði, began generation of electricity in the autumn of 2006 with two 45 MW_e turbines. A low-pressure turbine of 33 MW_e was added in 2007 and stage II of further two 45 MW_e turbines was added in 2008, bringing the installed capacity to 213 MW_e. A further expansion by four 45 MW_e units is planned in 2010–2011 in Hellisheidi and the nearby field Hverahlid. In 2008 the Hellisheidi Plant produced 1127 GWh.

The geothermal activity in the Hengill volcanic region is connected to three volcanic systems. The areal extent of the region is 110 square kilometers and it is one of the most extensive geothermal areas in Iceland. At least three volcanic eruptions have taken place in the Hengill area in the last 11,000 years, the most recent one 2,000 years ago. The construction area of the Hellisheiði geothermal plant is on Hellisheiði heath south of the Hengill volcano. The area is divided into the upper geothermal area above Hellisskarð pass and the lower area below the pass. Steam for the stage II turbines originates in Stóra-Skarðsmýrarfjall mountain in the upper area. A much larger area has, however, been investigated to assess the environmental impact of the power plant. Ground water exploration has been carried out in the area from the south coast, west to the Faxaflói bay, north to the Esja mountain and Lake Þingvallavatn and east to the Ölfusá river. Increased release of geothermal gases will be counteracted by reinjection of the gases with the geothermal waste fluid into the geothermal reservoir. A strong smell of hydrogen sulphide annoys people in certain weather conditions. Experiments are underway to extract the hydrogen sulphide from the steam and recover the sulphur or reinject it with the waste water.

Nesjavellir Power Plant.

Reykjanes Power Plant.

4.3.2 Hitaveita Sudurnesja Ltd (Now HS Orka Ltd. and HS Veita Ltd)

Based on extensive research and development and operation of two pilot plants, Hitaveita Sudurnesja (HS) Ltd. commenced in 1976 the construction of the first phase of six of its existing cogeneration power plants at Svartsengi on the Reykjanes peninsula. The plant utilises 240°C geothermal saline (salinity 2/3 of sea water) brine for 150 MW_{th} hot water production for district heating and 76.4 MW_e turbines for power generation, including a 30 MW_e low pressure unit added in late 2007. In 2008 the plant produced 11.1 million tons of district heating water, an average of 38 kg/s of geothermal brine for the Blue Lagoon Health Resort, and the electricity generation amounted to 566 GWh in 2008. An average of 192 kg/s of geothermal brine was reinjected into the geothermal reservoir after use to stabilize the reservoir pressure. The reinjection is about 44% of the production from the field. The plant supplies Keflavik Airport and four municipalities on the Reykjanes peninsula with hot and cold water.

The combined harnessing of all available resources in the Svartsengi-Blue Lagoon complex is a result of the Resource Park Concept of the company. The concept reflects the endeavor of HS Ltd. to minimise the waste of harnessed resources and the environmental impact of the operation and it is the company's method to support the sustainable development of society. Recently a contract was signed with Carbon Recycling International (CRI) on collaboration on building and operating plants for capturing CO_2 from the power plant for manufacturing methanol as a synthetic liquid fuel for automotive vehicles. CRI, the sole owner of the plant intends to construct a demonstration plant with a production capacity of 10 metric tons of methanol per day, commencing operation in 2010.

Hitaveita Sudurnesja (HS) Ltd. was demerged in year 2008 into HS Orka Ltd. and HS Veita Ltd. HS Orka operates geothermal power plants at Svartsengi, Reykjanes and HS Veita provides towns and villages with heat, electricity and potable water. Besides the operation in Svartsengi HS Veita has operating bases in Hafnarfjördur, Vestmannaeyjar and Árborg.

Reykjanes Power Plant

The Reykjanes Power Plant uses a sea water reservoir at temperatures up to 350°C to generate 100 MW_e of electricity.

A new power plant was designed and constructed in 2004–2006 in the Reykjanes geothermal field on the southwestern tip of the Reykjanes Peninsula. The reservoir fluid is sea water at temperatures up to 350°C. The first stage comprises two 50 MW_e state of the art sea water cooled condensing turbine-generators. An expansion by 80–100 MW_e is being considered. In 2008 the plant generated 864 GWh.

Blue Lagoon

The Blue Lagoon Health Resort has a unique healing power based on geothermal brine. The company is a market leader in the development of health related tourism, both in the area of spa and wellness activities and in developing natural medical treatments of psoriasis.

Blue Lagoon Ltd is a limited-liability company in which HS Orka Ltd is the largest shareholder (32%). The salubrious operation of the Blue Lagoon is based on a unique source of saline geothermal brine. The company has developed natural skincare products and services based on the pure active ingredients of the Blue Lagoon saline geothermal brine (minerals, salt, silica and algae) and its access to other pure ground resources and Icelandic environment. The company is a market leader in the development of health related tourism, both in the area of spa and wellness activities and in developing natural medical treatments of psoriasis.

The Blue Lagoon with Svartsengi Power Plant in the background.

4.3.3 Landsvirkjun

Landsvirkjun is the leading company of Iceland in hydropower but it also operates geothermal power plants in northeastern Iceland in the Námafjall and Krafla geothermal fields. The company is owned by the State.

The State Natural Heat Supply (Jardvarmaveitur ríkisins) at Bjarnarflag in the Námafjall field was a pioneer in cascaded use of high temperature geothermal energy in Iceland. It supplied steam to the Bjarnarflag geothermal 3 MW_e power plant which was built by the Laxárvirkjun power company in 1969, as well as steam for the Kísilidjan (diatomite plant) at Bjarnarflag which was operated from 1967–2004, hot water for the community around Lake Myvatn, a swimming pool and the concrete manufacturing industry Léttsteypan and lately bathing water for the new geothermal spa Jardbödin, from 2004. The Bjarnarflag power plant and the State Natural Heat Supply were bought by Landsvirkjun in 1986. In January 2008, the Engineering and Construction division of Landsvirkjun was transferred to a separate entity, Landsvirkjun Power, a limited liability company fully owned by Landsvirkjun, together with management of all new, on-going Landsvirkjun projects in Iceland and abroad.

Krafla Power Plant.

The Krafla power plant ran into difficulties due to volcanic activity that injected volcanic gases into the reservoir. Two decades later the reservoir has mostly recovered and the plant generates as planned.

The construction and initial running of the Krafla geothermal power plant which started production in 1978, was overseen by a parliamentary committee to meet urgent power requirements in North Iceland. Initial plans involved two 30 MW_e double flash dual flow condensing turbine units but due to volcanic eruptions during the construction period and a consequent increase in volcanic gases, affecting steam quality, only one turbine was installed. Two decades later, concentration of corrosive volcanic gases had decreased significantly and sufficient steam was available for the installation of the second turbine. Since 1985, the Krafla power plant, with the associated steam supply system, has been owned and operated by Landsvirkjun. The total electrical generation of the Krafla plant in 2008 was 487 GWh.

Currently, plans for further expansion of the Krafla power plant by 150 MW_e (Krafla II), building of a new 90 MW_e Bjarnarflag power station as well as up to a 200 MW_e power plant in the field of Theistareykir north of the Krafla field before 2015, are underway to meet power requirements for proposed power intensive industry in the area.

4.3.4 The Húsavik Power Plant

At Húsavik, in Northeast Iceland, the generation of electricity by 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 utilises 120°C water as an energy source to heat a mixture of water and ammonia, which in a 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 when in full operation. The plant's hot water is used for the town's space heating and hot water supply, as well as the local swimming pool.

The Husavik Power Plant utilises 120°C water to heat a mixture of water and ammonia, which in closed circuit acts as a working fluid for heat exchangers and a turbine.

4.3.5 Iceland Drilling Ltd

In order to meet the increasing demand for geothermal resources, considerable drilling has taken place. Drilling is carried out by private contractors. The largest company is Iceland Drilling Ltd, with many decades of experience in high and low temperature drilling. Iceland Drilling Ltd has grown significantly in recent years and is now the largest geothermal drilling company in world. Significant investments in machinery have caused Iceland Drilling Ltd to increase their activities abroad. The company possesses a fleet of new hydraulic rigs and modern drilling equipment that can be transferred swiftly from one part of the world to another. Iceland Drilling Ltd operates internationally and with a record of over 1000 geothermal wells, the company has well-grounded expertise in international drilling.

Iceland Drilling Ltd is now the largest geothermal drilling company in the world. The company operates internationally and possesses a fleet of new hydraulic rigs and modern drilling equipment.

Company operations

Iceland Drilling Ltd has a dominant share in the Icelandic market through years of successful work for the country's major power companies.

Reykjavík Energy and Iceland Drilling recently signed the largest ever drilling contract in Iceland. The project, which was put up for tender in the European Economic Area, includes the drilling of 50 wells in the Hengill area, of which 35 are high-temperature production wells and 15 are reinjection wells. Directional drilling will be employed, allowing inclined wells to be drilled in several directions from the same drilling platforms. This method significantly increases the chance of success, whilst being environmentally friendly, preventing damage of valuable nature conservation areas.

The company operates as a drilling contractor on the international market using the name of Hekla Energy through it's subsidiaries in Germany, the UK and the Azores. A contract was recently signed with two Azorean energy companies, Sogeo and GeoTerceira, for drilling exploration and production wells in high-temperature fields in the Azore Islands. The purpose of these wells is to generate electricity.

Drilling for the IDDP project

Iceland Drilling was selected as a drilling contractor to drill the first well of the deep drilling project in Iceland into a superheated geothermal reservoir in the Krafla area of northern Iceland, marking the beginning of deep drilling (down to 5 km) in high temperature geothermal areas. The project is unique worldwide and will be watched by scientists from around the world.

4.3.6 Harnessing deep-seated resources

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.

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 producing geothermal systems in Iceland. These systems are located at Krafla, Hengill (Nesjavellir) and Reykjanes (Fig. 9). This will require drilling to depths exceeding 5 km in order to produce hydrothermal fluids that reach temperatures upwards of 400-500°C. The IDDP was launched in 2000 by Deep Vision, a consortium of the three largest Icelandic energy companies: Hitaveita Sudurnesja, Landsvirkjun 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, fluid handling and evaluation was completed in 2003. In November 2003 Deep Vision decided to proceed to the operational stage and to seek out international partners. From the outset, Deep Vision has been receptive to including scientific studies in the IDDP. An international advisory group, SAGA, that has assisted Deep Vision with the science and engineering planning of the IDDP, 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 workshops held in 2002. Altogether some 160 participants from 12 countries participated in the workshops.

Modeling indicates that, relative to the output from conventional 2.5 km deep geothermal wells, 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, so that 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, reaching these conditions requires drilling deeper than 4 km (Fig. 10).

The feasibility study in 2003 also concluded that a 5 km deep IDDP well could be drilled using available technology but such a deep production well would cost between 8 and 9 million USD and a full-scale exploratory IDDP well, with the extensive coring required by the science program, could cost up to 15.5 million USD. 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.

In December 2003, a member of the Deep Vision consortium, Hitaveita Sudurnesja, offered to allow

A drilling rig at Hellisheidi.

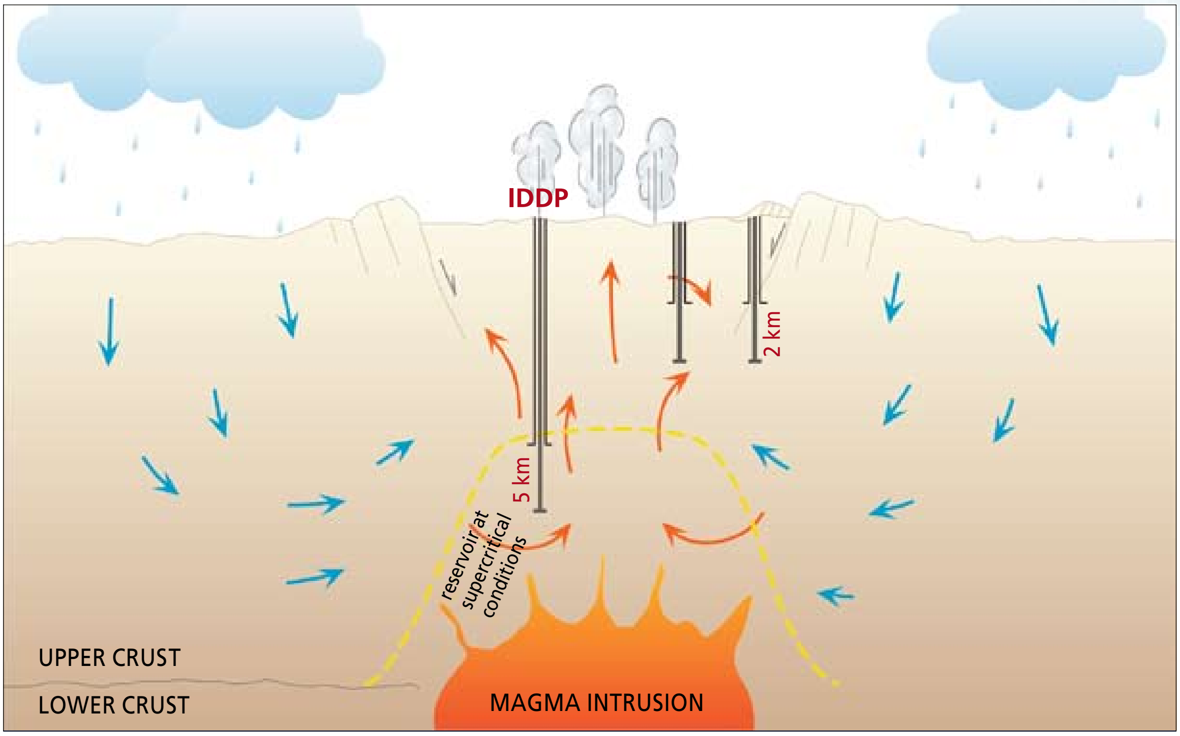

Fig 10. Conceptual model of a deep-seated resource.

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 and ideally located for scientific studies of supercritical phenomena and the coupling of hydrothermal and magmatic systems on mid-ocean ridges. The well, RN-17 at Reykjanes, was drilled to 3082 m depth in February 2005, as a conventional but barefoot production well. After a heat-up period the well was flow tested in November the same year. Unfortunately, the formation collapsed during the flow test and in February 2006 an attempt to redrill the well with a drill rig proved unsuccessful and the well was subsequently abandoned as a well of opportunity for IDDP. In 2006 the IDDP decided to move to Krafla and to drill the first well there. A new contract was signed in 2007 by the Icelandic partners and Alcoa, the international aluminum company, which joined the industrial consortium. In that contract each of the three Icelandic energy companies expresses interest to drill at their own cost a 3.5–4.0 km deep, fully cased drillhole at Krafla, Hengill and Reykjanes, to be made available for deepening, flow testing and pilot studies funded by IDDP. A year later, the 1st Accession protocol to this contract was signed by the partners adding Statoil Hydro ASA of Norway to the partners group. The drilling cost has almost doubled since 2005.

The drilling at Krafla was initiated in 2008 with intermediate casings set at 90 m, 300 m and 800 m. In March 2009 the largest drill rig in Iceland, Týr, continued drilling with a 12 ¼" bit with the aim of placing the next casing at 2400 m. In the depth interval of 2000 to 2100 m the rig ran into repeated troubles which turned out to be due to veins of molten lava. Superheated steam rich in HCl entered the well and turned corrosive when mixed with liquid water. The well was then completed with a casing cemented down to 2000 m and is waiting for testing and analysis. Decision on where to drill the next well has not yet been taken.

The geothermal fields in Iceland are ideally located for scientific studies of supercritical phenomena and the coupling of hydrothermal and magmatic systems on mid-ocean ridges. Although several exploratory wells will be drilled in the coming years it is, however, likely that many years will pass before supercritical geothermal resources are successfully commercialised.

An old swimming pool with natural hot water.

4.4 Other utilisation

4.4.1 Industrial uses

A plant using geothermal steam to dry diatomaceous earth was operated at Lake Myvatn in the years 1967 to 2004.

At Reykholar in West Iceland seaweed is chopped and dried with dry air heated to 85°C by geothermal water. The plant has been in operation since 1976.

- The diatomite plant at Lake Mývatn, near the Námafjall high temperature geothermal field, began operation in 1967, producing some 28,000 tons of diatomite filter annually for 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 Mývatn. Each year the plant used some 230,000 tons 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 Reykhólar in West Iceland, uses geothermal heat directly in its production. The company harvests seaweed found in the waters of Breidafjördur 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 and 4,000 tons of rockweed and kelp meal annually using 35 l/sec of 112°C water for drying. The product has been certified as organic. The plant's annual use of geothermal energy is about 250 TJ.

The State Natural Heat Supply was a pioneer in cascaded use of high temperature geothermal energy at Bjarnarflag.

Since 1986, a facility at Haedarendi in Grimsnes, South Iceland, has commercially produced liquid carbon dioxide (CO_2) from geothermal fluid.

- A salt production plant was operated on the Reykjanes peninsula for a number of years., The plant produced salt from geothermal brine and seawater for the domestic fishing industry as well as low-sodium health salt for export. During the plant's final years of operation, production was intermittent.
- Since 1986, a facility at Hædarendi in Grímsnes, South Iceland, has commercially produced liquid carbon dioxide (CO_2) from geothermal fluid. The Hædarendi geothermal field temperature is intermediate (160°C) and the gas content of the fluid is very high (1.4% by weight). The gas discharged by the wells is nearly pure carbon dioxide with a hydrogen sulfide concentration of only about 300 ppm. Upon flashing, the fluid from the Hædarendi wells produces large amounts of calcium carbonate scaling. In one well scaling is avoided by a 250 m 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 carbonate increased sufficiently to prevent scaling. The plant produces some 2,000 tons annually. The product is used in greenhouses for manufacturing carbonated beverages, and in other food industries. The production is sufficient for the Icelandic 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 on the fish, and the moisture from the raw material removed. About 20 small companies dry cod heads indoors. Most of them use geothermal hot water, and one uses geothermal steam. The annual export of dried cod heads is about 15,000 tons. The product is mainly shipped to Nigeria where it is used for human consumption.

Dried cod-heads.

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.

- In addition, drying pet food is a new and growing industry in Iceland with an annual production of about 500 tons. 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 Mývatn, and baking bread with steam.
- The total amount of geothermal energy used in Iceland to process heat for industrial purposes is estimated to be 750 TJ per year.

4.4.2 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. Geothermal steam is commonly used to boil and disinfect the soil. The increasing use of electric lighting in recent years has extended the growing season and improved greenhouse utilisation. This development has been encouraged through governmental subsidies spent on electricity for lighting. CO_2 enrichment in greenhouses is also common, primarily through CO_2 produced in the geothermal plant at Hædarendi.

Apart from space heating, one of Iceland's oldest and most important usages of geothermal energy is for heating greenhouses.

Greenhouse production is divided between different types of vegetables (tomatoes, cucumbers, peppers, 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 194,000 m^2 in 2008 with plastic tunnels for bedding and forest plants included. Of this area, 50% is used for growing vegetables and strawberries, 26% for cutflowers and potplants and 24% are nurseries for bedding and forest plants. Over the last few years, there has been an increase in total production, even though the total surface area of greenhouses has decreased. This is due to increased use of artificial lighting and CO_2 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 120,000 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 700 TJ per year. Because of the increased use of artificial light it has decreased in recent years as the lights also give heat.

Greenhouses in Hveragerdi.

4.4.3 Fish farming

In the middle of the 1980s, there was a marked increase in the number of fish farms in Iceland and for a while there were more than 100 farms in operation, many of them quite small. The 1990's were marked by stagnation and for most years the total production remained between 3000 and 4000 tons. During this time, however, the production of arctic char increased steadily from 70 tons in 1990 to around 900 tons in 1999 at the expense of salmon production. In 2003, the total production increased significantly and reached a maximum of around 10,000 tons in 2006, mostly on the account of expanded salmon ocean ranching. As this farming method did not prove profitable, the total production declined by around 50% the following year and amounted to approximately 5000 tons in 2007 and 2008. Arctic char accounted for 60% of the production, while cod and salmon accounted for 30% and 6% respectively.

Initially, Iceland's fish farming was mainly practised in shore-based plants. Geothermal water, commonly at 20-50°C, was used to heat fresh water in heat exchangers, typically from 5°C to 12°C. Although heat exchangers are still used in some plants, direct mixing has become more common as the geothermal water has in most cases been shown to have no adverse effects on the fish. In some plants, however, the dissolved oxygen content has been increased by aeration or direct injection. As this farming process requires large amounts of water, some farmers have cut back on consumption and costs by recycling water through appropriate filters and adding oxygen. Geothermal water is commonly used to elevate temperatures in the hatching and early development stages of all farmed species, but cod and salmon are moved to salty or brackish cold water when a certain size is reached. Arctic char, however, is commonly raised at elevated temperatures in land based plants until harvesting. A faster growth rate is achieved by the warmer temperatures, thereby shortening production time. The temperature varies between species and development stages and commonly gets colder as the fish grow older and larger, mostly due to increased risk of parasites in warmer water with a high density of fish. As production is expected to increase in the future, the utilisation of geothermal water in the sector is also expected to increase, especially in the smolt production (trout and salmon). In 2008, the total geothermal energy used in Iceland's fish-farming sector was estimated to be 1,700 TJ.

4.4.4 Bathing and recreation

After space heating, and electricity generation, heating of swimming pools is among the most important uses of geothermal energy. There are about 163 recreational swimming centers operating in Iceland, 134 of which use geothermal heat.

Until early last century, Iceland's geothermal energy was limited to bathing, laundry and cooking. These uses are still significant. After space heating, and electricity generation, heating of swimming pools is one of the most important uses of geothermal energy. There are about 163 recreational swimming centers operating in Iceland, 134 of which use geothermal heat, not counting natural hot springs or the Blue Lagoon, the Mývatn Nature Baths and Nauthólsvík geothermally heated beach.

Based on their surface area, 90% of the pools are heated by geothermal sources, 8% by electricity, and 2% by burning oil and waste.

Relaxing in an out-door swimming pool.

The combined surface area of all swimming centers in Iceland is about 37,550 m^2, not including the surface area of shallow relaxation pools. 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 the greater Reykjavik area alone there are 17 public swimming centers. The largest of these is Laugardalslaug with a surface area of 2,750 m^2 plus eight 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, comprising geothermal clay baths and water treatments. The latest development in the water health sector is a bathing facility at Bjarnarflag that uses effluent

A snow-melting system being installed.

geothermal water from wells.

Typically, about 220 m^3 of water or 40,000 MJ of energy is needed annually for heating one m^2 pool surface area. This means that a new, medium-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 7.5 million m^3, which corresponds to an energy use of 1,410 TJ per year.

4.4.5 Snow melting

Geothermal energy has been utilised to a limited extent to heat pavements and melt snow during the winter. The practice of snow melting has increased during the last two decades and now most new public car parking areas in regions enjoying geothermal district heating are provided with snow melting systems. Hot water from space heating returns at about 35°C, and is commonly used for de-icing sidewalks and parking spaces. Most systems have the possibility of mixing the return water with incoming hot water (80°C) when the load is high. In downtown Reykjavik, a snow-melting system has been installed under the sidewalks and streets over an area of 50,000 m^2. This system is designed for a heat output of 180 W per m^2 surface area. Iceland's total area of snow melting systems was about 1,200,000 m^2 in 2008, of which about 725,000 m^2 are in Reykjavik. About half of the systems is in public areas, one fourth at commercial premises and one fourth by private homes. 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 1,700 TJ per year. About two thirds of the energy is from return water from space heating systems.

Snow melting has been increasing during the last two decades and now most new public car parking areas in regions enjoying geothermal district heating are provided with snow melting systems.

4.4.6 Heat pumps

Until recently, geothermal energy has been economically feasible only in areas where thermal water or steam is found 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. Developments in the deregulation of the electricity markets and integration of the electricity networks in Europe have destabilised consumer electricity prices. This makes ground source heat pumps a favourable 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.

Heat pumps have not found much use in Iceland, since sufficient cheap geothermal water for space heating is commonly available. Subsidies of electrical and oil heating have also led to reluctance to invest in heat pumps. However a recent legislation has been set that allows users of subsidised electrical heating to get a contribution to improve or convert their heating system. The contribution corresponds to subsidies over 8 years. It is thus considered likely that heat pumps will become competitive in those areas of the country where water with temperature above 50°C is not found. In these places, heat pumps can be used to replace or reduce the use of direct electrical heating.

5. Institutions

5.1 The National Energy Authority

History

The National Energy Authority (NEA) is the official licensing authority and monitoring body for utilisation and research of resources in the ground. It also advises the government on energy issues and provides consulting services relating to energy development.

The National Energy Authority (NEA) is a government agency under the Ministry of Industry, Energy and Tourism. Its main responsibilities are to advise the Government of Iceland on energy issues and related topics, promote energy research and administrate development and exploitation of energy resources. The research facilities and 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, NEA has been instrumental in the execution of government policy regarding exploration and development of geothermal resources, and in advising communities, companies, individuals and foreign governments about their utilisation of these resources. Since 2003 steps have been taken to outsource exploration and monitoring services to ensure the financial independence and integrity of the NEA. The former research divisions of the NEA now found in independent state institutes, Iceland GeoSurvey and the Icelandic Meteorological Office.

Present organization

The NEA has now the responsibility for administration of licenses for prospecting and exploitation of energy resources and some other resources within the ground and the sea floor. It also administrates funding of governmentally financed research, surveying and monitoring with the aim of utilising the natural resources.

Projects funded through the NEA include the Master Plan for hydro and geothermal energy resources in Iceland, the Iceland Deep Drilling Project described in chapter 4.3.6. and participation in international projects on sustainability metrics for geothermal power and hydropower. The NEA is responsible for filing all research reports and data on energy resources as specified in issued licenses, to maintain databases for these and to provide access to all open domain information. NEA also runs a library with a unique collection of scientific papers and research reports on geosciences and exploitation of natural energy resources. The institute together with the Ministry plays an important role in national and international projects on the promotion and utilisation of renewable energy. The International Partnership for Geothermal Technology (IPGT) was established by the governments of Australia, Iceland and the United States in 2008. The purpose of the IPGT is to accelerate the development of geothermal technology through international cooperation. It provides a forum for government and industry leaders to coordinate their efforts, and collaborate on projects. One of the goals is to efficiently accelerate the development of geothermal technologies. The NEA participates as well in the Geothermal Implementing Agreement of the International Energy Agency (IEA-GIA). Energy Development in Island Nations (EDIN), also formed in 2008, was established by countries that strive to deploy renewable energy and energy efficiency technologies and help islands attain specific, measurable, clean energy targets. Partners include Iceland, New Zealand and the United States.

The UNU Geothermal Training Programme (UNU-GTP) which is described in chapter 5.3 is organized as a separate unit within the NEA.

5.2 Iceland GeoSurvey

Iceland GeoSurvey (ÍSOR) is a research institute providing specialist services to the Icelandic power industry, the Icelandic government and foreign companies in the field of geothermal science and utilisation. The personnel comprises about 90 people, most of whom have academic degrees and varied experience in geothermal research and training. Geothermal exploration and utilisation involve several disciplines such as geology, geophysics, geochemistry, reservoir physics and engineering.

Iceland GeoSurvey is a self-financed, non-profit government institution that operates in the free market like a private company. It gets no direct funding from the government but operates on a project and contract basis.

Each geothermal field is different from others and exploration methods as well as modes of utilisation 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 carry out the research as efficiently as possible. Specialized groups include: computerized GIS mapping, geological mapping, hydrogeology, borehole geology, geophysical exploration, marine geology, geochemistry, corrosion and deposition, environmental sciences and monitoring, drilling engineering, well design, well logging, well testing and stimulation, reinjection, reservoir modelling, resource management, and geothermal utilisation. Iceland GeoSurvey personnel 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 modelling 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 reservoir properties and the chemical composition of geothermal fluids. They also advise developers on cold water supplies and on disposal of effluent water. The company owns specialized research equipment, laboratories and computer software developed for the processing and interpretation of various types of data. The personnel takes an active part in international geothermal workshops and conferences, provides course work and lectures for specially tailored training seminars and the United Nations University Geothermal Training Programme. Iceland GeoSurvey has about 60 years of experience in geothermal research, services and consultancy abroad, including most categories of geothermal research and utilisation. Among the countries involved are: Kenya, Uganda, Eritrea, Ethiopia, Djibouti, Russia, Slovakia, Hungary, Romania, Germany, Guadeloupe, Greece, Turkey, Iran, USA, Indonesia, The Philippines, El Salvador, Costa-Rica, Nicaragua, Chile and China.

5.3 The United Nations University Geothermal Training Programme

The Geothermal Training Programme of the United Nations University (UNU-GTP) offers professional scientists and engineers from the developing and transitional countries six months of highly specialized studies, research, and on-the-job training in geothermal science and engineering.

The Geothermal Training Programme 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 on highly specialised studies, research, and on-the-job training in geothermal science and engineering. All candidates are university graduates with practical experience in geothermal work, and hold 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 Iceland GeoSurvey. Amongst the facilities is an excellent library specializing in energy research and development (in particular geothermal and hydropower), with some 19,000 titles, subscriptions to 60 journals, and internet access to 14,000 journals. Most of the teaching and research supervision of the UNU-GTP has been conducted by geothermal specialists of the Geoscience Division of the NEA. This division was separated from the NEA in 2003 to become the self-contained, government owned institution, Iceland GeoSurvey described above. The integration of the UNU Fellows with specialists and the research atmosphere is, however, unchanged. The UNU-GTP cooperates closely with the University of Iceland (UI). Staff members of the Faculty of Science and the Faculty of Engineering have been among key lecturers and supervisors of UNU Fellows. In 2000, a cooperation agreement was signed between the UNU-GTP and the UI on MSc studies in geothermal science and engineering. This programme is designed for UNU Fellows who have already completed the traditional six month course at the UNU-GTP, and who would like to further their studies in geothermal sciences. The six month course constitutes 25% of the MSc program. In the same fashion the UNU-GTP initialized a PhD programme in cooperation with UI in 2008, and the first UNU PhD Fellow arrived during the summer of 2008.

Specialised 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 utilisation, and drilling technology.

Specialised 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 utilisation, and drilling technology. The curriculum of the specialised courses can be accessed at www.unugtp.is. The aim is to assist developing and transitional countries with significant geothermal potential to build up groups of specialists in order to become self sufficient in geothermal exploration and sustainable development. All trainees are selected by private interviews with UNU-GTP representatives during site visits to the countries concerned, in order to become acquainted with the geothermal fields, research institutions and energy utilities of the home country of the prospective candidate. Participants are selected for training in the specialised fields that are considered most relevant to promote

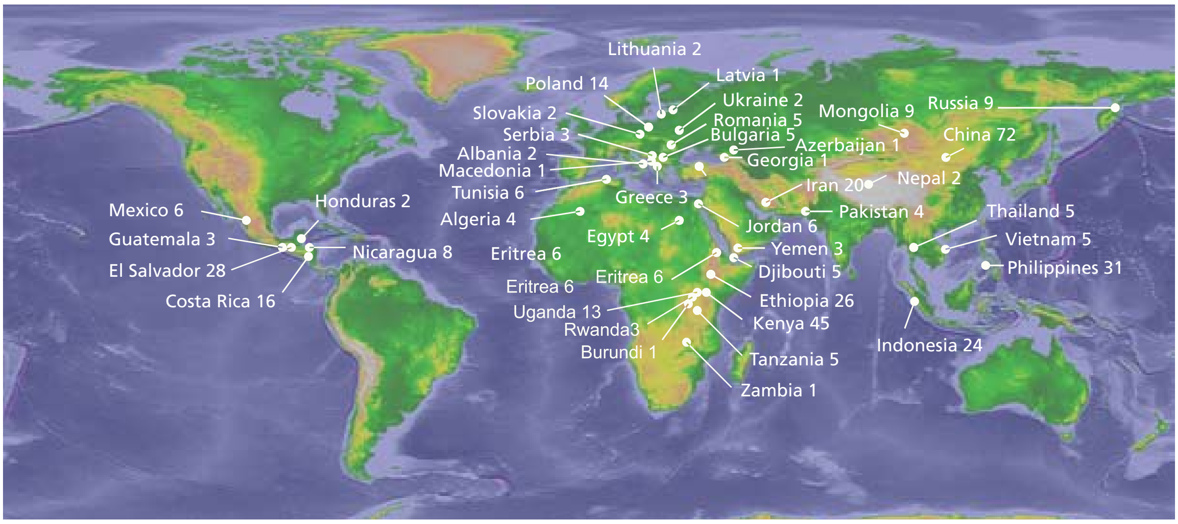

Fig. 11. Geographical distribution of Fellows completing the six-month courses at the UNU-GTP in Iceland 1979–2008.

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 where they work side by side with Iceland's geothermal professionals. The training is tailor-made for the individual and the needs of his institution/country. Candidates must have a university degree in science or engineering, a minimum of one year of practical experience in geothermal work, speak English sufficiently, have a permanent position at a public energy company/utility, research institution, or university, and be under the age of 40.

UNU-GTP class of 2008 on excursion in Iceland.

Participants from developing countries normally receive scholarships, financed by the Government of Iceland and the UNU, to cover international travel, tuition fees and per diem in Iceland. The participants therefore do not need additional funds for their training.

From 1979 to 2008, 402 scientists and engineers from 43 countries have completed the six-month specialized courses offered. Of these, 44% have come from Asia, 26% from Africa, 15% from Latin America, and 15% from Central and Eastern European (CEE) nations. The largest groups have come from China (70), Kenya (42), Philippines (31), Ethiopia (26), El Salvador (27), Indonesia (24), Poland (14), Iran (19), and Costa Rica (15). In all, there have been 67 women (17%). Sixteen people have graduated from the MSc program to date.

In many countries, UNU-GTP graduates are among the leading specialists in geothermal research and development. They have also been very active internationally, as was abundantly clear 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 co-authored 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.

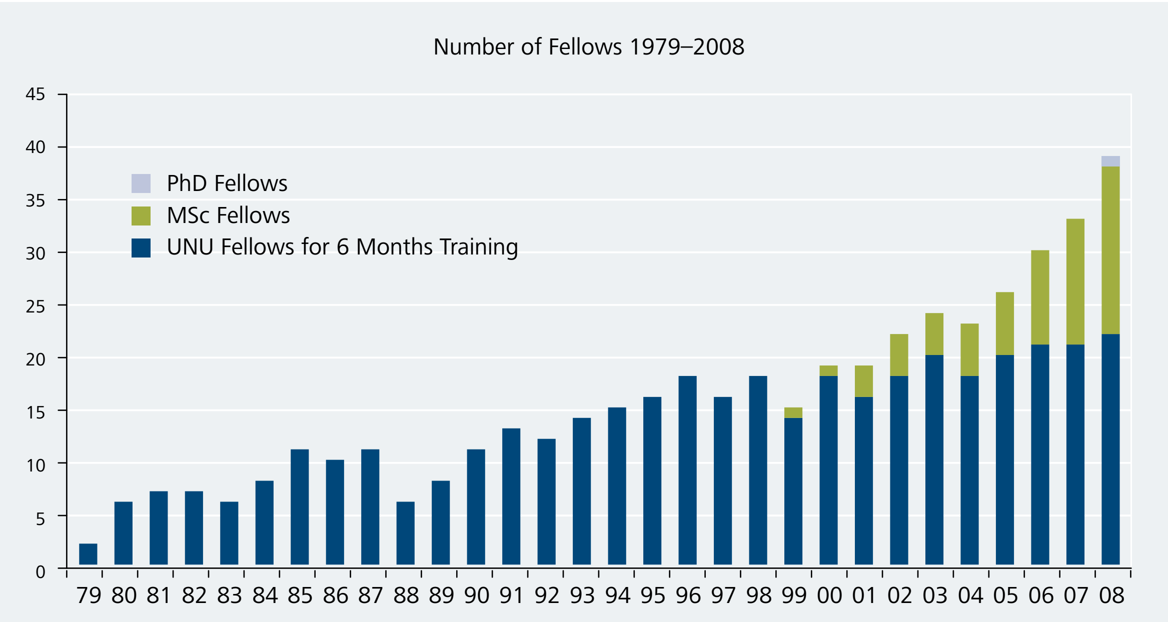

Fig. 12. Number of Fellows completing six-month courses, and studying for MSc and PhD 1979–2008.

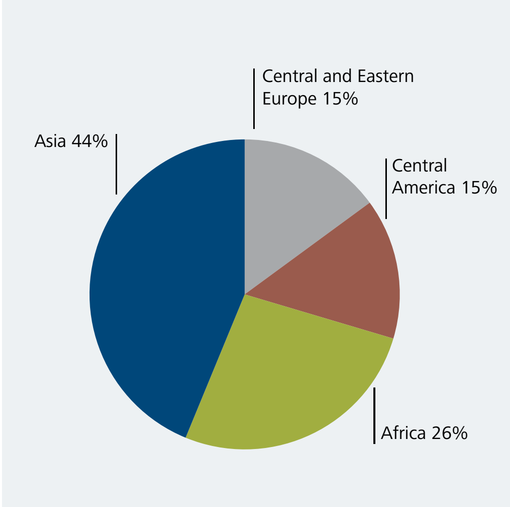

Fig. 13. Sectoral distribution of Fellows completing the six-month courses at the UNU-GTP in Iceland 1979–2008.

The Government of Iceland has secured core funding for the UNU-GTP to expand its capacity building activities by annual workshops/short courses in geothermal development in selected countries in Africa (started in 2005), Central America (started in 2006), and in Asia (started in 2008). This is a contribution of the Government of Iceland to the Millennium Development Goals of the UN. The courses/workshops are set up in cooperation with energy agencies/utilities and earth science institutions responsible for the exploration, development and operation of geothermal energy power stations and district heating utilities in the respective countries/regions. A part of the objective is to increase the cooperation between specialists in sustainable use of geothermal resources. The courses may in the future develop into sustainable regional geothermal training centres. Requests for establishing such centres have been received from China and Kenya.

In the next few years the UNU-GTP is expected to invite about 20 UNU Fellows per year for the six month course, and that the MSc program will admit up to six former UNU Fellows per year to commence MSc studies in geothermal science and engineering in cooperation with the UI. Additionally, the UNU-GTP will grant one or two PhD Fellowships per year, also in cooperation with the UI.

The UNU-GTP maintains contact with the majority of the over 400 UNU Fellows from that have graduated since 1979. The Yearbooks of the UNU-GTP (with research reports of the year) are sent to over 300 former UNU Fellows, and about 250 of them are in active e-mail contact. The UNU-GTP awards travel stipends to former Fellows to attend international geothermal conferences, and many former Fellows are lecturers and co-organizers of the UNU-GTP Workshops and Short Courses held in Africa, Asia and Central America. Former UNU Fellows have also been active with their colleagues in arranging regional and international conferences/workshops, e.g. in China, Ethiopia, Kenya, Uganda, Philippines, Poland, and Romania.

5.4 Other Academic Programmes

The School for Renewable Energy Science (RES)

Since 2007, RES has offered an intensive and unique interdisciplinary research oriented one-year graduate programme in renewable energy science. The programme is offered in cooperation with University of Iceland and University of Akureyri, as well as in partnership with a number of leading technical universities around the world. In 2009 the school will offer four specialisations of study: Geothermal Energy; Fuel Cell Systems & Hydrogen; Biofuels & Bioenergy; and Energy Systems & Policies.

Reykjavik Energy Graduate School of Sustainable Systems (REYST)

Since 2008 the school has offered an international graduate programme based on the three pillars of engineering, earth science and business. The programme is characterised by its focus on sustainable energy use, practical experience in the field and ready access to on-site work with experts on various subjects.

University of Iceland

University of Iceland is an active coordinative partner in the programmes of UNU-GTP, REYST, RES and Keilir but also offers in-house graduate studies in the field of Renewable Energy Engineering: an interdisciplinary study on the technical and environmental aspect harnessing, distributing and consuming energy in asustainable manner.

Reykjavik University

Reykjavik University offers a BSc programme in Mechanical and Energy Engineering with a strong tradition of practical orientation in cooperation with the industry. The research focus is on applied research in cooperation with specialized companies and institutions in the energy field.
All these programmes are supported by the leading energy companies, providing access to expertise and facilities.

5.5 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. In 2008 it went up to 0.43% but will be lower than 0.35% in 2009 due to general reduction in the government budget.

Sustainable development is one of the pillars of Iceland's development cooperation. Within that pillar, Iceland will increase its focus on sustainable development, emphasise the sustainable use of natural resources, particularly with regard to energy. Increased focus will be placed on geothermal energy and cooperation with countries with untapped 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 eight countries; Eritrea, Malawi, Mozambique, Namibia, Nicaragua, Sri Lanka and Uganda, and the islands Nevis and Dominica in the West Indies.

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 finalise a pre-feasibility study of three prospective geothermal sites in western Uganda. Because of the promising results, further technical assistance was provided until 2008. In Nicaragua, ICEIDA initiated in 2008 preparations for geothermal projects in cooperation with geothermal organisations in Iceland, such as the National Energy Authority, Iceland GeoSurvey, the UNU Geothermal Training Programme and the Icelandic Ministry of Industry.

ICEIDA has also participated in preparing a joint project with six states in East-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). Under this project Iceland GeoSurvey has initiated geophysical exploration in Eritrea.

The National Energy Authority is assisting ICEIDA on the islands Nevis and Dominica in the West Indies in revising legislation and directives for natural resources.

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National Energy Authority: www.os.is
RES – The School for Renewable Energy Science: www.res.is
Reykjavik Energy Graduate School of Sustainable Systems (REYST): www.reyst.is
Reykjavik University: www.ru.is
University of Iceland: www.hi.is
UNU Geothermal training programme: www.unugtp.is

Engineering and consulting companies:

Efla: www.efla.is
Hnit: www.hnit.is
Iceland GeoSurvey: www.geothermal.is
Mannvit: www.mannvit.is
Verkis: www.verkis.is
VSO-radgjof: www.vso.is

Investors and contractual services:

Iceland Drilling: www.iceland-drilling.com
Islandsbanki: www.islandsbanki.is/energy
Reykjavik Energy Invest: www.rei.is
Reykjavik Geothermal: www.reykjavikgeothermal.com

Energy companies:

HS Orka: www.hsorka.is
HS Veitur: www.hsveitur.is
Husavik Energy: www.oh.is
Iceland State Electricity: www.rarik.is
Landsvirkjun: www.lv.is
Landsvirkjun Power: www.lvp.is
Nordurorka: www.nordurorka.is
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6.3. List of figures and tables


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